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Investigating the development of a developmental disorder:

Mapping the trajectory of lexical development in Specific Language Impairment

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Declaration of Originality

The material presented in this thesis is the original work of the candidate except as otherwise acknowledged. It has not been submitted previously in part or in whole, for any award at any university, at any other time.

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Abstract

There is increasing consensus that to understand developmental disorders we must apply developmental theoretical models and methodologies. To develop a fully specified developmental model of a developmental disorder we must understand both the nature of the innate causal processing deficits of the disorder and also how these deficits in early processing mechanisms then change the developmental process. This study aimed to examine the second of these issues with respect to Specific Language Impairment (SLI) and so describe the altered trajectory of development in this group of children.

Explanatory models which propose hypothetical trajectories of development from impaired processing mechanisms in the infant to the patterns of linguistic impairments typically found in SLI are beginning to be developed. To date however there is very little empirical research which maps these trajectories. This study sought to contribute to that necessary empirical data and so to our understanding of the development of SLI. In addition it aimed to consider whether the application of a developmental methodology and perspective adds to our understanding of this disorder.

A series of longitudinal case studies of children with SLI were completed. The participants were seen for four blocks of comprehensive assessment of language processing, language knowledge and "language relevant" processing over a 15 month time period. Cross sectional data from 38 typically developing (TD) children was also collected for comparison purposes. The data presented represents a part of this larger study and focuses on the *development of the lexicon* in SLI. Lexical and phonological processing and their interaction with phonological working memory capacity are thought to be crucial to the ontogeny of SLI. A series of tasks were developed to create a window into the nature of the developing lexicon. Data is presented from a novel non-word repetition task which manipulated the phonological characteristics of the stimuli and from a fast-mapping task where both phonological and lexical variables were manipulated. The influence of these factors on performance and changes in their influence across development were examined.

Analysis of the trajectory of development of the two measures in TD children showed evidence of increasing abstraction of sub-lexical/phonological knowledge from lexical knowledge across development. In addition the developmental trajectory of fast mapping abilities demonstrated a significant and radical shift in processing bias across the age range. This result suggests that functional reorganisation in the developing lexicon, and hence the speech processing mechanism, may be taking place and which may occur as a result of increasing sub-lexical/phonological abstraction. The developmental trajectories of the children with SLI suggest that this group of children develop a different lexical processing architecture from typically developing children which does not reach the levels of efficiency of TD children's speech processing mechanisms. There is tentative support for a deficit in schema abstraction across the lexicon and an absence of functional reorganisation. The possibility that these results represent entrenchment within a self-organising network, and the possible relationship to issues of timing and critical periods is discussed. In addition it appears that compensatory strategies for this inefficient speech processing architecture may result in impaired semantic learning and so may have effects on the wider trajectory of atypical language development in SLI.

Applying a developmental emergent perspective to SLI and so considering trajectories of development rather than static group comparisons can begin to uncover the nature of change within an interactive system and the nature of interdependence of processing mechanisms across development. Such an approach holds promise for revealing the nature of SLI and providing a more ecologically valid explanation of this complex disorder. The implications of developmental emergent conceptualisations of language impairment for research methodologies, diagnosis and therapy are discussed

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CHAPTER 1

INTRODUCTION

A Developmental Approach to SLI: The Case for a New Conceptualisation

1.1 Introduction

The acquisition of language is arguably the most important and the most complex achievement of the developing child. However, despite its complexity most children appear to acquire language with ease. Pinker states that "in general language acquisition is a stubbornly robust process; from what we can tell there is virtually no way to prevent it happening short of raising a child in a barrel"(Pinker, 1984, p. 29). Despite this assertion it has also long been recognised that for some children, the task of acquiring language is not "stubbornly robust" at all and, despite the absence of any obvious cause, a significant minority of children find the pathway to adult language a difficult one (Tomblin *et al.*, 1997). Many diagnostic labels and descriptive terms have been devised to describe this group of children, the most recent being Specific Language Impairment (SLI).

SLI is a diagnosis which was conceived when modularity of functioning in cognitive processing was widely accepted and indeed rests upon the assumption of a dissociation between language and cognitive development. That is, SLI is defined as a developmental disorder which involves "an impairment of language comprehension, language production, or both in the absence of hearing impairment, the absence of a general developmental delay (i.e. a normal performance IQ), the absence of any neurological impairment (e.g. perinatal bleeds, seizure disorders), and no diagnosis of autism"(Schwartz, 2009b, p. 3). In addition SLI has been used as evidence in support of claims both for modularity of processing, and for nativist approaches to language acquisition (Pinker, 1994). However, current research from a wide range of disciplines is now converging on the view that although adult processing systems may be modular, this is unlikely to be the starting point for the child. Rather the child begins life with a generalised processing system with an innate set of domain general biases and abilities which, over time, and in interaction with the child's environment, repeatedly reorganises and incrementally constructs the adult processing system, wherein specialisation

and localisation of functioning has emerged. Disciplines which have converged on this developmental, emergent, neuroconstructivist approach to language and cognition include developmental psychology, psycholinguistics, linguistics, genetics and neurobiology.
In the field of developmental psychology Karmiloff-Smith and Thomas, have advanced the neuroconstructivist theory of child development, applying it to both typical and atypical development. This theory places the process of development itself at the centre of our understanding (Karmiloff-Smith, 1998; Karmiloff-Smith & Thomas, 2003; Karmiloff & Karmiloff-Smith, 2001; Thomas, 2005; Thomas *et al.*, 2009; Thomas & Johnson, 2008; Thomas & Karmiloff-Smith, 2002, 2005). The neuroconstructivist approach suggests that children are born with a set of biological constraints but that these constraints are domain-general rather than domain-specific. Domain specificity emerges across development as a result of learning and processing. Hence the infant is not a blank slate but rather certain structures in the neo-cortex are more relevant to processing one kind of input over another, and so these domain-relevant systems are the most likely to be harnessed for processing particular types of input. These systems are likely to also be usable for other types of processing, albeit often with sub-optimal outcomes but, in this way plasticity and compensation are possible. Over development an iterative cycle of processing, learning and re-organisation leads to the progressive formation of domain specific processing systems. This therefore implies that the nature of the child's underlying processing system will change repeatedly across development and so the mechanism with which 'child meets world' will differ significantly across childhood. From this premise therefore, to understand typical development, we must understand both the detailed *nature of the processing architectures of the child at different stages in development* and also the *processes and drivers of change across development.*

Also from the field of developmental psychology, Elizabeth Bates, with many collaborators, focussed the challenge to modularity on the process of language acquisition (Bates *et al.*, 1988; Bates *et al.*, 1984; Plunkett *et al.*, 1997). She suggested that language is not the product of processing in a language module but rather that it is an emergent behaviour which is the product of complex interactions between many simpler sub-systems. Her approach emphasised emergence and interactivity in language processing in the moment of processing, across development and indeed across evolutionary time. An additional natural corollary of her approach is that surface linguistic forms do not necessarily map onto corresponding linguistic processing structures in any simple, transparent fashion. Rather the ability to use or understand, for example, a passive construction does not link directly to a 'passive processor' but is a product of interactions between psycholinguistic subsystems. She states that "we must be careful not to take various formal linguistic models too literally when we apply them to psychological functioning" (p. 346), "the description of conventions…is a separate enterprise from psychological explanations of how people acquire and use conventions" (Bates, 1976, p. 353). In addition Bates viewed the study of individual difference as important suggesting that it "can provide evidence about the biological substrates of language" (Bates et al., 1988, p. 275).

A close collaborator of Elizabeth Bates, Michael Tomasello has also been a key contributor to this new perspective with a large body of work in the fields of developmental psychology, linguistics and cognitive science, which has culminated in the formulation of a usage-based theory of language acquisition (Tomasello, 2003). This theory suggests that children construct language from the input that they hear around them and that language acquisition isn't a process of triggering innately specified mechanisms along a pre-specified developmental pathway, rather it involves the child rote learning aspects of language, abstracting rules about that new knowledge, and then re-organising their language processing system in the light of these new rules. Acquiring an adult grammar is therefore a slow process and the 'grammars' which children create at different stages of the language acquisition pathway develop incrementally from very simple item-based patterns to abstract grammatical rules.

In the field of psycholinguistics, the tool of connectionist modelling has been used by many researchers, including Bates, Karmiloff-Smith and Thomas, in an attempt to test whether these neuroconstructivist, developmental and emergent assumptions about language acquisition and cognition can be instantiated in computerised models of acquisition. This is a developing field, with models being produced which can explain patterns of observed developmental change such as past tense learning (Plunkett & Marchman, 1996; Rumelhart & McClelland, 1986), learning to read single words (Seidenberg & McClelland, 1989), the vocabulary growth spurt (Plunkett *et al.*, 1992), and the phenomenon of 'critical periods'(Seidenberg & Zevin, 2006).

In the field of linguistics, the school of cognitive linguistics, of which Tomasello's usage-based theory of language acquisition is an influential member, also includes models of phonology. Pierrehumbert's 'probabilistic phonology' suggests that an abstract phonological system exists in parallel to a store of lexical representations which contain fine grained phonetic detail from numerous presentations, and that the phonological categories represented in the phonological system are created through the abstraction of patterns over the lexical representations of word types in the lexical store (Pierrehumbert, 2003).

Together these approaches identify the components which need to be understood if we are to explain development. They are: the nature of the *sub-systems* from which the complex behaviours of language and cognition emerge, the nature of the *interactions* between the subsystems, the *pathways of change* across development of these subsystems and their interactions, and the nature of the *drivers of this change*. In addition, both Bates' work and insights from genetics emphasise the fact that explanatory models of development must also be able to accommodate *individual differences* and the role of the *environment.* That is, each individual child is born with a unique set of biases and abilities which interact with their unique set of life experiences. In genetic terms, the phenotypic outcomes for each individual will therefore be a result of a complex interaction between the child's genotype and their environment and the subsequent ontogenetic variation which results from this interaction (Pennington & Bishop, 2009). Such an approach predicts that children will demonstrate multiple diverse trajectories of development from infant to adult, with certain pathways being more probable than others but with the potential for wide ranging heterogeneity (Karmiloff-Smith, 1998). In this way atypical developmental profiles can emerge as the ontogenetic consequences of subtle differences in genetically determined domain-general abilities and in interaction with the child's experience.

In summary the process of learning and development from a developmental, emergent, neuroconstructivist perspective can be characterised as an iterative cycle of *uptake*, where the child learns new information with whatever processing mechanisms are available to them at that particular point in their development; *abstraction*, where the child finds commonalities and differences between the items which they have learned and creates a set of rules/and or abstract representations for these abstracted patterns; and *re-organisation*, where the child's processing system is changed in some way as a result of the rules or patterns abstracted and the representations created in the first two steps of learning. The process happens iteratively and with each successive iteration the child's processing system becomes more sophisticated and domain-specific and the nature of what is learned during 'uptake' changed as a function of these changes.

This study seeks to synthesise these perspectives and apply them to create a 'developmental, emergent' approach to our understanding of Specific Language Impairment. Its motivation to do so is not derived from any pre-determined theoretical standpoint of the author, nor is it to use SLI as a testing ground for theory. Rather the motivation derives from the fact that, as new insights have been gained about SLI in the almost 30 years since its inception as a diagnostic term, (Leonard, 1981), it has become apparent that the modular model of SLI has become an 'uncomfortable fit' for this new data. The author's search for a new explanatory framework for SLI is not a 'top-down', theoretically motivated enterprise but rather has itself emerged both from the empirical data of recent research in the field of SLI and the author's experience as a Speech and Language Therapist working with individuals with this impairment and their families. I argue that a developmental, emergent, approach to SLI provides a more 'comfortable fit' between the empirical data and the explanatory model than a modular, nativist conceptualisation. That is, the components and characteristics of a developmental emergent conceptualisation of the developmental process are such that they have the necessary scope and explanatory power to accommodate and explain a number of the more recent findings about the nature of SLI which are difficult to accommodate within a modular framework.

1.2 Research findings which challenge the 'modular approach' to SLI

A number of studies have demonstrated that the apparently 'pure' grammatical impairments found in SLI are in fact affected by and interact with other aspects of processing. For example, bound morpheme use in this group of children, has been shown to interact both with the complexity of the argument structure of the sentence as a whole (Pizzioli & Schelstraete, 2008) and with the phonological characteristics of the verb stem to which they are attached (Leonard *et al.*, 2007a). These results have not only emphasised the *interactive* nature of language processing which is central to the developmental emergent approach, but also its *emergent* qualities. That is they underline the fact that, because language emerges from interactions between subsystems rather than from a grammatical module, the nature of surface linguistic forms do not necessarily reflect the nature of psycholinguistic processes. Hence an apparently specific impairment in grammatical morphology (omission of the bound morpheme –ed) may in fact result from the influence of phonological processing abilities on the acquisition of grammatical morphology and on morphological processing 'in the moment' of speech production (Leonard et al., 2007a). Further support for this emergent perspective is found in the pattern of errors demonstrated by children with SLI in grammatical comprehension probes. That is, children with SLI tend not to demonstrate completely systematic errors which might indicate lack of *knowledge* of grammatical structures but rather evince sporadic errors (i.e. performing at a level above chance but with a high degree of inconsistency) suggestive of difficulties with *processing* of these structures. (Bishop, 1997b; Bishop, 2003b). In addition, in the domain of predicate argument structure development (PAS), children with SLI have been shown, not to make errors per se, but to be limited in the flexibility and complexity of the argument structures used (Thordardottir & Weismer, 2002). The limited flexibility in PAS use is hard to explain form a nativist perspective as this would predict that if a child can use a particular PAS they should be equally able to do so whichever lexical items are used. In fact, Thordardottir and colleagues found that, for the children with SLI, their use of particular PAS was tied to the particular verb in the sentence. Such a pattern has been described in Tomasello's work with very young children such that whilst the grammar is in the process of being 'constructed' children begin by using particular PAS in an item-based fashion and flexibility only emerges once the grammatical rules have been abstracted (Tomasello, 2003). An emergent perspective to language acquisition provides the necessary scope to accommodate and explicate such findings.

Further support for a developmental emergent approach is found on consideration of heterogeneity in this disorder. A high degree of heterogeneity in SLI has long been acknowledged as a necessary consequence of a diagnosis by exclusion. The modular approach has led researchers to frame their understanding of such heterogeneity in terms of subgroups (see Schwartz, 2009b for a review) or as co-morbidity of separate disorders (Pennington & Bishop, 2009). The many attempts to describe sub-groups in SLI have been based upon the assumption that impairments can exist in isolated domains of language processing within the developing system and that other aspects of the system can be spared. Once developmental change is considered however the validity of developing distinctions on such bases is challenged. That is the children's profiles of strengths and weaknesses, and hence assigned subgroup, have been shown to be highly unstable across development (Conti-Ramsden & Botting, 1999). Indeed when development is followed into adolescence such changes can, for some children, point to a changed diagnosis, to one of an autistic spectrum disorder (Conti-Ramsden *et al.*, 2006).

With respect to co-morbidity, associations have been found between speech sound disorders (SSD) reading disability (RD) and SLI across development (Pennington & Bishop, 2009). Although, it is certainly not the case that an impairment in one domain necessarily implies an impairment in the other, related domains, the increased probabilities of such associations point not to entirely separate impairments occurring together by chance, but rather to disorders sharing some degree of genetic causality and/or some relationships in terms of ontogeny. For example the very high risk of a later RD in children with co-morbid pre-school diagnoses of SSD and SLI. These patterns of heterogeneity, co-morbidity and change across development can be understood if they are characterised, not as static diagnostic sub-categories, but as changes in patterns of impairment emerging through dynamic interactions across development. From this perspective increased understanding of the multiple and diverse *trajectories* in SLI holds promise for a more valid explanatory model of heterogeneity and interactivity across development in this group of children.

Another group of research findings which support the developmental emergent approach to SLI are those in the field of genetics. Current understanding of the nature of the influence of genes on complex cognitive processes and on disorders, like SLI, is that they are genetically influenced but have multi-factorial aetiologies, with the genes involved exerting probabilistic influences on the disorder rather than acting as on-off switches for the impairment (Pennington & Bishop, 2009). Hence in twin studies, often co-twins of children with SLI do not fit the strict diagnostic criteria for SLI but do have communicative problems, evincing probabilistic phenotypic outcomes from similar genotypes (Bishop, 2002). These studies have also emphasised another important factor in the developmental emergent approach, that of the environment. That is, genes alone cannot account fully for the phenotypic outcomes of children with SLI. Pennington and Bishop suggest that, in addition to the main effect of the environment on outcomes in developmental disorders, there are likely to be gene x environment interactions. Although this has not been explicitly demonstrated in children with SLI, it has been demonstrated in children with SSD such that genetic effects in children with SSD on their later language and literacy outcomes have been shown to be detectable in language "rich" environments but not in less-optimal environments (McGrath *et al.*, 2007). An obviously crucially important environmental factor for the ontogeny of SLI is the language which the child is acquiring. Despite the obvious importance of this issue it is only very recently that cross-linguistic comparisons in the nature of SLI have been made (Leonard, 2007, 2009). The very different patterns of impairments found in SLI across languages, with different aspects of language differentially affected in response to the nature of the language being learned, emphasise the fact that apparently specific impairments and uneven profiles of abilities can emerge as a product of interactions between innate abilities and the environment through the neuroconstruction of higher order cognitive processes across development (Leonard, 2007, 2009; Stokes *et al.*, 2006).

Finally, a developmental emergent model of SLI challenges a key premise upon which the diagnosis of SLI is based; that of "residual normality". If, as this approach suggests, atypical cognitive and linguistic systems are the products of domain general deficits interacting with the process of development such that the subsequent process of emergent modularization is "perturbed" (Thomas & Karmiloff-Smith, 2005), it is highly unlikely that entirely "specific" deficits can exist. As Thomas and Karmiloff-Smith (2002) state:

> when marked behavioural deficits arise in a single domain, it is likely that the cognitive processes underlying apparently intact performance in other domains are also atypical in subtle ways – which may go undetected without sensitive testing of abilities outside of the behavioural impairment. (p.6)

In accordance with this prediction and despite the fact that the diagnosis of SLI is in fact based upon intact non-verbal cognition, many researchers have demonstrated subtle non-verbal impairments in this group of children in spatial processing (Kamhi et al 1988), visuo-spatial memory (Hick et al 2005), attentional control (Bishop and Norbury 2005), executive functions (Im-bolter et al 2006), processing speed (Leonard et al 2007), and Piagetian conservation tasks (Mainela-Arnold *et al.*, 2006). These findings therefore directly challenge the diagnosis of SLI, particularly the 'specific' nature of the language impairment. Hence from a developmental emergent perspective the term SLI is obviously a misnomer. However, settling on an alternative diagnostic label is not a simple task. The term Primary Language Impairment has been advocated by a number of researchers (Kohnert & Windsor, 2004; Munson *et al.*, 2005b; Windsor & Kohnert, 2004). The term Primary Language Impairment (PLI) describes children whose language difficulties are not secondary to more generalised cognitive, psychosocial or medical difficulties, hence fulfilling the diagnostic criteria for SLI but without the implication made by the 'S' in SLI, of the total absence of any associated non-verbal impairments. This theoretical position and identified population of children match the approach of the author and the children of concern in this study. However the term PLI is itself problematic.

The acronym, PLI is widely used in the UK to refer to children with Pragmatic Language Impairment, a differential diagnosis in the field of developmental language and communication disorders, and so used contrastively with SLI. A developmental emergent account of developmental language disorders also questions the validity of the diagnosis of Pragmatic Language Impairment (although on different grounds to those which apply to SLI) and so abandoning both diagnostic terms may be justified. However this is perhaps premature and, in order to avoid confusion it may be advisable to avoid the use of PLI to refer to a different group of children.

Furthermore, the developmental emergent model of SLI predicts that even in SLI the language impairment is not primary but secondary to some, as yet unidentified, domain general impairment or group of impairments. Hence, replacing Specific Language Impairment with Primary Language Impairment could simply be replacing one misnomer for another. Norbury, Tomblin and Bishop recently favoured the term Developmental Language Disorder, (Norbury *et al.*, 2008). However this term is also used as a broader term for all developmental language impairments whether of known or unknown aetiology (Schwartz, 2009a). In the light of the issues identified above the approach adopted in this thesis is to use the term Language Impaired (LI), to describe that group of children previously described as having SLI, and so to recognise the probability of the existence of impairments outside of the language system, and the use of the term Developmental Language Disorder to refer to all developmental language impairments with or without an identifiable cause. Hence this latter term will be used as an umbrella term encompassing the language disorder LI, and those found in Autistic Spectrum Disorders (ASD), Williams syndrome and other developmental disorders.

A developmental emergent approach to LI therefore has the necessary scope and explanatory power to accommodate and explain many of the more recent findings about the nature of this disorder but in addition creates new challenges and points up new directions for research and practice. To date there is very little empirical data which has been completed from an explicitly developmental emergent perspective and so some crucial factors are missing from our understanding of the disorder, namely the nature of the developmental trajectory of LI, the nature of individual difference in that trajectory and the nature of interactivity between domains and subsystems in the moment and across development in this disorder. This study seeks to contribute to that necessary empirical data and to test whether the expectation that a developmental perspective and methodology adds to our understanding, is justified.

1.3 The Structure of the thesis

The remainder of the current introductory chapter "A developmental approach to SLI: The case for a new conceptualisation", reviews the current explanatory models of LI, and within that considers the current state of knowledge in developmental emergent conceptualisations of this disorder. A rationale is then described for the focus of this thesis on the developing lexicon and, finally the specific aims of the thesis are detailed.

Chapter 2 "Methodology" describes and justifies the methods employed, the participants included and the statistical analyses applied.

Chapter 3 "Building a Lexicon in LI: The Nature of the Emerging Lexicon" describes and reviews current research regarding the nature of the developing lexicon in TD children and those with LI and provides a rationale for the use of a non-word repetition measure as an index of the nature of lexical and sub-lexical knowledge. This chapter then goes on to present empirical data from the non-word repetition task in the form of cross-sectional developmental trajectories and individual longitudinal trajectories in non-word repetition abilities. Comparisons are made to TD children's trajectories of development and the results discussed with reference to the insights gained from these analyses regarding the nature of the developing speech processing mechanism in LI.

Chapter 6 "Building a Lexicon in LI: The Process of Word Learning" reviews the current literature relating to the influence of lexical and phonological factors on the word learning abilities of TD children and those with LI. Empirical data is presented which describes the trajectory of influence across development of these factors on the word learning abilities of both TD children and those with LI and these trajectories are compared. Insights regarding the nature of the word learning difficulties found in children with LI are discussed.

Chapter 5 "A developmental approach to LI: Insights and future directions" presents a discussion of the empirical data presented herein and considers the future implications for research and practice of a developmental emergent approach to LI.

1.4 Current explanatory models of LI

There are a number of explanatory theories of LI. Leonard (1998) identifies three groupings for these theories, LI as a deficit in linguistic knowledge, LI as a limitation in general processing abilities and LI as a processing deficit in specific mechanisms. There is a fourth group which has some overlap with the latter two groupings; LI as a developmental emergent disorder.

1.4.1 LI as a deficit in linguistic knowledge

The group of theories which describe LI as a deficit in linguistic knowledge include the Extended Optional Infinitive account (EOI) (Rice *et al.*, 1995) which has recently been modified and presented as the Extended Unique Checking Constraint hypothesis (EUCC) (Wexler, 2003); the Representational Deficit for Dependent Relationships (RDDR) (van der Lely, 1994) which had also recently been updated and presented as the Computational Grammatical complexity hypothesis (CGC) (van der Lely, 2005); and a newer hypothesis relating to thematic role transfer in non-canonical sentence constructions (Friedmann & Novogrodsky, 2007). These, in turn, describe and account for the difficulties children with LI have with finite verb morphology (specifically third-person singular inflection *–s,* regular past *–ed,* copular and auxiliary *be,* and auxiliary *do*) (Rice et al., 1995; Wexler, 2003); with case and "long-distance" syntactic dependencies (such as anaphoric reference, reversible passives, and wh-movement: van der Lely, 2005); and phrasal movement (such as in relative clauses, wh- questions, and reversible passives: Friedmann & Novogrodsky, 2007). These accounts are based on both large, statistically powerful samples (Rice *et al.*, 1998) and meticulous and detailed case studies (Friedmann & Novogrodsky, 2007; van der Lely, 2005) and their data are not challenged by this study. However this study does question their nativist premise of innate modular language processing mechanisms which can be impaired in fractionated and highly specific ways, and so particularly challenge their claims with regard to the existence of the separate subtypes of LI of G-SLI (Grammatical SLI) (van der Lely, 2005), and Syntactic SLI (Friedmann & Novogrodsky, 2007). That is, the developmental emergent perspective suggests that such apparently specific profiles can be the developmental outcomes of domain general deficits and hence it is unlikely that the broader language abilities in children with G-SLI and Syntactic SLI will be entirely spared. Hence, subtle deficits in lexical and phonological knowledge are also likely to co-exist in these children. In fact this expectation was recently confirmed through detailed assessment of children with a diagnosis of G-SLI (Norbury *et al.*, 2002). Secondly and, perhaps, most importantly, claims for the existence of G-SLI and Syntactic SLI rest upon data from children aged nine years and above without consideration of the developmental pathway which has led them to their current profile of strengths and weaknesses and so claims of specificity reflect a narrow perspective of the child's difficulties. The developmental emergent approach advocated here does not question the grammatical profiles of G-SLI and Syntactic SLI but views them as descriptive terms for a language profile which is one possible end product of a developmental trajectory of language impairment involving the construction of an atypical language processing mechanism through the interaction of innate domain general impairments, the child's environment and the process of learning itself.

1.4.2 LI as a limitation in general processing abilities

In terms of general processing abilities, researchers have posited impairments in complex working memory (CWM), processing speed and attention mechanisms. With respect to a processing capacity limitation in LI, most recently Montgomery (2003, 2004, 2005) and Ellis Weismer and colleagues (2002) have presented the case for limitations, particularly in complex working memory (CWM), to be considered as potentially crucial to the aetiology of LI. In addition Gathercole and colleagues (Gathercole *et al.*, 2005) and Bishop and colleagues (Briscoe *et al.*, 2001; Norbury *et al.*, 2001) suggest that difficulties with CWM *in conjunction* with limited phonological working memory (PWM) could create the context for the emergence of LI. Whether or not CWM deficits are entirely independent from long term language knowledge or the efficiency of language processing is moot (Mainela-Arnold & Evans, 2005). Schwartz (2009b) suggests that "one way of characterizing the working memory limitations of these children is that their working memory is less well able to deal with linguistic complexity...in comparison to their typically developing peers" (p. 8-9). Work with respect to processing speed has yielded mixed results with not all children with LI exhibiting slowed processing and this slowing not being evident in all domains (Miller *et al.*, 2006). It is also possible that slowed processing may be an associated feature in the phenotype of some children with LI which does not directly affect the language abilities of these children (Lahey *et al.*, 2001).

Whether or not researchers consider children with LI to have attention deficits relates partly to the researcher's interpretation of what working memory tasks entail. That is, whether or not the researcher views working memory tasks as tapping attentional mechanisms (Engle, 2002). Indeed as models of working memory have become more detailed in their specification, more candidate mechanisms for the possible locus of impairment have emerged, including both attention (Bishop & Norbury, 2005) and increased interference (Marton & Schwartz, 2003). In addition, when framed within a model of executive function, deficits have been found in three mechanisms relevant to working memory; attention, interruption (which involves inhibition) and updating from long term memory (Im-bolter *et al.*, 2006).

1.4.3 LI as a processing deficit in specific mechanisms

In accounts of LI as a processing deficit in specific mechanisms, again, a number of candidates have been put forward including phonological working memory (PWM), phonological sensitivity, and speech processing.

The PWM explanation for LI has been extremely influential. The approach is based on Baddeley and Hitch's model of working memory (Baddeley & Hitch, 1974) and suggests that children with LI have a limitation in the capacity of one component of this working memory mechanism, that of the phonological loop. The phonological loop is posited to be a specialised mechanism for processing and maintaining verbal material and an impairment in this mechanism is thought to impede lexical and morphological learning (Gathercole & Baddeley, 1993). This hypothesis and the model upon which it is based have been adapted and updated since their inception but a difficulty with phonological storage for short term processing remains a core premise of this account (Baddeley, 2003; Gathercole, 2006).

A number of other researchers have proposed a more qualitative impairment with phonological processing suggesting that there is a direct link between the quality of lexical and phonological representations in the child's language processing system and the efficiency with which they can deal with that information. Sometimes termed the "phonological sensitivity hypothesis" this approach suggests that it is the quality of phonological processing which then predicts the capacity of the phonological storage available to the child (Bishop, 1997b; Bowey, 2001, 2006).

The final account of LI as a processing deficit in specific mechanisms, relates to speech processing. Most research in this area has focussed on a claim advanced by Tallal and colleagues of a deficit in temporal processing, that is, in processing rapidly presented sequences of aural stimuli (Tallal, 2000). This research is controversial in terms of whether the deficit detected truly represents a deficit in temporal processing or whether it relates to skills such as categorical perception, perception of formant transitions, memory, and attention and further whether these skills are really independent of language knowledge (Coady *et al.*, 2007; Coady *et al.*, 2005). In addition it would appear that although speech processing deficits may exist in children with LI, they are unlikely to be causal (Bishop, 2006) and may in fact relate to environmental rather than genetic factors (Bishop, 2002).

1.4.4 LI as a developmental emergent disorder

The processing accounts described can be seen as implicitly developmental and emergentist in their approach in that they imply that the domain general processing impairments implicated in each account can create the specific and uneven profile of impairments found in LI.

However they are generally not explicit either in terms of their links to the developmental emergent approach or regarding how exactly the mechanism described can, through interaction with development, create the LI profile. In other words the question, "how does the child get from there to here?" is not answered. Hence the fourth group of explanatory accounts, LI as a developmental emergent disorder, includes three groups; the processing accounts previously described (both specific and general); accounts which explicitly align themselves with a developmental, emergentist or neuroconstructivist perspective; and those which may not make this link explicit, but who do attempt to specify how a domain general impairment may interact with the developmental process to create the language profile of LI. The second group, those who explicitly appropriate the developmental emergentist or neuroconstuctivist labels include Thomas and Karmiloff-Smith (Karmiloff-Smith, 1998; Thomas, 2005; Thomas & Karmiloff-Smith, 2002, 2005), and Joanisse and Seidenberg (Joanisse, 2004, 2009; Joanisse & Seidenberg, 2003). These researchers use connectionist modelling to test whether the uneven profiles of impairment in complex linguistic behaviours found in LI can emerge from self organising networks which have been 'impaired' with a domain general processing impairment. Through the instantiation of models of processing and impairment they have demonstrated how a phonological/speech processing impairment can lead to the highly specific grammatical impairments found in LI. For example, with respect to the pattern of past tense morphological impairment found in LI, when a network built to learn the English past tense was impaired, the network demonstrated delayed development in proficiency, an asymptotic growth pattern with the ceiling occurring at a level of accuracy below that of the 'typically developing' network, fewer over-regularisation errors and more zero marking errors than the 'typically developing' network, and a delayed ability to generalise past tense marking to non-words. Hence it exactly mimicked the pattern of impairment found in LI (Joanisse, 2004).

Using a connectionist model of sentence comprehension, Joanisse and Seidenberg (Joanisse & Seidenberg, 2003) examined the pattern of errors in pronoun comprehension found in LI. That is children with LI have difficulty with anaphoric reference in sentences where semantic information cannot support comprehension (e.g. *Harry says Bob slapped him/himself* is more difficult to comprehend than *Harry says Mary slapped him/herself*). The network included a set of hidden units representing a form of 'working memory' where a representation of the sentence was maintained until the meaning could be resolved. When this network was created with a phonological/speech processing impairment, it was slower to learn the meanings of the words and sentences in the training corpus, eventually doing so, but with a specific difficulty in resolving pronouns and reflexives with anaphoric reference in sentences where semantic information did not support comprehension, hence mimicking the impairment found in LI. The authors suggest that this impairment had emerged as a result of a working memory limitation affecting the network's ability to hold all of the words of the sentence in memory until the meaning of the sentence was resolved. They point out that the impairment which induced this limited capacity was not a difference in the architecture of the working memory system but a weakened quality of the phonological input the network received. Hence the model suggests that impaired phonological/speech processing within a developmental emergent model, can induce both a working memory deficit and a highly specific syntactic deficit.

Thomas and Karmiloff- Smith's approach to LI is very similar to that of Joanisse and Seidenberg but, in addition to a psycholinguistic level of explanation, Thomas and colleagues argue that neurobiological and genetic evidence also exist for their neuroconstructivist approach to LI. For example Thomas et al. (submitted) cite a study by Soriano-Mas et al. (2009) which analysed structural brain images of children with LI and found that, overall, this group of children have more grey and white matter than typically developing (TD) children and that these differences are greatest in younger children (aged 5 – 11 years versus aged 12 – 17 years). Thomas and colleagues suggest that the differences in brain structure may reflect an atypical trajectory in cortical development and the fact that these differences are greatest in the younger children reveals the effects of plasticity, developmental change and the effects of compensation. With respect to genetics, Thomas, Karmiloff-Smith and colleagues (Westermann *et al.*, submitted) cite the work of Plomin and colleagues (Hayiou-Thomas *et al.*, 2006) who have demonstrated that for disorders such as autism, LI and dyslexia, multiple genes contribute to the behavioural outcome of the individual, each with small effects. Hence epigenesis of the disorder is thought to be probabilistically determined with only broad genetic regulatory control and a significant effect both of the environment and the process of development on the phenotypic outcome. The work of Joanisse and Seidenberg and Thomas and Karmiloff-Smith provide an important contribution to the application of developmental emergent approach to LI. However they do not provide a fully specified account of how the specific phenotype of LI emerges from the effects of the impaired processing mechanism. For a developmental emergent approach to LI to develop further, hypothetical trajectories of development must be described and tested with empirical data. Such developmental models and data are rare.

One such account is Chiat's "Mapping Theory of Developmental Language Impairment" (2001). In this important paper Chiat presents a developmental model of LI that suggests that an early phonological processing deficit is a plausible source of many of the difficulties observed in LI. She argues that an initial processing deficit which interferes with a child's ability to learn to parse the speech stream into words would result in impaired mapping and hence impaired word learning. Possible causes of the initial processing deficit include an impairment in the processing of prosody (Echols, 1996) or an insensitivity to the relative frequency of patterns of sounds in the ambient language (Jusczyk *et al.*, 1994). The resulting mapping deficit would necessarily imply a smaller lexicon and therefore the process of lexical restructuring (the increasing specification of lexical representations which is thought to occur as a lexicon grows (Walley *et al.*, 2003)) would be much slower than for the TD child. Chiat's argument continues that a lexicon containing more holistic representations would hinder the development of morphology and thence syntax, and would make phonological processing more difficult. It would then follow that semantic bootstrapping would be less accessible to the child with LI due to their limited vocabulary, syntactic bootstrapping would be impaired due to limited morphology and phonological bootstrapping would be affected by deficient phonological processing. Hence a vicious circle would develop such that new word learning would be difficult because the child has a limited lexicon and the child has a limited lexicon because they find word learning difficult. As this phonological-lexical deficit compounds, Chiat's model predicts differential effects on the learning of specific linguistic forms across multiple linguistic domains, suggesting that where phonology plays a role in cueing the semantics of a specific structure or where phonological processing of that structure is particularly complex, then that it will be disproportionately impaired. Chiat ends her paper suggesting that the twin theories outlined, a mapping theory of developmental language impairment and a phonological theory of LI, could serve "as a catalyst for research which is of theoretical interest and practical consequence" (Chiat, 2001, p. 139). Indeed it also provides the first fully specified hypothesised developmental trajectory for LI, against which empirical trajectories can be compared and from which hypotheses can be generated and tested.

Another author who has attempted to specify how a domain general impairment may interact with the developmental process to create the language profile of LI is Leonard. His Surface account of LI suggested that, in combination and in the context of a developing system, a speech processing impairment linked with a generalised processing capacity could cause the deficits in bound morpheme use found in LI (Leonard, 1998). More recently Leonard presented an account which links generalised processing limitations with Tomasello's usage-based model of language acquisition to explain some of the patterns of grammatical impairment found in LI (Leonard, 2007). In particular he identifies how the often observed sentence construction found in children with LI of a pronoun error in subject position, associated with missing auxiliaries, copulars and inflections, may result from the child rote learning syntactic constructions (as predicted by usage-based theories) but doing so with a limited processing capacity. In this way Leonard argues that the pattern of errors described could result from children with LI hearing long, fully grammatical adult utterances but, through recency effects, only learning the final part of the sentence, the non-finite clause. So for example '*me do the dishes*' would be learned from '*will you help me do the dishes*', and '*him jump*' from '*let's watch him jump*'. Leonard's proposition has added power as he considers its application cross-linguistically to German, Dutch, Swedish and Italian. This hypothesis requires further empirical research but would seem an exciting synthesis of processing and linguistic approaches which could yield new and important insights for LI.

Bishop has long advocated a phonological impairment as being a causal deficit in LI (Bishop, 1997b). However she has also argued that single deficit explanations for this disorder are likely to be overly simplistic (Bishop, 2006). Bishop's conceptualisation of LI has evolved over the last decade and her approach now applies developmental emergent theory more explicitly, expressing dissatisfaction with the application of adult psycholinguistic paradigms to developmental disorders (Bishop, 1997a), considering the interaction between genes and the environment on the disorder (Bishop, 2002) and directly applying developmental psycholinguistic theories to the acquisition of phonology and syntax (Bishop, 2000). In this latter paper, Bishop remains undecided as to whether the impairment found in the child with LI is created prenatally, setting the child up with a brain function which is not optimally organised for language development, or whether the impairment arises over development. More recent work, with respect to genetic influences on LI has led Bishop to favour the first explanation (Bishop *et al.*, 2006; Pennington & Bishop, 2009). That is, results from twin studies have suggested that impairments in grammar and phonological working memory are highly heritable but that *different* genes are implicated in causing these difficulties. Hence the two impairments co-exist at levels above chance but also can exist entirely independently of one another. From this result, Bishop infers that the syntactic deficits in LI are not created by domain general impairments but by specific impairments to brain mechanisms which have, over evolutionary time, become, adaptively specialised for syntax. The distinction between her approach and that of the previously described developmental emergent approaches is subtle. That is, she acknowledges the interaction between genes and the environment, she describes phonological, lexical and grammatical development in developmental emergent terms, and she considers language to be the product of numerous interacting skills and systems. Where Bishop's account diverges from Thomas and Karmiloff-Smiths's account is in the degree to which infant processing systems are seen as domain-specific and the nature of influence of genes on those systems. That is, Bishop argues for domain specific rather than domain relevant structures existing in the infant and for genetic impairments which can exert tight and highly specific control over neuronal outcomes. Thomas and Karmiloff Smith (Westermann et al., submitted) and Plomin and colleagues (Kovas & Plomin, 2006) would suggest, on the other hand, that if developmental genetic disorders are characterised as probabilistically determined outcomes, resulting from only broad genetic regulatory control and with a significant effect both of the environment and the process of development on the phenotypic outcome, then this pattern of distribution of impairments could be explained without recourse to domain specificity in grammatical development.

1.5 The future for LI: a developmental emergent disorder?

Form the above review it is apparent that the developmental emergent approach to LI is itself emerging and that although it shows great promise for accommodating current understanding of the nature of LI, there is still a great deal of work to do. What is greatly lacking is empirical longitudinal data with which to begin to test the theories and to explore trajectories. Indeed the trajectory of language development and the nature of change in language relevant sub-systems across development has not yet been fully specified in typical development (2003) and, although some longitudinal studies have been completed tracking development in LI, their methodologies have not allowed for conclusions to be drawn regarding the detailed nature of emergence of the language processing system. That is, such studies have tended to use standardised tests, to test the children at wide time intervals, and to analyse change at a group rather than individual level (Conti-Ramsden, 2008; Conti-Ramsden & Botting, 1999; Conti-Ramsden & Botting, 2008; Conti-Ramsden *et al.*, 2001; Conti-Ramsden *et al.*, 2008; Conti-Ramsden *et al.*, 2009; Stothard *et al.*, 1998; Tomblin, 2008). Hence, despite uncovering important insights regarding outcome and risk, they have not uncovered the detailed nature of the neuroconstruction of a developmental Language Impairment. The current study therefore aims to contribute to this much needed empirical data regarding the nature of the developmental trajectory in LI.

1.6. Why focus on the developing lexicon?

In many of the accounts of LI previously described, a phonological processing deficit, either in terms of quality (Bishop, 1997b; Bowey, 2006; Chiat, 2001) or capacity (Gathercole, 2006), is advanced. Current models of phonological knowledge consider the development of phonological and lexical knowledge to be mutually dependent (Pierrehumbert, 2003; Walley et al., 2003). Hence, an impairment in phonological processing has been characterised as both a cause and a consequence of limited lexical knowledge (Munson et al., 2005b). The influence of long term lexical knowledge on PWM and processing capacity is now widely acknowledged (Gathercole, 2006; Gupta, 2006; Mainela-Arnold & Evans, 2005) and, although it seems likely that lexical knowledge cannot explain all of the variability in children's processing capacity and working memory abilities (Archibald & Gathercole, 2007; Leonard *et al.*, 2007b), it does undoubtedly exert a significant and important effect on verbal processing capacity and efficiency in children with LI. It is plausible therefore to assume that other impairments found in LI may emerge from this mutually dependent triad of impairments in lexical knowledge, phonological processing, and verbal processing capacity.

There are many examples of broader language difficulties in children with LI which emerge from this triad of impairments. Alt and Plante (2006) have demonstrated that a limited processing capacity and/or phonological processing difficulties cause children with LI to learn less semantic detail about novel words during word learning than TD children; Leonard and colleagues (2007a) have demonstrated that, unlike TD children, the abilities of those with LI to use bound morphemes is influenced by the phonological characteristics of the verb stem to which they will attach; Criddle and Durkin (2001) showed that children with LI were less able to learn novel morphemes than their TD peers when the morphemes were not in sentence final position; Marshall and van der Lely (2006) identified that children with LI were less able to use bound morphemes in contexts where the sound sequences formed were monomorphemically illegal than when they were monomorphemically legal (i.e. whether or not the cluster formed through the addition of the bound morpheme ever occurred in monomorphemic words in English), and that TD children were unaffected by this constraint; Pizzioli and Schelstraete (2008) found that the frequency of grammatical morpheme errors made by children with LI interacts with the sentence's argument structure complexity, suggesting that these errors are linked to the children's overall processing capacity.

Fundamentally, if language is constructed over development through iterative cycles of uptake-abstraction-reorganisation, then the triad of impairments in lexical knowledge, phonological processing, and verbal processing capacity found in LI will affect the first step in this cycle, of 'uptake' in both quantitative and qualitative terms. The other elements of the learning cycle, of abstracting rules and reorganising the processing system, will be affected by this more limited uptake. Through additional processes of compensation, altered timing of emergence of skills and the properties of critical periods produced by self-organising networks, this slower uptake will not simply create a slower trajectory but, as in LI, an atypical and uneven profile and trajectory.

It is also possible that genetic control of neurological development, with respect to processes such as neuronal proliferation and synaptic pruning, could exert additional detrimental effects on the abstraction and reorganisation stages of the cycle of learning over and above those occurring as a direct result of limitations in uptake.

Understanding the nature of the trajectory of the developing lexicon in TD and LI could therefore provide important insights into the early ontogeny of LI. Through careful description of the process of neuroconstruction of the early LI profile it may prove possible to uncover important insights into causal mechanisms, to describe atypical trajectories and to identify potential drivers of change which could be harnessed for early interventions.

This study therefore has the following aims with respect the developing lexicon in LI:

1. To provide a first detailed description of the "perturbed" process of emergent modularisation in young children with LI based on empirical longitudinal data
2. To pilot the methodology of longitudinal case studies of language impaired children and hence consider whether the expectation that a developmental perspective and methodology adds to our understanding is justified.

3. To consider what this empirical longitudinal data tell us about current theories as to

    i. the causal mechanisms

    ii. the course of the perturbed emergent pathway

    iii. the nature of the relationships between 'early' and 'late' patterns of impairment and of interactions between domains

CHAPTER 2

METHODS

In the previous chapter the issues which provide the impetus for this research were identified and the rationale for its aims explained. In this chapter the study design, participants and data gathering instruments will be described and, in addition, a rationale provided for the choice of methodology and the domains of assessment.

The main aim of this research is to improve our understanding of the *development* of language impairment in children (LI) and specifically to address the following aims:

1. To provide a first detailed description of the "perturbed" process of emergent modularisation in young children with LI based on empirical longitudinal data
2. To pilot the methodology of longitudinal case studies of language impaired children and hence consider whether the expectation that a developmental perspective and methodology adds to our understanding is justified.
3. To consider what this empirical longitudinal data tell us about current theories as to
    i. the causal mechanisms
    ii. the course of the perturbed emergent pathway
    iii. the nature of the relationships between 'early' and 'late' patterns of impairment and of interactions between domains

The focus of this thesis is on the *nature of the developing lexicon* for the reasons described in Chapter 1. The results presented in this thesis therefore derive only from those measures which are pertinent to the developing lexicon: that is a novel non-word repetition task and word learning task and a number of standardised measures. However the study as a whole aimed to consider language development more broadly and to consider interactions between domains of language and language relevant skills. To that end, data was collected on a number of measures, the results of which are not presented here. The following chapter will describe the rationale for and the broad aims of all of the measures included in the study; however descriptions of task methodology will only be provided for those tasks which are the main focus of the thesis and these will be presented in detail in the relevant empirical chapters. The following therefore describes the rationale for the choice of methodology, the rationale for the domains of assessment, the study design, the participants, the measures, the data collection methods, and finally the data analysis approach.

2.1 Rationale for the choice of methodology

At the core of this research is a desire to explore the nature and ontogeny of a complex developmental disorder in detail. It begins from the premise that developmental systems such as language are multiply determined and emerge from changes in their component parts, interactions between these component parts and the process of development itself.

This study therefore aims to apply a developmental, emergent, neuroconstructivist perspective to our understanding of the nature of LI. As described in detail in Chapter 1 neuroconstructivist models suggest that whereas functional modularity in adult processing is possible it is unlikely to be the starting point for the infant. That is, the infant's cognitive processing is more likely to consist of a group of domain general processes some of which are relevant to language (and to other systems) and some of which are not. These processes can be considered "domain relevant" rather than "domain specific" and modularisation emerges through a process of interactions between the child, their environment and their changing cognitive system (Thomas, 2005).

From this perspective, LI and other developmental disorders can therefore be characterised as the result of some early, unknown effect of the disorder on domain relevant processing systems which results in a perturbation of the process of emergent modularisation. As yet we do not know what these early effects are and the process of "constrained development" has not been charted in this disorder. To fully understand a developmental disorder we need to understand both how the early domain relevant mechanisms are altered and how this difference changes the developmental process (Thomas, 2005). This study seeks to examine the second of these issues, that of the "perturbed" process of emergent modularisation in children with LI.

In order to describe the developmental process Thomas and Karmiloff-Smith (2005) suggest that there are three fundamental characteristics of a developing system which must be considered; interactivity, compensation and timing. Each of these characteristics necessarily implicates a specific choice of methodology for the research. Firstly, in order to consider *interactivity* between multiple sources of information and processing mechanisms, detailed and comprehensive assessments of language processing and language 'relevant' systems must be carried out. Secondly, for *compensation* to be considered then individual differences in *language processing* must be considered even in the context of apparently typical levels of *language knowledge,* and thirdly, in order to consider *timing* a longitudinal methodology must be applied.

The research questions also implicate certain methodological choices. To determine whether there are a number of different pathways of development in LI then individual longitudinal case studies must be described and compared. To track interdependence of skills then a comprehensive assessment of language skills must be completed and considered over time. The aims and central assumptions of this research therefore dictate the choice of methodology; that of a series of detailed, longitudinal, descriptive case studies, considering language processing, language knowledge and other possible "domain relevant" skills.

2.2 Rationale for the domains of assessment

In creating a rationale for the choice of language and language relevant domains to be assessed in this study, two fundamental factors were considered, those of scope and specificity. In defining scope a decision needed to be made as to the range of language processing and language relevant processing mechanisms which should be examined. In defining specificity a decision as to the degree to which the language processing mechanism should be sub-divided was required.

These decisions however were problematic because, as Tomasello (2003) states with reference to the huge and complex task of language acquisition, " There are no fully adequate theoretical accounts of how young children do all of this" (p. 321). Therefore a fully specified pathway of development from domain general mechanisms to domain specific processing has not been mapped and, crucially for this study, the nature and level of granularity of "proto-processing" systems at different stages in development has not been clearly defined.

A pragmatic and eclectic approach was therefore applied using evidence from three key sources; current models of adult and child language processing mechanisms, current theory regarding typical language development from a neuroconstructivist perspective, and research into the nature and causes of LI.

Firstly, with respect to existing models of language processing, there is a wide array of candidates ranging from the highly modular (Morton, 1969) to the highly interactive (Schwartz *et al.*, 2006: see Figure 2.1) and those which fall somewhere in between (Chiat, 2000; Nickels, 1997). Connectionist models are most consistent with the assumptions of a neuroconstructivist approach however work using this approach has mainly focussed on processing at the word and morpheme level, very little has been completed with respect to syntax (c.f. Joanisse, 2009). Hence, the approach adopted in this study is to consider the lexicon with reference to connectionist models (Gupta & MacWhinney, 1997; Luce *et al.*, 2000; Schwartz et al., 2006) but for other areas of language processing, no specific model has been adopted. However those described by Chiat (2000), and Garrett (1980) have informed the choices made.

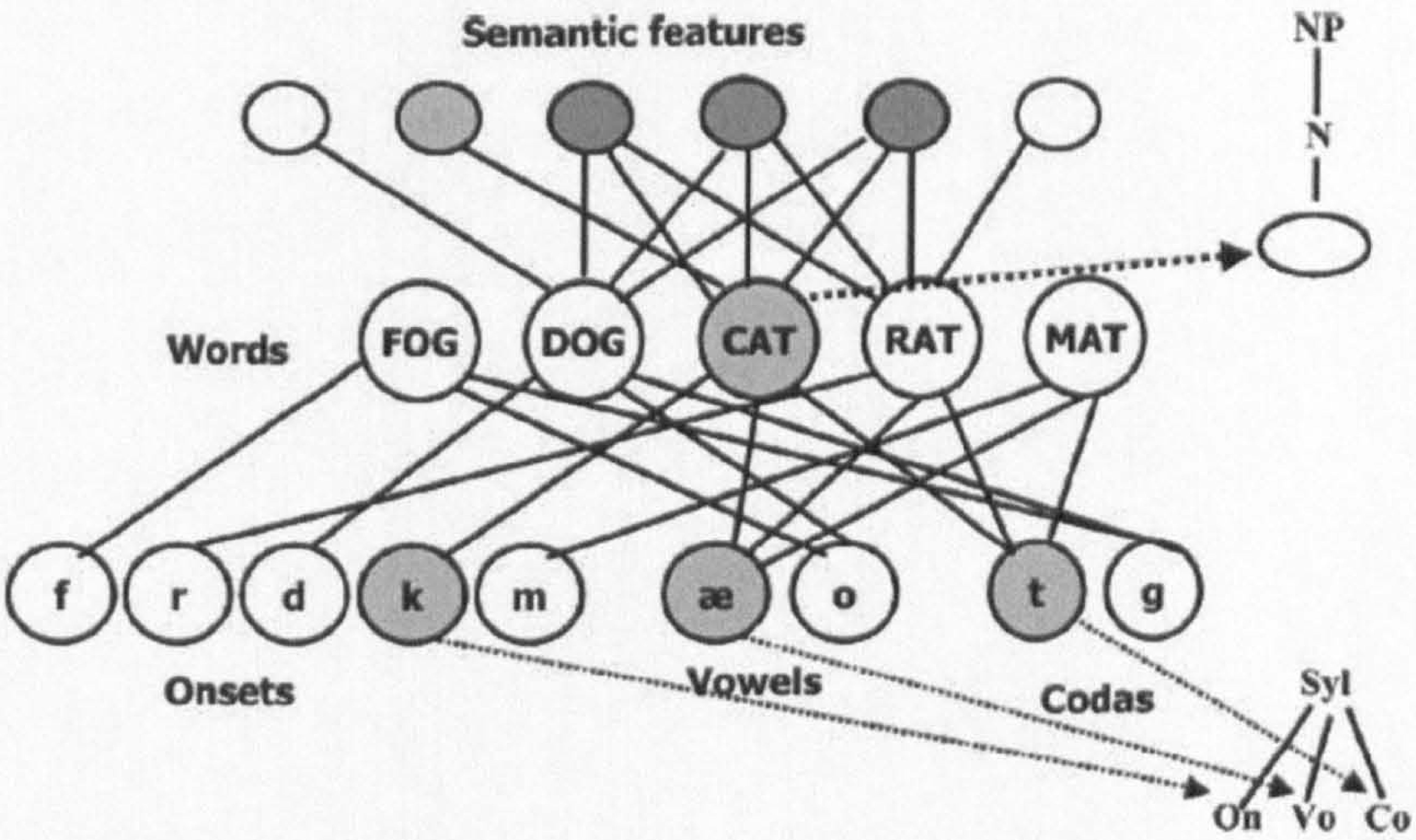


Figure 2.1. The Two-Step Interactive-Activation Model (Schwartz et al., 2006)

The second source of evidence which informed the choice of domains of assessment was the group of current theories regarding the nature of typical language development which take a developmental emergent perspective. These theories have been described in detail in Chapter 1. Those which have specifically informed the domains of assessment chosen include usage-based theories (Tomasello, 2003), the emergent-coalition model of word learning (Hirsh-Pasek *et al.*, 2000) and connectionist models of the acquisition process (Elman, 2001).

All three of these theoretical approaches emphasise interactivity and emergence in the language system. The usage-based theory posited by Tomasello (2003) provides a lens with which to analyse expressive language development from a neuroconstructive perspective. This provided both the impetus to use spontaneous language sampling as a data collection strategy and also a framework within which to consider changes in the expressive language skills of the participants.
Tomasello (2003) suggests that the most crucial domain general mechanisms for driving language acquisition are intention reading (broadly a set of skills which relate to theory of mind) and pattern finding. Intention reading is also emphasised as crucial to language learning in the emergantist coalition model. This provided the impetus to include assessment of the participants' pragmatic skills as an assessment domain in this study. The emergantist coalition model informed further choices of assessment domains when considered in conjunction with theories of LI and so will be discussed further below.

The connectionist models of the acquisition process, as mentioned above, relate mainly to the areas of lexical and morphological development (Elman, 2001; Marchman, 1997). The structure of these connectionist models identify the domains of semantic, lexical and phonological levels of representation but also posit relationships between characteristics of the lexicon and other processing skills such as word learning ability, working memory, phonological sensitivity, phonological awareness and bound morpheme development (De Cara & Goswami, 2003; Gathercole, 1999; Marchman *et al.*, 1999; Storkel, 2001). Connectionist models of development therefore provided the impetus to include these domains and skills in the assessment regimen of the study and to include analysis of interactions between them.

Research which considers the nature of the developing lexicon identifies two important areas of debate; the exact nature of *lexical representations* in the developing lexicon and whether the child's lexicon is *organised* in the same way as an adult lexicon. The issue in question regarding the nature of the *lexical representation* relates to its level of specificity, that is whether the phonemic segments of a word are present and functional from the beginning of speech development or whether they emerge over time. The point of debate with regard to the *organisational structure* of the developing lexicon relates to whether the lexicon is organised in the same way as an adult lexicon both in terms of the density of the similarity neighbourhoods and also the unit of sound used to organise those neighbourhoods. These issues informed the design of measures used to probe the lexical-phonological domain, auditory processing, and more general processing skills and will be discussed in more detail in relation to the individual task methodologies (Section 2.5 Measures).

A final point with reference to developmental connectionist models relates to their rejection of the assumption of "Residual Normality" in developmental disorders. As Thomas and Karmiloff-Smith (2002) state:

> when marked behavioural deficits arise in a single domain, it is likely that the cognitive processes underlying apparently intact performance in other domains are also atypical in subtle ways – which may go undetected without sensitive testing of abilities outside of the behavioural impairment. (p.6)

LI is a diagnosis based on the assumption of residual normality in non-verbal cognition and pragmatic abilities (Bishop, 1997b; Leonard, 1998), however recent research has called these assumptions into question (Bishop & Norbury, 2002; Botting & Conti-Ramsden, 2003; Botting *et al.*, 2005). This study therefore included assessments of non-verbal skills and pragmatics not simply as diagnostic measures but also in order to consider their development with reference to the concept of residual normality and their interaction with language processing.

Finally, to consider the contribution of current theories relating to causes, characteristics and "markers" of LI to the choice of assessment domains: as outlined in Chapter 1 there are a number of explanatory theories of LI: LI as a deficit in linguistic knowledge, LI as a limitation in general processing capacity, LI as a processing deficit in specific mechanisms and LI as a developmental emergent disorder. The group of theories which describe LI as a deficit in linguistic knowledge (Friedmann & Novogrodsky, 2007; Rice et al., 1995; van der Lely, 2005) provide the impetus to consider the development of those grammatical structures which are appropriate to the age range of the children in this study. These deficits will be considered within a developmental emergent framework and therefore the influence of phonological and lexical processing on the development of grammatical morphology is considered.

The group of theories which describe LI as a limitation in general processing capacity (Ellis Weismer & Evans, 2002; Montgomery, 2003, 2004, 2005) have presented the case for limitations, particularly in complex working memory (CWM), to be considered as potentially crucial to the aetiology of LI. In addition Gathercole and colleagues (Gathercole et al., 2005) and Bishop and colleagues (Briscoe et al., 2001; Norbury et al., 2001) suggest that difficulties with CWM *in conjunction* with limited phonological working memory (PWM) could create the context for the emergence of LI. Hence a CWM and a PWM memory measure have been included in the assessment battery. The influence of processing limitations on the grammatical comprehension and sentence production were also considered.

In accounts of LI as a processing deficit in specific mechanisms, a number of candidates have been put forward. A phonological working memory deficit which impedes lexical and morphological learning (Gathercole & Baddeley, 1993) is one such mechanism and a measure of PWM was therefore included in this study. A second candidate is a deficit of temporal processing as advanced by Tallal and colleagues (Tallal, 2000). This research remains controversial and it would appear that this deficit may not be causal in LI (Bishop, 2006). Temporal processing abilities were therefore not measured in this study. Leonard and colleagues suggest that poor grammatical competence may result from a perceptual deficit (the Surface Hypothesis) and so this study included an auditory processing assessment tapping the phonological level of processing.

The fourth group, LI as a developmental emergent disorder, as established in Chapter 1, is a newly developing approach and, on the whole, such models are underspecified in terms of the nature of their hypothetical trajectories of development in LI. An exception is Chiat's mapping theory of LI (2001). In this account Chiat argues that a phonological processing deficit is a plausible source of many of the difficulties observed in LI. She argues that an initial processing deficit which interferes with a child's ability to learn to parse the speech stream into words would result in impaired mapping and hence impaired word learning. The resulting mapping deficit would in turn affect the nature of the representations in the lexicon of the child with LI such that the process of lexical restructuring would be much slower than for the TD child. Chiat's argument continues that a lexicon containing more holistic representations would hinder the development of morphology and thence syntax, and would make phonological processing more difficult. It would then follow that semantic bootstrapping would be less accessible to the child with LI due to their limited vocabulary, syntactic bootstrapping would be impaired due to limited morphology and phonological bootstrapping would be affected by deficient phonological processing. Hence a vicious circle would develop such that new word learning would be difficult because the child has a limited lexicon and the child has a limited lexicon because they find word learning difficult. This model provided the impetus, together with the emergent coalition model of word learning, to include a measure of word learning ability in this study. In addition the influence of existing lexical knowledge on that mapping process was also considered. Indeed, this model of LI suggests that the nature of the child's lexical representation and/or their access to this representation may be crucial to a number of processing mechanisms. This provided the motivation to consider the influence of this lexical knowledge/specification in measures of phonological sensitivity/awareness, auditory processing, phonological working memory, lexical representation and, as previously mentioned, word learning.

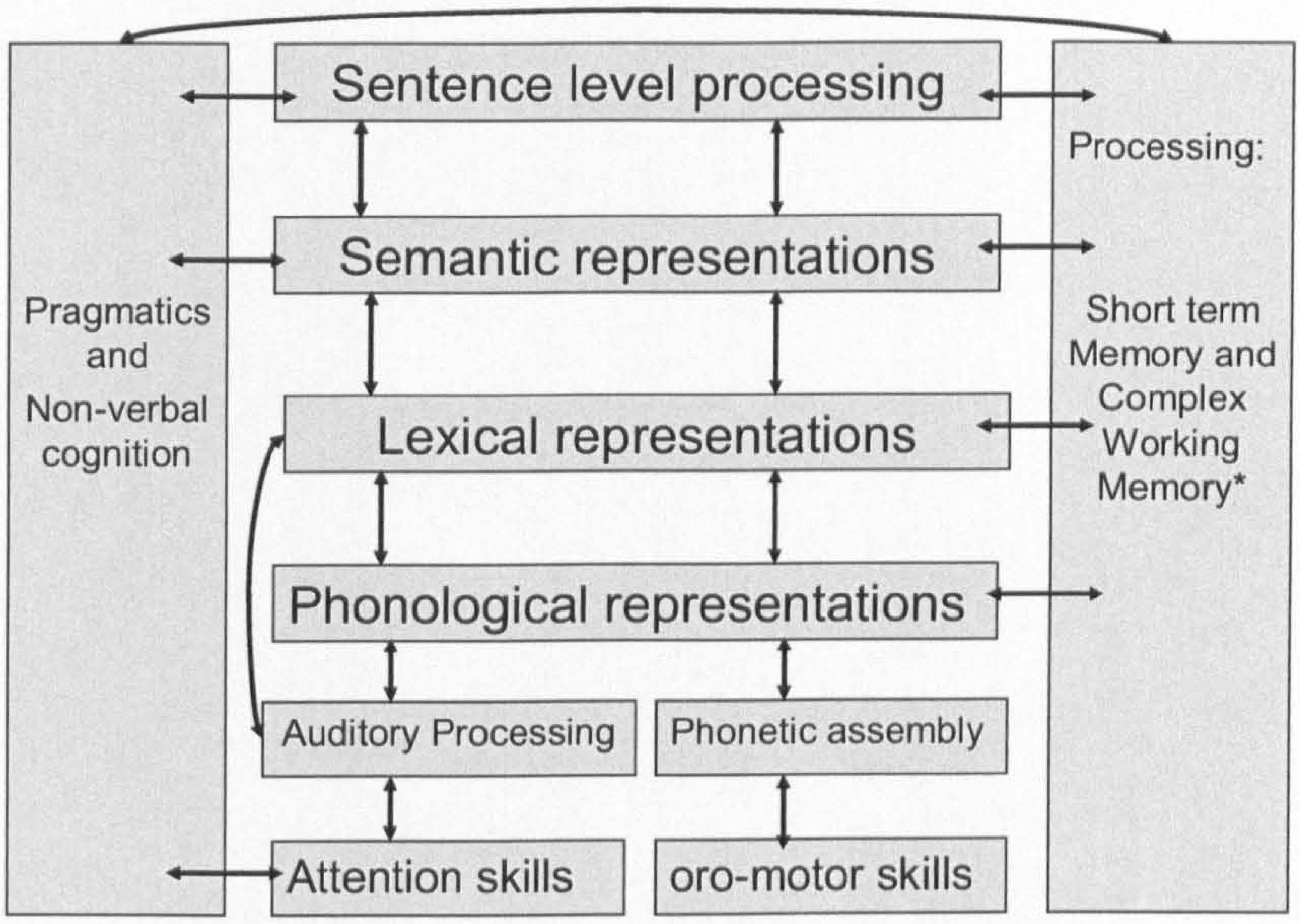
The resulting domains of assessment can therefore be summarised as:

- **Sentence level:** expression and comprehension of syntax, semantics and morphology
- **Lexical-semantic**: receptive, expressive and conceptual
- **Lexical-phonological** :awareness, "sensitivity"/representation and output phonology
- **Auditory processing**
- **Attention skills**
- **Processing**: working memory and word learning
- **Pragmatic skills**
- **Non-verbal skills**

The hypothesised relationships between these domains are represented in Figure 2.2.

The actual measures used are listed in Table 2.5 and the detail and specifics of their methodology described in section 2.5 "Measures".

One extremely important caveat runs through the data collection and analysis process: that is that the model of language processing adopted may not be applicable at all of the developmental stages under scrutiny in this study and therefore that the tasks used may not be tapping equivalent mechanisms in different age groups or indeed in the same individual over time.



* Short term memory and complex working memory may be by-products of language processing or may be separate but related processing mechanisms which exert additional unique variance on performance. This model remains equivocal as to their status.

Figure 2.2. Schematic representation of the language and language relevant domains considered and their hypothesised interactions

2.3 The Study Design

As this study aimed to examine the ontogeny of specific language impairment in detail, a quasi-longitudinal case series design was employed, with detailed assessment of language processing, language knowledge and 'language relevant' processing. Thomas (2005) suggests that "an explanation of developmental deficits consists in identifying how (…) initial domain relevancies have been altered in the disorder and then how the subsequent process of emergent modularization has been perturbed" (Thomas, 2005, p.15). Providing a complete picture of both the causality and ontogeny of LI is beyond the remit of this study. The focus of this research is to consider ontogeny and to describe the emergent properties of a disordered language system. As stated above, a quasi-longitudinal methodology was chosen to meet this aim. That is, a series of longitudinal case studies of children aged 3, 4, 5 and 6 years at the outset of the study were completed. The participants were seen for 4 blocks of comprehensive assessment over a 15 month time period, each block consisting of between 5 and 7 sessions depending on the child's attention and availability (Figure 2.3 illustrates the timeline). In this way both empirical longitudinal trajectories for each child could be examined and in addition a quasi-longitudinal hypothetical trajectory inferred from the data across the age groups of the children, from 3 years to 8 years, on completion of the study.

Block 1	Break 5-7 months	**Block 2**	Break 4-5 months*	**Block 3**	Break 2-3 months	**Block 4**

*Control data from TD children was collected over this period

Figure 2.3. Data collection timeline children with LI

A group of TD children provided a cross-sectional data set for comparison with the children with LI. These children were seen for one block of assessment comprised of 5 sessions over a 3 month period. As indicated in Figure 2.3 this data was collected between the LI data collection blocks 2 and 3.

The planned data collection timeline had equal time periods between each block of assessment of approximately 3 months. However issues regarding recruitment, availability of the participants and the TD data collection resulted in the timeline described above. That is participant recruitment was more difficult than anticipated and so participant recruitment continued whilst Block 1 had begun for some participants, hence the total time taken to complete all of the Block 1 assessments was longer than planned. This, together with the constraints of the school terms resulted in a longer gap between Block 2 and 3 than originally planned. The identification of a school and participants for the TD children's data collection was also more time consuming than originally predicted hence increasing the gap between Block 2 and 3. As a result of extension of the two preceding breaks between blocks, and, once again, the constraints of the school terms, the gap between blocks 3 and 4 was shorter than planned.

The data collected was analysed as individual longitudinal data sets and in addition, considered using a quasi-longitudinal approach such that possible trajectories of development from 3-8 years could be hypothesised. This methodology was chosen as a realistic and practical strategy with which to take the first steps towards mapping the emergence of LI although it must be acknowledged that it has less validity than a truly longitudinal data set of individual children from 3-8 years.

In describing the trajectory of development in LI a starting point of 3 years of age was chosen. Beginning this mapping process in infancy would obviously be very desirable however this approach was rejected for a number of reasons. Firstly, it is not possible to identify children who will go on to have LI in infancy. This fact, together with the relatively low incidence of LI (Leonard, 1998) would mean that a prospective study hoping to capture a sample of infants who do develop LI would need very large numbers. A targeted approach of selecting children "at risk of LI" as they have siblings with a diagnosis of LI may go some way to reducing the numbers required but would add complexity and perhaps bias to the sampling process. That is, children cannot be categorically diagnosed as having LI until the age of five years. The number of families who will go on to have more children after the elder sibling reaches this age will be small and it is also likely that this approach would favour inclusion of those families most likely to present to services. Secondly a study of this design would need to run for a minimum of 4 years in order to reliably categorise the participants as developing typically or developing LI. Thirdly although there are tried and tested methods available for assessing infant processing such as head-turn procedures, preferential looking tasks and familiarisation techniques (Hollich, 2006) due to the often very small differences observed and the level of reliability of infant behaviour, identifying *individual* differences in processing is difficult.

The age of 3 years was chosen as the starting point for data collection as it is at this age that most children who develop LI, first come to the attention of Speech and Language Therapy services in the United Kingdom. This allowed a purposive sampling method to be applied, an approach which is often necessary in research which involves "special populations" (Holden, 1990). In addition, many children at this age can begin to cooperate with more adult directed assessment procedures and so trajectories of performance on the same measures can be plotted for children from 3 - 7 years for many of the identified domains of assessment; a methodological feature which significantly increases the reliability and validity of the measurement process.

The study was designed in order that the data could be considered as follows: as individual longitudinal case-studies, as profiles of development for comparison between individuals and as quasi-longitudinal data.

The individual longitudinal case studies elucidate:

- individual trajectories of development
- interactions between skills at single time points and in terms of 'early-later' relationships
- the influence of timing and the sequence of emergence of skills

The comparisons between individuals elucidate:

- inter-individual differences in strengths, weaknesses and patterns of trajectory

The quasi-longitudinal analysis allows for the development of empirically based hypotheses regarding:

- probable trajectories of development in LI from 3-8 years
- possible identification of skills to be targeted by early interventions

2.4 Participants

Prior to recruitment, ethical and research governance approval for the study design and recruitment procedures was obtained from the relevant NHS Research Ethics Committee and Trust Research Governance organisations.

2.4.1 Children with LI

Thirteen children in 4 age groups (3, 4, 5 and 6 years) who met the classic criteria for a diagnosis of SLI (Language test score falls ≤ 1.25 SD below the mean/≤ 10^{th} centile; A non-verbal test score ≥ 1 SD below the mean/≥ the 16^{th} centile; excluding any child with a hearing impairment, visual impairment, physical disability, autism diagnosis, motor-speech difficulty, or English spoken as an additional language) were recruited from Speech and Language Therapist's caseloads (SLTs) in the North East of England. The detailed inclusion and exclusion criteria provided to the SLTs supporting the recruitment process can be found in Appendix 1. The summary assessment data for the children with LI is presented in Table 2.1. The children aged 3 and 4 years at the outset of the study were considered to be "at risk" of LI and those aged 5 and over as having a confirmed diagnosis of LI.

Sixteen children were recruited to the study. Two were excluded after baseline assessment. For one child this was because the author suspected a possible diagnosis of ASD and, on discussion with other professionals involved it became apparent that this was beginning to be recognised by a number of members of the multi-disciplinary team. Another child had made significant progress in her language skills between referral by the SLT and the baseline assessment and so did not fit the criteria for a diagnosis of LI at this assessment. A third child was lost to the study after three assessment visits due to a change in family circumstances. Of the remaining 13 participants, all remained involved for the full study protocol.

Two of the participants with LI did however have issues around their diagnostic status. MH (aged 4 years) failed a hearing screen during Block 1 of the assessment protocol. He was referred to Audiological and ENT services as a result of this and was diagnosed as having Middle Ear Effusion (MEE). Grommets were inserted between Block 1 and 2. It was decided to retain MH in the study for a number of reasons. Firstly, results of studies regarding the relationship between MEE and speech and language difficulties present a mixed picture with no overall consensus as to whether or not MEE has an effect on language development (Ruben, 2003). Certainly all children who have MEE do not have language difficulties and all children with language difficulties do not have MEE. In addition a recent study demonstrated that children who had MEE in the first 3 years of life had no increased risk for language difficulties at 7 years of age (Johnson *et al.*, 2007), and Schwartz states that "subgroups of children…with hearing impairments may have SLI" (Schwartz, 2009b, p.3). No definitive answers exist regarding whether a child who presents with MEE and who also fits the classic LI profile should be diagnosed as having primary LI and whether such children should be included in research studies of the disorder. As 10% of children will have at least one bout of MEE the effects of which will extend to 4-6 weeks, co-morbidity between LI and MEE is highly likely (Ruben, 2003). It was decided therefore to retain MH in the study but to monitor his hearing status. MH passed the hearing screen at blocks 2 and 3 but failed it at block 4. He was re-referred to ENT services.

The second child with issues around his diagnostic status was ST (aged 3 years). ST had a diagnosis of Klinefelter's Syndrome which was made during pre-natal screening. This screen was offered to his mother because her age increased the risk of conditions such as Down's syndrome. In the United Kingdom, Klinefelter's Syndrome is not routinely screened for, and many cases remain undiagnosed because of substantial variation in clinical presentation (Lanfranco *et al.*, 2004), with many cases only coming to light in adulthood when the individual presents with issues with fertility (Khalifer & Struthers, 2002). Indeed it is estimated that 65% of cases remain undiagnosed (Bruining *et al.*, 2009). There is a growing body of evidence of language and academic difficulties in individuals with Klinefelter's syndrome, although with a recognition of a wide variety of outcomes and severities (Ross *et al.*, 2008). It is highly probable therefore that a number of children who fit the classic SLI profile may have undiagnosed Klinefelter's syndrome. Indeed Bruining and colleagues found that 63% of a self-selected sample of children with Klinefelters syndrome fitted the diagnostic criteria for LI (Bruining et al., 2009). On the grounds then that many samples of children who fit the classic criteria for SLI will include children with undiagnosed Klinefelter's syndrome, ST was not excluded from the study.

The assessment battery used at Baseline and Block 4 to determine whether or not the children fitted the classic criteria for a diagnosis of SLI was as follows: Language was assessed using the RDLS III (Edwards *et al.*, 1997) and the CELF-4 (Semel *et al.*, 2003) for two children who were too old for the RDLS III by the end of the study; Non-verbal skills were assessed using the Block Building and Picture Similarities sub-tests of the British Ability Scales (BAS) (Elliot *et al.*, 1996); and hearing was screened according to ASHA guidelines (ASHA, 1997). All of the children in the study passed the screen at either the 20 or 30dB level (see section 2.5.1 Diagnostic Measures) with the exception of MH, as previously discussed, and AM who would not cooperate with the screening process. Her GP was contacted regarding previous audiological testing who forwarded a copy of a letter from the Community Medical Officer which stated that her hearing was "normal at 20dB for all frequencies".

The decision was made not to exclude children with co-morbid phonological delay/disorder but to attempt to allow for such difficulties in scoring tasks. Children with oro-motor difficulties were excluded (c.f. Table 2.2). Co-morbidity of LI and speech sound difficulties (SSD) is high with estimates of relative risk ranging from 2.2 to 9.1 (Pennington & Bishop, 2009). The rationale for including children with SSD was threefold. Firstly, the practice of excluding children with SSD and LI from research studies about LI challenges the ecological valid and applicability of these studies to the population of children with LI seen by SLTs. Secondly, their exclusion from research may bias the samples of children with LI included in studies such that more children with a profile of impairment disproportionately affecting syntax are included than may actually exist in the clinical population of children with LI. Thirdly, a developmental emergent perspective to LI questions whether, an SSD is a separable, co-morbid disorder but suggests that rather, it may be part of a profile of strengths and weaknesses which has emerged in this individual child as a product of an atypical trajectory of development, through interactions between innate impairments in the child, the child's environment and the process of developmental change. Their co-existence may in fact provide important clues as to the aetiology of both SSD and LI. Furthermore, from a developmental emergent perspective it is not possible to 'detach' phonological development from broader language development in a meaningful way. A summary of DEAP scores is presented in Table 2.2 When including young "children at risk of LI", who fit the classic criteria for LI it is interesting to note that only 2 of the 13 children do not have co-morbid SSD.

In order to attempt to exclude children with oro-motor difficulties, those children whose Percentage Phonemes Correct scores on the DEAP Phonological Assessment fell below the 16th centile were assessed using the DEAP Oro-motor Assessment. All of the children scored above the 16th centile on at least 2 out of 3 oro-motor probes.

It was anticipated that in the 3 year and 4 year age groups a number of children's language difficulties would resolve over the course of the study. This was indeed the case for 4 children and details are presented in Table 2.1. However the children who did not fit the criteria for LI at the end of this study all continued to have residual speech sound difficulties as measured by the DEAP Phonological Assessment (Dodd *et al.*, 2002).

All of the children were included in group analyses whether their difficulties resolved (Resolving LI – R-LI) or persisted (Persisting LI – P-LI). The rationale for the inclusion of children with R-LI in subsequent analyses is based on two issues, the phenomenon of "illusory recovery" and the concept of LI as part of a "language endowment spectrum".

With respect to illusory recovery, it has been demonstrated that many children whose pre-school language impairments appear to resolve such that their language skills no longer fall below 1.25 SD below the mean, continue to fall below the mean for language skills when compared with their chronological aged peers (Rescorla, 2005; Stothard et al., 1998), many go on to have literacy difficulties (Pennington & Bishop, 2009) and for some children, when the language demands of the curriculum increase their 'dormant' language impairments once again become apparent (Nippold, 2004).

With respect to the "language endowment spectrum" this approach questions whether LI exists as a separate and distinct phenotype or whether it represents the extreme of a spectrum of language abilities (Ellis Weismer, 2007; Rescorla, 2009). This approach calls into question the use of arbitrary cut-offs for attributing impaired and unimpaired status.

The children with R-LI were therefore not excluded from the group analyses for three reasons: they may in fact be demonstrating only an illusory recovery; the use of arbitrary cut-offs on language tests for diagnoses is in question; and for at least some of their developmental trajectory their difficulties fell within the range of performance classically defined as LI.

			Data Point 1			Data Point 4		
Age group		Child	Age (months)	RDLS III centile scores*	BAS centile scores**	Age (months)	RDLS III centile scores*	BAS centile scores**
3 years	R-LI	TB	43	2/1	34/10	58	88/23	90/84
		KM	40	38/1	79/42	55	98/88	95/54
		RM	42	3/1	16/46	56	85/68	31/54
	P-LI	OB	42	6/1	16/69	57	1/4	14/27
		KF	45	2/1	34/66	57	1/1	27/31
		ST	40	9/4	58/84	56	50/6	58/27
4 years	R-LI	MH	52	4/2	86/96	67	70/12	93/76
	P-LI	AM	55	1/1	5/42	69	17/1	1/24
		OM	50	9/1	18/34	64	36/1	34/42
5 years	P-LI	MB	65	1/1	42/18	79	1/1	4/27
6 years	P-LI	TG	81	1/1	21/38	96	0.1***	66/27
		AF	78	4/1	92/31	94	3***	42/27
		PB	74	2/4	42/24	88	46/1	50/34

*Comprehension/Expression **Block Building/Picture Similarities *** CELF 4

Table 2.1. Children with LI: summary characteristics

			Data Point 1		Data Point 4	
Age group		Child	Age (months)	DEAP Phonological Assessment centile scores	DEAP Oro-motor* Assessment centile scores	Age (months)	DEAP Phonological Assessment centile scores
3 years	R-LI	TB	43	1	50/63/50	58	5
		KM	40	1	63/63/84	55	1
		RM	42	1	50/63/84	56	5
	P-LI	OB	42	1	NC/25/37	57	63
		KF	45	1	50/75/91	57	1
		ST	40	1	63/84/91	56	1
4 years	R-LI	MH	52	1	75/50/75	67	1
	P-LI	AM	55	37	-	69	50
		OM	50	1	50/50/50	64	1
5 years	P-LI	MB	65	5	NC/50/75	79	16
6 years	P-LI	TG	81	1	25/9/25	96	(73%)
		AF	78	84	-	94	(100%)
		PB	74	1	25/50/50	88	(91%)

*DDK/Isolated Movement/Sequenced Movement; NC = not completed due to refusal; ( ) = percentage phonemes correct where centile ranks not available as children's ages fall outside the DEAP reference sample

Table 2.2. Children with LI: DEAP scores

2.4.2 Typically developing children

A local primary school gave permission for the recruitment and assessment of TD children to be completed in the school. Parents of those children in the nursery and reception class who were not attending speech and language therapy and who had not been identified by the school SENCO[1] as having additional needs were contacted to request their consent for participation in the study. This resulted in the recruitment of 38 children in the age range 3;01-5;02. The children's language (RDLS III: Edwards et al., 1997), non-verbal skills (BAS Block Building and Picture Similarities subtests: Elliot et al., 1996) and hearing status (ASHA screening protocol, ASHA, 1997) were assessed. See Table 2.3 for summary data of these assessments. Three children fell outside of the criteria for "typical development" (Language and non-verbal scores ≥ 1 SD below the mean/≥ the 16th centile, and passing the ASHA hearing screen). These children were, DB, scoring at the 4th centile for expressiv language, SM, scoring at the 7th centile for non-verbal ability and EW who failed the hearing screen on 2 separate occasions. However, it was decided not to exclude these children in order to use the data from the TD group of children as a representative normative sample against which to compare the results of the children with LI, and in recognition of the reliability of the tests. That is, using the standard error of measurement (SEM) for the standardised tests (RDLS III and BPVS) it is possible to determine the range of scores within which the child's true score is likely to fall to a 68 % confidence level (1 SEM either side of the test score) and to a 95% confidence level (1.96 x SEM either side of the test score). Both SM and DB's scores fell within the range of "typical development" when the 95% confidence level was considered (see Table 2.4).

[1] SENCO is a Special Educational Needs Co-ordinator. This person is a member of school staff who has responsibility for coordinating SEN (Special Educational Needs) provision and for the day to day operation of the school's SEN Policy (DfES, 2001)

With respect to the ASHA hearing screen, the sensitivity and specificity of this screening protocol for identifying children with hearing loss is not known, but full audiological testing is recommended after two consecutive failures. EM was referred for audiological assessment but the outcome of this assessment is not known. As 10% of children will have at least one bout of MEE, the effects of which will extend to 4-6 weeks, it was decided that excluding EW may bias the TD data set, making it less representative of the typical degree of variation found in the average school classroom. EW was therefore not excluded. One child (ZF) refused to complete the non-word repetition task and so was excluded from the analysis for that task.

Child	Age (months)	RDLS III centile scores*	BAS centile scores**	Child	Age (months)	RDLS III centile scores*	BAS centile scores**
JFF	37	32/45	34	LH	52	85/17	88
SS	37	18/30	3/34	ZF§	52	73/20	27
JFM	38	68/22	18	PR	54	62/44	38
ES	41	80/44	58	CT	55	66/62	27
JH	44	29/56	69	EW	55	77/47	69
JL	45	58/35	34	JT	56	75/26	69
KW	45	50/38	54	KMC	56	77/40	69
PW	45	54/36	38	AR	57	91/38	90
DB	46	24/4	4/34	SI	57	80/80	8/54
RH	46	66/82	21	PH	58	90/52	38
SN	46	44/50	54	DC	59	68/63	38
AH	47	60/78	96	RW	59	56/28	42
AG	48	62/54	76	SP	59	88/24	18
SM	48	46/37	7/4	AB	60	80/75	42
TH	48	78/89	46	TW	61	50/34	42
DS	51	56/41	34	JM	62	76/78	96
KH	51	95/76	38	JP	62	93/73	16
SB	51	55/38	50	MC	62	50/23	27
KD	52	94/52	86	SR	62	99/29	27

*Comprehension/Expression **Block Building/Picture Similarities; the latter only completed where the child fell below the 16th centile on the Block Building subtest § ZF refused to complete the non-word repetition task and so was excluded from that analysis

Table 2.3. TD children: summary characteristics

	Scores which fell below the 16^{th} centile		Range of centile scores	
	BAS centile scores	RDLS III centile scores	to 68% confidence	to 95% confidence
SM	7*	-	4 – 10	2 – 16
	4**		1 – 7	1 – 12
DB	-	4§	2 – 11	1 – 20

*Block Building subtest §**Picture Similarities subtest § Expressive sub-test

Table 2.4. Range of centile scores within which 'true' test scores fall to 68% and 95% confidence levels for SM and DB (TD group)

2.5 Measures

The measures used form three categories: those used to establish whether the children fitted the inclusion and exclusion criteria (i.e. diagnostic measures); experimental measures designed for the study, which were completed but which are not reported in this thesis; and experimental measures included in the thesis. The following first present the rationale and aims for the diagnostic assessment measures used then briefly describes the experimental measures and their aims. Details of the specifics of the task design and implementation for the measures reported in this thesis (the non-word repetition task and the word learning task) are presented in Chapters 3 and 4.

2.5.1 The diagnostic measures

In order to determine whether or not the children met the criteria for inclusion in the study recognised standardised assessments of language knowledge and of non-verbal skills were used together with an audiological screening procedure. In addition, those children who had an additional phonological delay/disorder completed an oro-motor assessment in order to exclude children who may have childhood motor speech disorder (Ozanne, 2005) the DEAP Oro-motor Assessment was used, and the children included if they scored above the 16th centile on at least 2 of the 3 oro-motor probes (Dodd et al., 2002).

The RDLS III (Edwards et al., 1997) was chosen as an omnibus language measure as it covered the planned age-range of the children in the study, is standardised on a British English population and provides both expressive and receptive measures. Delays in the study's implementation resulted in two children falling outside the requisite age range for the RDLS III by the end of the study (AF, TG) and so the CELF 4 (Semel et al., 2003) was also completed for these children at the final assessment in order to determine their diagnostic status with reference to appropriate norms. Those children whose scores fell at or below the 10th centile (≤ 1.25 SD below the mean) on one or more of the subtests (receptive and/or expressive) were included in the study. This level of cut-off is in line with current research practices (Schwartz, 2009b).

The Block Building and Picture Similarities subtests were chosen from the non-verbal sub-tests of the Early Years Core Scales of the British Ability Scales (Elliot et al., 1996) and used to establish non-verbal cognitive abilities. Using both sub-tests gave the children optimal chance to demonstrate intact non-verbal abilities as using either subtest in isolation may have biased the results. That is, some children with LI have been shown to have associated visuo-spatial difficulties and so may fail the Block Building subtest despite intact non-verbal cognition in other areas (Botting et al., 2005). Also the Picture Similarities subtest has many items which involve the child identifying semantic associations between objects and so scores on this sub-test could be affected by the child's language abilities. Again this test covered the planned age-range of the children in the study, and is standardised on a British English population. The children were required to score at a level > 16th centile (≥ 1 SD below the mean) on one or more of the subtests. Two subtests were chosen from the five non-verbal tasks in the Early Years Core Scales in order to minimise the testing time for the children. The Pattern Construction Test was not used as it tests similar abilities to the Block Building subtest and yet is a much longer task, the Number Concepts subtest was not used as it has a very high verbal comprehension component and the Copying subtest was not used in order to rule out the confound of co-morbid fine-motor difficulties on the children's performance. The Hearing Screen was conducted according to ASHA Audiologic screening guidelines for children aged 3 – 5 years (ASHA, 1997) and using a Madsen Electronics Micromate™ 304 Screening Audiometer. A Conditioned Play Audiometry (CPA) approach was used. The children watched a Teddy Bear have her hearing tested and place rings on a stacking toy when she 'heard' a sound. The children were then trained to do the same and hearing screening began once the child demonstrated a consistent response to two consecutive trials at 55dB (i.e. a presumed suprathreshold level). Screening then began for 1000, 2000 and 4000 Hz tones at 20dB. If the child responded at least 2 out of 3 times for each tone in each ear then the child passed the hearing screen. As the children were being visited in schools and at home the testing context was not always ideal and some background noise was an unavoidable consequence of the testing contexts. Therefore, where background noise was an issue and where children failed at the 20dB level, they were retested at the 30dB level. Again, if the child responded at least 2 out of 3 times for each tone in each ear then the child passed the hearing screen.

2.5.2 The Profiling measures

The domains of assessment for the study as a whole were:

- **Sentence level:** expression and comprehension of syntax, semantics and morphology
- **Lexical-phonological** :awareness, "sensitivity"/representation and output phonology
- **Lexical-semantic:** receptive, expressive and conceptual

- **Auditory processing**
- **Attention skills**
- **Processing**: working memory and word learning
- **Pragmatic skills**
- **Non-verbal skills**

Table 2.5 details the assessments used for each domain.

	3-4 year-olds (measures stopped when child reaches ceiling)	**4-6 year-olds** (in addition to those for 3-4 years)
Sentence level processing: Expression	• Spontaneous language sample • Sentence repetition task (McKean, 2006a) • Thematic role and predicate argument structure elicitation task (McKean, 2006h) • RDLS III (Reynell Developmental Language Scales) (Edwards et al., 1997)	
Sentence level processing: Comprehension	• RDLS III (Edwards et al., 1997) • Thematic role and predicate argument structure comprehension task (McKean, 2006h)	• TROG-2 - Test of the Reception of Grammar (Bishop, 2003b)
Lexical-semantic	• ROWPVT - Receptive One Word Picture Vocabulary Test (Brownell, 2000b) • Non verbal semantic knowledge for nouns and verbs (McKean, 2006g) • EOWPVT - Expressive One Word Picture Vocabulary Test (Brownell, 2000a)** • CDI – Communicative Development Inventories (Fenson *et al.*, 1997)	• PIPA - Preschool and Primary Inventory of Phonological Awareness (Dodd *et al.*, 2000) • PhAB- Phonological Assessment Battery: when children reach 6 years (Frederickson *et al.*, 1997)

	3-4 year-olds (measures stopped when child reaches ceiling)	4-6 year-olds (in addition to those for 3-4 years)
Lexical-phonological	• Non-word repetition task varying phonotactic probability and length (McKean, 2006i)** • Matched naming and repetition task varying neighbourhood density and controlling age of acquisition and frequency (McKean, 2006e) • Word learning task varying neighbourhood density and phonotactic probability orthogonally (McKean, 2006b)** • Picture name verification task orthogonally varying ND and PP (McKean, 2006c). • DEAP Diagnostic Evaluation of Articulation and Phonology (Dodd et al., 2002)*** • EOWPVT (Brownell, 2000a)**	
Attention	• Reynell attention levels in child directed and adult directed activity (Edwards et al., 1997)	

	3-4 year-olds **(measures stopped when child reaches ceiling)**	**4-6 year-olds** **(in addition to those for 3-4 years)**
Processing	• Verbal Short Term and Complex Working Memory task (McKean, 2006f) • Non-word repetition task varying phonotactic probability and length (McKean, 2006i)** • Word learning task varying neighbourhood density and phonotactic probability orthogonally (McKean, 2006b)** • Auditory discrimination task using same different judgements varying neighbourhood density and syllable structure (McKean, 2006d)	
Pragmatic skills	• Pragmatics Profile (Dewart & Summers, 1995)	• CCC-2 Children's Communicative Checklist (Bishop, 2003a)
Non-verbal ability	• BAS - Non-verbal subtests of the British Ability Scales (Elliot et al., 1996)	
Oro-motor Skills*	• DEAP Oro-motor Assessment (Dodd et al., 2002)	
Hearing Screen*	• Screened according to ASHA Guidelines (ASHA, 1997)	

*measures used for diagnosis only **measures relevant to more than one domain***Additional items were added to the DEAP

Table 2.5. List of all experimental and standardised measures used for each assessment domain

In addition to the diagnostic measures previously discussed, the measures pertinent to the research presented in this thesis are: the EOWPVT, the DEAP, the non-word repetition task and the word learning task.

The Expressive One Word Picture Vocabulary Test (EOWPVT) (Brownell, 2000a) was used as a measure of expressive vocabulary knowledge. This test is standardised on American English children therefore all comparisons made between children and between assessment points were made with respect to raw scores only. The choice of this test reflects the absence of a well standardised British English test of expressive vocabulary knowledge for the age range of the children included in this study.

The Phonological Assessment from the Diagnostic Evaluation of Articulation and Phonology (DEAP) test battery (Dodd et al., 2002) was used both to provide a standardised score of phonological production abilities and to consider the child's phonological difficulties when scoring the experimental tasks. The DEAP Phonology Assessment was analysed and any substitutions or omissions used by the child were noted and the experimental tasks scored in the light of the analysis. Therefore, any errors in the tasks which coincided with speech sound substitutions present in the DEAP Phonology Assessment were scored as correct. An additional 11 items were added to the DEAP assessment, specifically for use when scoring a sentence repetition task (which forms part of the wider test battery not reported here), these were included in the list of words used to inform scoring of the experimental tasks (see Appendix 3).

The detailed methods of the experimental tasks are presented in the relevant empirical chapters. That is the non-word repetition task is described in Chapter 3 and the word learning task in Chapter 4.

2.6 Data collection methods

2.6.1 Frequency and Duration of sessions

The number of visits at each block ranged from 3 to 7 visits and the duration of each visit ranged between 45 and 60 minutes. The number of visits was determined both by the number of assessments planned for each block and also the developmental level of the child. Hence gathering data from the youngest children tended to involve more visits than for the older children. An itinerary of which assessments were completed at each block is presented in Appendix 2.

The standardised tests used for diagnostic purposes were completed at blocks 1 and 4 thus adhered to the psychometric principle of ensuring a gap of greater than 6 months between testing. The DEAP (Dodd et al., 2002) and the EOWPVT (Brownell, 2000a) were completed more frequently. The DEAP was used as a standardised measure at blocks 1 and 4 only. At blocks 2 and 3 the DEAP data were used only to inform scoring of the experimental tasks. Hence its use did not violate psychometric principles.

As the aim of this study was to describe the nature of developmental change in LI, and as the nature of the developing lexicon is assumed to be central to the ontogeny of LI, the ability to calculate the *rate of change* of vocabulary knowledge was essential. The EOWPVT was therefore completed three times, at blocks 1, 3 and 4 in order to gain the minimum number of Data Points to calculate the *rate of change* in scores over the trajectory of development sampled. It was therefore unavoidable within the present study design that the gap between testing was less than 6 months for this test.

2.6.2 Location

The children were seen individually in their homes and/or their schools. When visited at home all background distractions (such as radios and televisions) were switched off and parents asked to ensure that siblings did not participate in the tasks or distract the child. When visited in schools children were taken to a withdrawal area used for small group work. These locations minimised the distractions and provided a familiar context for the child. There was obviously a degree of variety in the extent to which these locations were free of distractions but these were managed as much as possible by the author to create an appropriate context for assessment.

2.6.3 Order of testing

The aim at the outset of the study was to use a fixed order of presentation for the tasks. However as the children's ability to concentrate, their motivation and temperament varied greatly, it became apparent that the order would need to be tailored to the child's individual needs in order to gain a valid representation of their abilities. A target order of presentation was therefore devised for each block and wherever possible, adhered to. Alterations were made for individual children as and when necessary.

2.7 Data analysis

In order to answer the research questions the data was analysed in two ways, as *cross-sectional developmental* trajectories (Thomas et al., 2009) and as *individual longitudinal* trajectories.

2.7.1. Cross-sectional developmental trajectories

The aims of this study include describing the developmental process in LI, determining whether a developmental perspective and methodology adds to our understanding of LI and considering the nature of interactions between skills across development. In order to meet those aims it was essential that an appropriate statistical methodology was chosen; one which could focus on change over time, could enable comparisons between groups with respect to change over time, which could elucidate developmental relations between skills and which could compare those developmental relations between groups.

The approach chosen was Thomas's 'Trajectory Analysis' (Thomas et al., 2009). This method applies linear regression and ANCOVA analyses to create developmental trajectories for groups of children from cross-sectional data and to make comparisons between those trajectories. In order to consider the data from the children with LI as cross-sectional trajectories it was necessary to remove the issue of autocorrelation of the four measures taken from the same individual. To this end, four separate cross-sectional data-sets were created from the LI data from each of Data Points 1-4.

The Trajectory Analysis approach has a number of stages. Firstly a task-specific developmental trajectory is constructed for the control group using linear regression linking performance with age. Then a trajectory is constructed for the disorder group, in this case the children with LI, again with respect to age. These regressions are used to consider whether there is meaningful age-related change in each of the groups as indicated by whether the gradient confidence intervals obtained from the regression are above zero; and to determine the presence or absence of delay by considering whether or not the confidence intervals for the intercept values overlap in the two groups, an overlap indicating no significant differences at onset and the absence of overlap, indicating the presence of delay. This second comparison, with respect to determining the presence or absence of a delay, requires that the data is first centred on the youngest age of the LI group. In this way the intercept for the two groups occurs at the same age for each group and fair comparisons regarding performance at that age can be made.

Secondly group comparisons are made using ANCOVA analysis to compare rate of change between groups with respect to age. That is if the age x group interaction is significant then differences in the *rate of change* in scores between the groups exists.

The third stage, if required, is to compare developmental relations between tasks, for example between high and low frequency words on a memory span task. This analysis allows for the consideration of relationships between the rates of change of trajectories within groups to be considered using ANCOVA analysis of within subject differences. In this case a significant frequency x age interaction would indicate differences in the rate of change of development in the two tasks conditions for a given group of children hence, perhaps suggesting that the children improved more rapidly in the high frequency condition. In addition differences in the nature of these developmental relations between tasks can then be compared between groups using Mixed ANCOVA analyses. In this way a significant group x age x frequency interaction would indicate a difference between groups in the developmental relationship between the high and low frequency condition. This might indicate that for one group of children the rate of change for the two conditions in a task were equivalent across the age range whereas for the other group scores in one condition developed faster than the other condition.

The final step is to compare the groups not with respect to age, where by definition differences are usually to be expected for a 'disorder group', but with respect to some other theoretically motivated 'matching criteria'. For example for children with William's syndrome it may be more informative to consider whether their performance differs from TD children with equivalent mental age rather than chronological age. In this way whether trajectories of development and developmental relations exhibit a simple profile of delay and equivalence to a younger TD profile or whether atypical trajectories and developmental relations exist can be explored. In the children with LI in this study 'matching' according to a language measure would therefore be most informative. In this way it is possible to explore whether an atypical trajectory or atypical developmental relationship exits or whether the group differences simply represent a delayed trajectory or delayed developmental relationship which can be explained by the child's level of language knowledge. In order to complete the trajectory analysis therefore the first three stages of Trajectory Analysis described above are repeated but change is measured with respect to the theoretically motivated matching variable rather than with respect to age. In this study, as the developing lexicon is the major focus the 'matching variable' used was the children's raw scores on the EOWPVT. This measure was chosen in order to consider whether group differences in performance could be explained due by the child's level of language and, more specifically, vocabulary knowledge. The EOWPVT was used rather than the ROWPVT as expressive vocabulary has been shown to be a stronger predictor of developmental changes in linguistic abilities than receptive vocabulary (Marchman & Bates, 1994), and raw scores were used as they provide a more sensitive method for comparison between TD and LI groups than standard scores.

In this way the second wave of analyses reveal the following about a given experimental task: whether the LI group are delayed in their development with respect to their vocabulary knowledge; whether they evince meaningful improvement in scores as their vocabulary knowledge increases; whether the *rate of change* between groups differs with respect to vocabulary knowledge; and whether *developmental relations between two skills or task conditions* differs between groups when considered with respect to vocabulary knowledge.

Thomas and colleagues (2009) argue that it is essential to make comparisons both with respect to age and comparisons with respect to the theoretically motivated 'matching criteria' for four reasons. Firstly, many developmental disorders predict differences from the typical trajectory in some but not all domains. Testing whether a difference exists with respect to age is therefore an important first step. Secondly, considering the developmental trajectory with respect to age is a theory neutral first step which can be used a baseline measure against which to compare the theory dependent trajectories and so to consider the validity of the choice of the matching criteria. Thirdly, this approach ensures that the important and clinically relevant fact that a particular group of children perform more poorly than their age matched peers on a specific task is not forgotten in the process of comparing profiles of impairment. Finally, understanding the developmental relations between abilities with respect to age allows for interpretations of these relations with respect to the theoretically motivated matching criteria to be made with the appropriate level of caution. That is, it could appear that two abilities may be causally related in a group of children with a developmental disorder but not in TD children. However the reality may be that the two abilities are predicted by the severity of the developmental disorder rather than evincing any causal relationship. Considering the age related nature of developmental relations would help to identify this pattern.

Thomas and colleagues acknowledge that longitudinal designs are superior to cross-sectional designs for studying development but argue that analysis of cross-sectional trajectories may offer a compromise approach which is less resource intensive than prospective longitudinal designs. They suggest that cross-sectional trajectories can be validated through longitudinal follow up of the participants and the construction of a cross-sectional trajectory for the same participants at a later time point. In this way predictions about the nature of longitudinal change can be tested using empirical data. This approach was used in the current study through the creation of four cross-sectional data sets from the LI data. In addition the validity of the cross-sectional trajectories was also considered through the creation of individual longitudinal trajectories.

The final caveat which Thomas and colleagues identify regarding their trajectories analysis approach is that the validity of the trajectories rests on the ability of the tasks measured to tap the target skill appropriately across the age range studied. This is a fundamental yet challenging premise, and relies both on the absence of floor and ceiling effects but also on the premise that the task is tapping the same processing systems across development. In fact, the developmental emergent perspective predicts that the nature of processing mechanisms will alter across development and it is this change which is being measured by the developmental trajectories approach. What needs to be ensured therefore is that the experimental task is conceptually and theoretically well founded regarding what it is measuring across the age range with the theoretical expectation that it is measuring the processing of proto-systems as they develop into fully mature systems.

2.7.2. Individual Longitudinal Trajectories

In order to consider the nature of individual trajectories the data was analysed using two methods, descriptive and statistical. The descriptive analysis involved considering the empirical growth plots for each individual both non-parametrically, by considering the graphical summary of each child's pattern of change, and parametrically, by creating Ordinary Least Squares (OLS) regression trajectories for each child (Singer & Willett, 2003). As part of the descriptive analysis the individual children's OLS regression trajectories were compared to the cross-sectional trajectory of the TD children. These comparisons were made between OLS regression trajectories with respect to age and to vocabulary knowledge. Hence comparing whether the children with LI were performing as would be predicted by their age and their level of vocabulary knowledge. The conclusions drawn from these comparisons were limited to whether or not the trajectory of the child with LI fell within the typically developing range of performance for the particular age and level of vocabulary knowledge. Conclusions with respect to shape of the developmental trajectory, rate of change and relationships between trajectories for different skills were not possible from this data as the

TD cross-sectional trajectory was not informative regarding the shape of the possible individual trajectories of the children in the sample. That is, the shape of a mean trajectory is not informative as to the possible shapes of any longitudinal trajectory which individuals within the TD group may have displayed, had longitudinal data been collected. However it was possible to comment on whether the scores of the individual children with LI fell below the 5^{th} centile of the trajectory of performance of the TD children at any point in the trajectory and to consider whether any differences found with respect to age remain when performance is considered with respect to vocabulary knowledge. Figure 2.4 presents hypothetical TD cross-sectional trajectories and individual LI trajectory with respect to age and vocabulary knowledge. The 95^{th} and 5^{th} centile trajectories for the TD group are included. Figure 2.4 therefore illustrates how it is possible to draw conclusions regarding whether the scores of the individual children with LI fell below the 5^{th} centile of the trajectory of performance of the TD children at any point in the trajectory and to consider whether differences exist when performance is considered with respect to age and vocabulary knowledge. For example for the hypothetical trajectories in Figure 2.4 the child with LI appears to be performing at around the 5^{th} centile of ability of the TD children with respect to age for the trajectory of development sampled, but that when compared with respect to vocabulary knowledge he performs within the low average range.

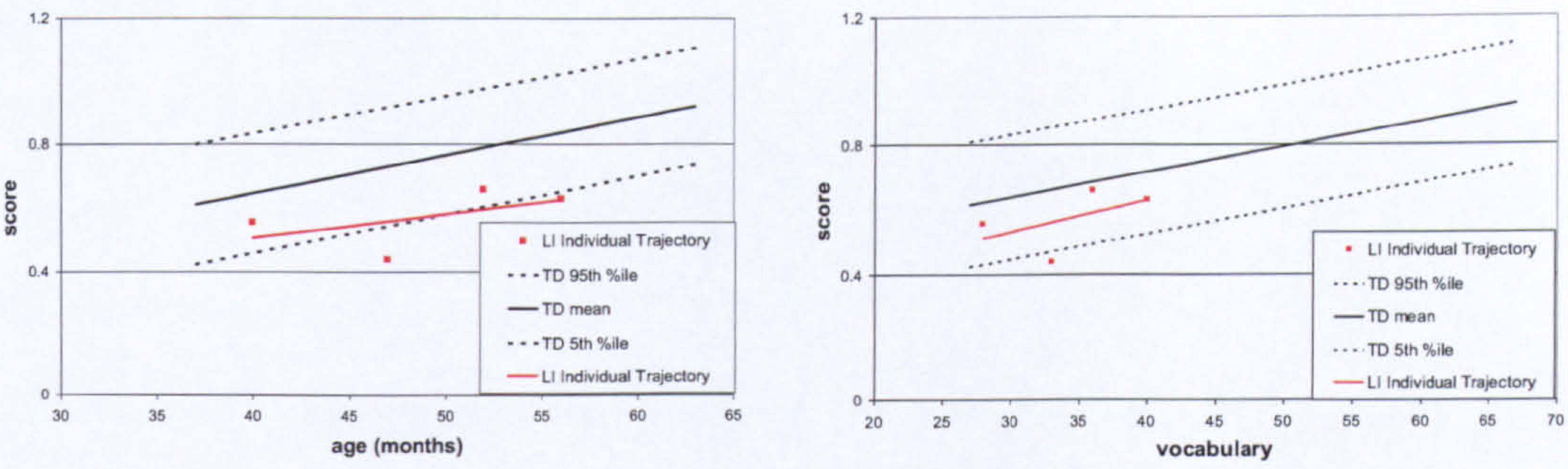


Figure 2.4. Descriptive comparisons of individual trajectories to cross-sectional comparison trajectories

As previously noted it was not possible from the descriptive comparisons to make meaningful comparisons with respect to the shape of the developmental trajectory, rate of change and relationships between trajectories for different skills. For conclusions to be drawn about the *shape* of the trajectory many more Data Points than were collected would be required. However a statistical methodology was devised in order to consider the latter two issues: rate of change and relationship between trajectories in different skills.

The individuals were compared to the TD children statistically using an approach which combines the use of summary measures of change (Matthews *et al.*, 1990) with Crawford's t-test (Crawford & Howell, 1998). These two approaches are designed, in turn, to cope with the issues of autocorrelation of repeated measures (Matthews et al., 1990) and the problems of increased Type I errors when comparing individuals to small normative samples (Crawford & Howell, 1998). This statistical approach does not completely answer the difficulties in comparing an individual's longitudinal data to a group's cross-sectional data. Making inferences about the average rate of change with age, for an individual based on the rate of change with age in the averages of a group of individuals, is obviously not comparing like with like. However such comparisons are intrinsically conservative. That is, the use of TD cross sectional rather than longitudinal data increases the uncertainty about the gradient of the slope. The true variability of the slope for each individual is likely to be less than that estimated by cross-sectional data where variability arises both from differences between the individuals and variability across the age range. Hence, if differences *do* exist between the individual trajectory and the cross-sectional TD trajectory then these differences are likely to be highly significant. The detail of the statistical approach is presented in Chapter 3 where it is applied to the individual trajectories of non-word repetition abilities of children with LI.

CHAPTER 3

Building a Lexicon in LI: The Nature of the Emerging Lexicon

This chapter presents empirical longitudinal data which describes the process of lexical development in LI and explores the influence of development, lexical knowledge and phonological processing on the growth and organisational structure of the developing lexicon in the context of impaired language development. To this end, this chapter describes and reviews current research regarding the nature of the developing lexicon in TD children and those with LI and provides a rationale for the use of a non-word repetition measure as an index of the nature of lexical and sub-lexical knowledge. The chapter then goes on to present empirical data from the non-word repetition task in the form of cross-sectional developmental trajectories and individual longitudinal trajectories in non-word repetition abilities. Comparisons are made to TD children's trajectories of development and the results discussed with reference to the insights gained from these analyses regarding the nature of the developing speech processing mechanism in LI.

3.1 Mapping Changes in Lexical and Sub-Lexical Representations in LI

A number of models of speech processing propose that phonemic representations emerge as products of schema abstraction from lexical representations (Walley, 2005; Werker & Curtin, 2005). This process of schema abstraction is purportedly driven by vocabulary growth and the resulting increased density of similarity neighbourhoods in the lexicon (Storkel, 2002). The majority of children with LI have delayed and slow lexical development as measured by tests of vocabulary knowledge (Bishop, 1997b; Leonard, 1998). In addition this group of children have difficulties in a wide range of lexical processing tasks which have been interpreted as indicative of poor access to lexical and phonological information arising from poorly specified lexical representations (Bishop, 1997b; Bishop, 2000; Chiat, 2001; Constable *et al.*, 1997; Conti-Ramsden, 2003a; Maillart *et al.*, 2004; Mainela-Arnold *et al.*, 2008; Seiger-Gardner & Brooks, 2008). Emergent models predict that a smaller lexicon implies less well abstracted and specified lexical and phonological representations and, as phonological knowledge facilitates word learning, impaired phonological knowledge can therefore be conceptualised as both a cause and a result of slowed lexical acquisition. Indeed, these gradually compounding difficulties could, in part, explain the widening gap found between vocabulary growth in adolescents with LI and their peers (Stothard et al., 1998). This vicious circle in lexical development in LI raises an important question, both for devising appropriate early intervention approaches and for furthering our understanding of the ontogeny of LI. That is, do children with LI have poorer access to phonemic units *purely* as a result of having smaller lexicons or does an additional impairment, perhaps in schema formation, exist?

This study seeks to explore whether new insights regarding this issue can be found through the application of a longitudinal case-series methodology which considers the relationship between vocabulary growth and changes in the nature of lexical and sub-lexical representations over time in typically developing children (TD) and those with or "at risk" of developing LI. A longitudinal case-series methodology provides new insights in two ways. Firstly it is unlikely that the relationship between vocabulary and other levels of processing is constant over the course of development and so a longitudinal methodology can help elucidate the changing nature of this relationship. Secondly, by comparing individual trajectories of development over time rather than using static group comparisons it is possible to explore relationships between *rates of change* in vocabulary growth and the emergence of sub-lexical representations and also any individual differences in these relationships. Hence, a longitudinal methodology could identify that *trajectories* of development may differ significantly between the two groups in terms of rate and even direction of change over time. This additional information could begin to tease out whether growth in the ability to manipulate sub-lexical units is related to growth in vocabulary knowledge in the same way for both groups and so shed some light on the question; do children with LI have poorer access to sub-lexical units *purely* as a result of having smaller lexicons or does an additional impairment, exist?

The question of how to measure the nature of lexical and sub-lexical representations is not a simple one. Any such measure must be based on our understanding of the nature of lexical representations, on how the developing lexicon changes over time and on data drawn from developmentally appropriate tasks. This study aims to explore whether a novel non-word repetition task which manipulates the phonotactic probability (PP) of the stimuli, comparing performance on non-words with high PP to those with low PP, can be used as a measure of lexical specification and emerging sub-lexical knowledge. Phonotactic probability is a measure of the likelihood or frequency of particular sequences of sounds in a language. For instance in English the sequence /teɪ/ has a high probability of occurrence whereas the sequence /hɔɪ/ has a very low probability. In order to explain the rationale for the choice of this measure it is necessary to consider current theoretical models regarding the nature of the adult lexicon, and the developing lexicon upon which it is based.

3.1.1 The adult lexicon

Many models of adult speech recognition and speech production posit three main levels of representation in the lexicon (Figure 3.1) (Dell *et al.*, 1997; Gupta & MacWhinney, 1997; Luce et al., 2000; Norris *et al.*, 2000; Schwartz et al., 2006). That is, to know a word a person must store a semantic representation, a lexical representation and a phonological representation. The semantic representation contains information regarding the meaning of the word, the lexical representation is a node which connects the semantic representations for a given word to the phonological level representations for that word, and the phonological representation is a series of links between the lexical level and the appropriate phonemes at the phonological level.

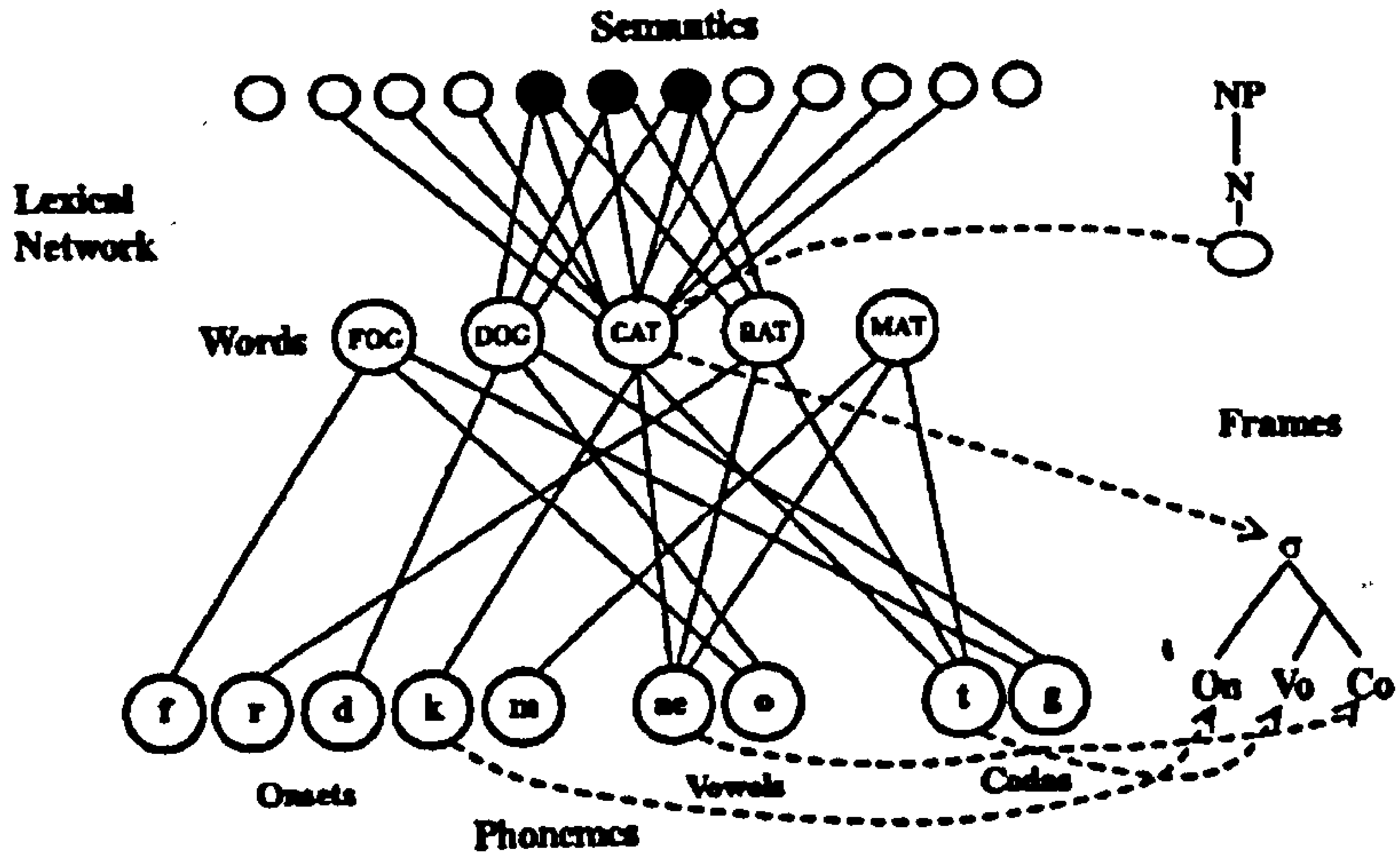
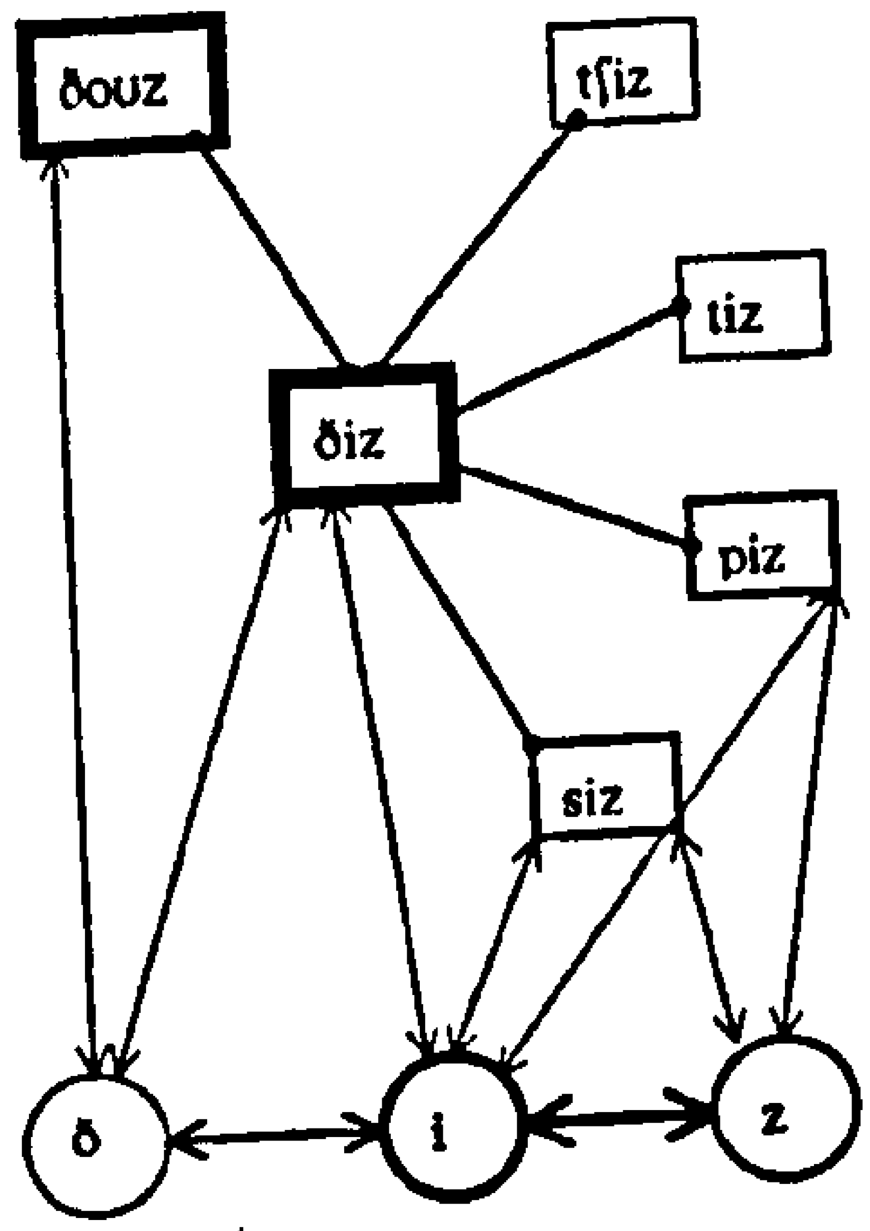


Figure 3.1. The Two-Step Interactive-Activation Model (Schwartz et al., 2006)

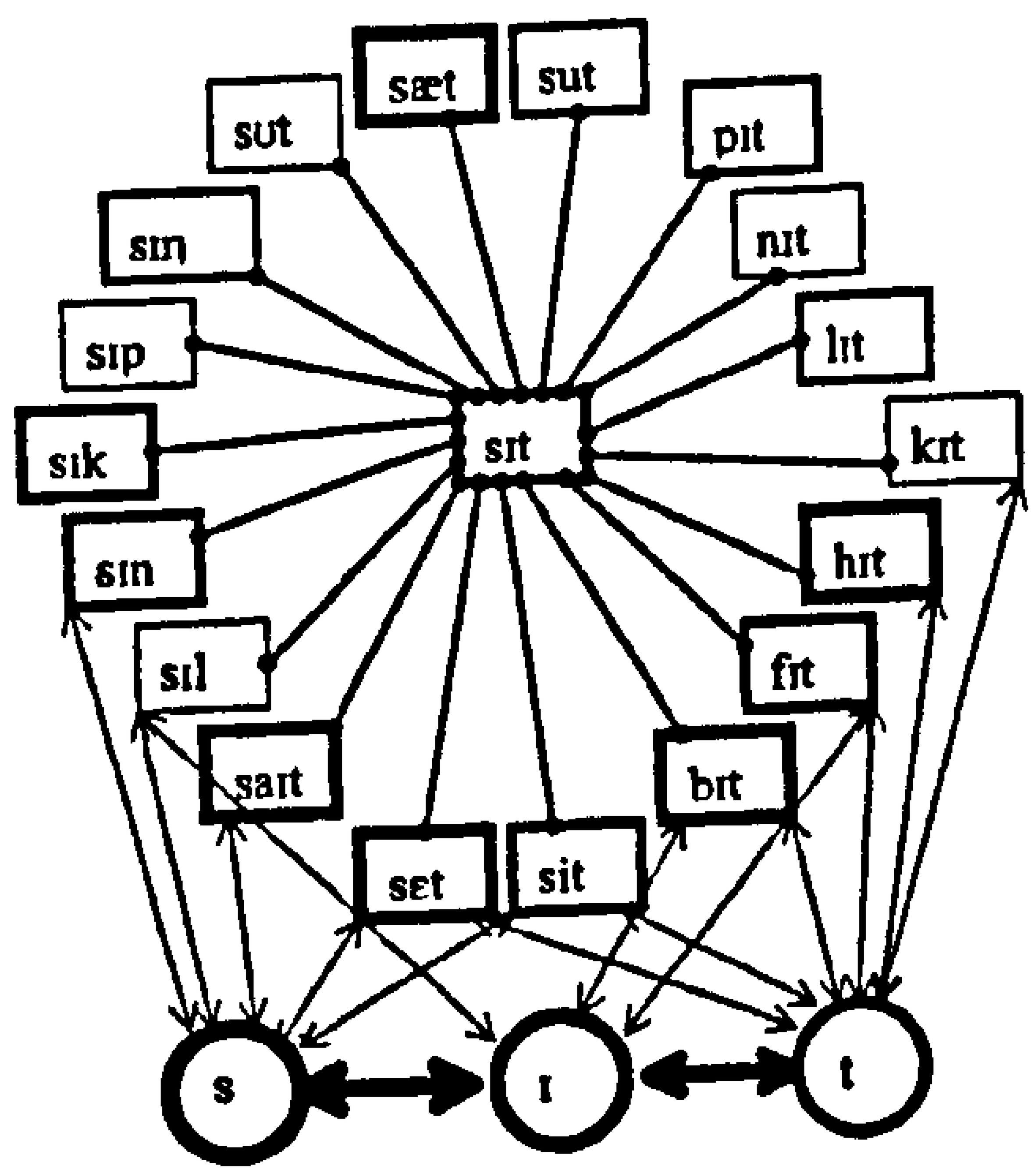
The majority of models of spoken word recognition and speech production suggest that lexical representations are organised into "similarity neighbourhoods" and generally it is thought that these neighbourhoods contain the words which differ from one another by one phoneme substitution, deletion or addition (Luce & Pisoni, 1998). In spoken word recognition members of the similarity neighbourhood compete with one another and so words which reside in "dense" neighbourhoods (those with many neighbours) are recognised more slowly and less accurately than those in more "sparse" neighbourhoods (Luce & Pisoni, 1998; Vitevitch & Luce, 1999). In spoken word production however the effect is less clear and controversy remains as to whether higher neighbourhood density facilitates or inhibits production accuracy and speed (Harley & Bowm, 1998; Storkel & Morrisette, 2002).

A second factor affecting processing at the lexical level is word frequency. The frequency with which a word is used and/or heard influences the ease with which its representation can be accessed. That is, in models such as those posited by Luce *et al* (2000) and Gupta and MacWhinney (1997), a word which is heard or spoken more frequently has a lower resting threshold for activation than those with lower frequency counts and so is activated more quickly and accurately than lower frequency words.

At the phonological level of processing, frequency effects have also been shown to be significant. In the case of phonological processing the metric of phonotactic probability has been used to determine the frequency of the phonological components of a given word. High phonotactic probability has been shown to speed processing in such tasks as same/different judgements and *non-word* repetition (Vitevitch & Luce, 1999; Vitevitch & Luce, 2005). However in other tasks, such as lexical decision task and *real* word repetition, higher PP is associated with slower processing (Vitevitch & Luce, 1999; Vitevitch *et al.*, 1999). This result has been explained due to the high correlation between neighbourhood density (ND) and PP. That is, tasks such as lexical decision and real-word repetition bias processing toward the lexical level such that the inhibitory effects of high ND predominate and tasks such as same/different judgements and non-word repetition bias processing toward the phonological level such that PP effects predominate (Vitevitch & Luce, 1998; Vitevitch et al., 1999).(See Figure 3.2).



Lexical and phonological level representations of the word 'These': A sparse neighbourhood with low PP phoneme sequences



Lexical and phonological level representations of the word 'sit': A dense neighbourhood with high PP phoneme sequences

Figure 3.2. Lexical and phonological level representations of words differing in ND and PP (Storkel & Morrisette, 2002)

3.1.2 The developing lexicon

There is less consensus in the literature regarding the nature of the developing lexicon with three main areas of contention. Firstly regarding the nature of the *organisational structure* of the developing lexicon, is it organised in the same way as an adult lexicon in terms of the density of the similarity neighbourhoods and the unit of sound used to organise those neighbourhoods. Secondly, the degree of specification of *lexical representations,* that is whether the phonemic segments of a lexical representation are present and functional from the beginning of speech development or whether they emerge over time. Thirdly, the nature of *phoneme level representations* and their relationship to lexical level representations, that is, whether phoneme level representations are created and refined from generalisations made across lexical level representations or created purely from auditory analysis of the speech stream, and, if they do emerge through schema abstraction from the lexicon then what is the changing nature of these representations over development.

Converging evidence from a number of experimental paradigms support an emergent perspective of phonemic and lexical knowledge based on probabilistic phonology (Pierrehumbert, 2003; Werker & Curtin, 2005). That is, over development vocabulary growth influences the segmentation of words into phonemes, and this process generates the representation of phonemic categories through generalisations across lexical level representations. These phoneme category representations allow the child to produce and process phonemes independently of the words in which they occur and so become more efficient and flexible in their speech processing (Garlock *et al.*, 2001; Walley et al., 2003). The following will describe in turn the evidence relating to the organisational structure of the developing lexicon, the nature of lexical representations and of phoneme level representations and, finally a series of models of speech processing will be presented representing a synthesis of our current understanding as to the nature of the lexicon across development.

3.1.2.1 Organisational structure of the developing lexicon

Similarity neighbourhoods in the adult lexicon are thought to be organised by links between words which differ from one another by one phoneme substitution, addition or deletion. Processing of words is influenced not only by the density of the neighbourhoods but also by the nature of the relationship of the neighbours to the target word such that "spread" of the neighbourhood (i.e. the number of phoneme positions that can change to make a real word) has an additional effect over and above the density (Stemberger, 2004; Vitevitch, 2007). For example the word 'mop' produces phonological neighbours if changes are made at three phoneme positions whereas for the word 'mob' this is only the case for two phoneme positions. Vitevitch (2007) found that processing in a number of tasks was slower for words with greater spread but which were matched for neighbourhood density.

There has been some debate relating to whether young children's similarity neighbourhoods are sparse or dense (Charles-Luce & Luce, 1990, 1995; Dollaghan, 1994). It would seem logical to assume that a smaller lexicon will necessarily be sparse and will become more dense over time. However, although density obviously does increase through development it seems that children tend to begin their lexical acquisition by collecting new words which are similar to those already in their lexicons. That is, short words with high PP and high ND tend to be acquired first hence neighbourhoods tend to increase in density quite rapidly for this particular group of words (Storkel, 2001, 2003, 2004a; Storkel & Rogers, 2000). This finding has been used to support claims that early lexical representations must be very fine grained (Coady & Aslin, 2003). However, as cited above, data from adult processing suggest that it is both the number of neighbours and their specific relationship to the target word which influence a lexical representation (Stemberger, 2004; Vitevitch, 2007). In smaller lexicons therefore, even if early neighbourhoods are dense, this does not predict fully specified lexical representations. Rather an interaction between density and the position of the overlap between the neighbours would predict the level of specificity of the representation. To illustrate this point, the words listed in Table 3.1 are the phonological neighbours for the word 'cat' (computed using the DeCara and Goswami Lexical Data-base (De Cara & Goswami, 2002)) which are also typically found in the vocabulary of children of 3 years and under (Fenson et al., 1997; Morrison *et al.*, 1997).

Position of Phoneme change		
Initial	**Medial**	**Final**
bat	coat	catch
pat	kite	cap
hat	cut	
fat	cot	
sat		
that		
at		

Table 3.1. Neighbours of 'cat' in the lexicon of a typically developing 3 year old child

On consideration of Table 3.1 it is apparent that, despite this word having a relatively dense neighbourhood the pressure to specify the lexical representation to adult levels appears to be absent. That is, although it is *possible* that the 3 year old child uses phonemes as the unit of sound with which to organise the lexicon, it is not *necessary* for them to do so in order to recognise or to choose the word 'cat' for production. That is, word initially, the developing child would need to be able to distinguish between some aspects of manner (fricative vs.

plosive) and between some aspects of place (labial and alveolar). However there would be no need for further detail regarding other manner and place distinctions and the voicing distinction could be less well defined for appropriate recognition and production to take place. In addition, medially and finally even less information would be required to access this lexical representation.

In the adult lexicon however the pressure to discriminate between many more neighbours requires that the unit of sound used to organise the lexicon be much more detailed and indeed able to code all aspects of contrast found in English phonology. Table 3.2 lists the neighbours for the word 'cat' found in the adult lexicon and demonstrates the need for the adult to be able to distinguish between all aspects of manner used contrastively in English (plosive, nasal, fricative, approximant, affricate) all aspects of place (labial, labio-dental, alveolar, post-alveolar, velar) and voicing.

Position of Phoneme change		
Initial	**Medial**	**Final**
bat	coat	catch
pat	kite	cap
hat	cut	cash/cache
fat	cot	cab
sat	curt	cad
that	cart	caff
at	court	cadge
gat	kit	cam
mat/matt	cote	can
gnat	coot	
rat		
tat		
vat		
scat		
chat		

Table 3.2. Neighbours of 'cat' in the adult lexicon

Zamuner (in press, under review) has demonstrated that for English and Dutch, early childhood neighbourhoods have many more similarity neighbours for onset changes than for vowel or coda changes. Storkel (2002) demonstrated that this bias towards onset neighbours has demonstrable effects on the nature of TD children's lexical representations and thence their speech processing abilities. Storkel compared the performance of TD children aged between 3;7 and 5;11 when categorising words with reference to a standard word as being the same as, 'like' or different from that standard word. The word pairs varied in neighbourhood density (high or low), the position of the overlap with the standard word (in the CV or VC section of a CVC word) and in the type of change from the standard word (identical to the standard word; the same consonant as the standard word in the targeted position of overlap; the consonant sharing manner only; the consonant sharing place only). Storkel found that in the CV and the VC sections of the word children accepted identical words and words sharing the same consonant as being the same or 'like' the standard word. They were much less likely to categorise words containing consonants sharing only manner or place in this way and when they did, were more likely to do so in the VC than in the CV position. In addition neighbourhood density had a significant effect such that for words from dense neighbourhoods, children classified words as similar based on phoneme level similarities alone in both CV and VC. However words from sparse neighbourhoods were categorised in this way only for the CV position. In the VC position the children classified words with both phoneme level similarities *and* those which shared only manner similarities as 'like' the standard word. Hence it would seem that children's lexicons do restructure over development and that density and spread of neighbourhoods exert demonstrable and separable effect on this process. Storkel (2002) summarises two possible trajectories for this process of restructuring; strong and weak restructuring accounts.

The strong restructuring account suggests that in infancy, neighbourhoods are organised by manner similarity in the onset + nucleus position only. Then phonemic coding emerges in the onset + nucleus position and rime coding (although not yet specified at the level of the phoneme) also becomes important for neighbourhood membership. Finally in adulthood neighbourhoods are determined by phoneme similarity in all word positions.

This account is termed "strong" restructuring as words actually change their neighbourhood memberships over time, being members with one set of words at one point in development and a different set at a later stage (see Figure 3.3).

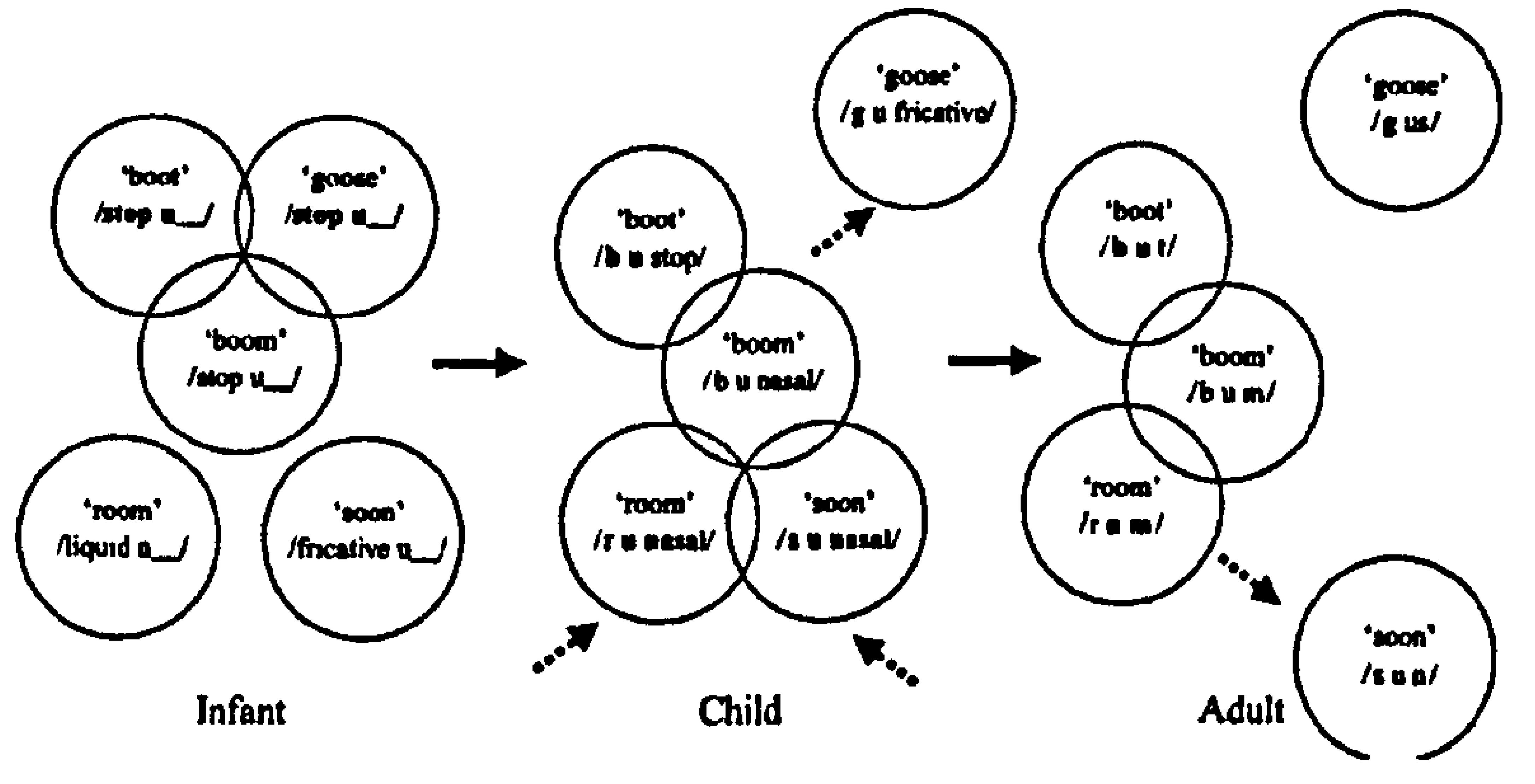


Figure 3.3. Stages in the strong restructuring account (Storkel, 2002)

The "weak" restructuring account (Nittrouer, 1996) is so called as, although lexical representations increase in their level of specification, they do not change their neighbourhood membership.

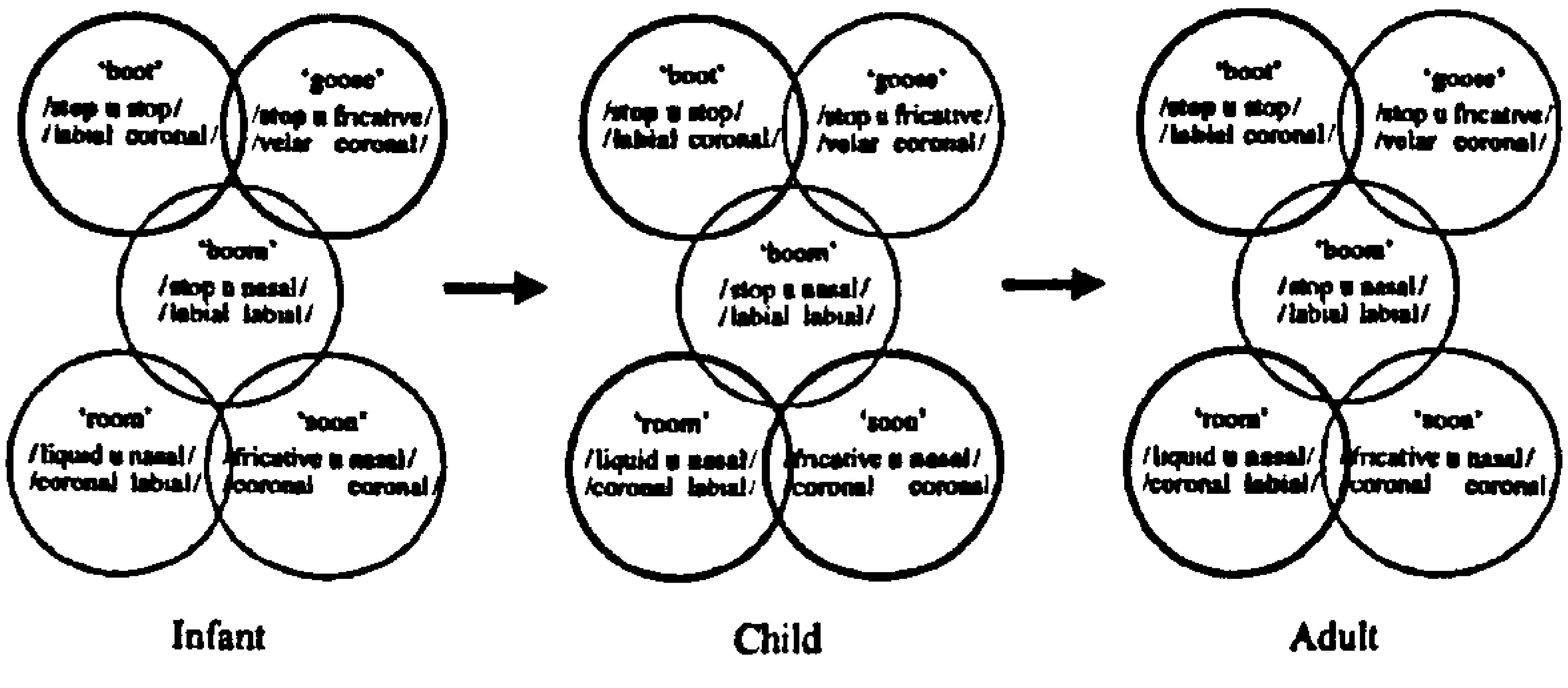


Figure 3.4. Stages in the weak restructuring account (Storkel, 2002)

That is, rather than neighbourhood membership changing over development it is the *salience* of the similarity relationships which alter. That is, in the infant, attention is paid to the manner of the onset + nucleus segment only, in the child the initial phoneme and the manner of the rime become most salient and in the adult, phonemic coding takes precedence in all word positions.

These biases towards onset neighbours in early neighbourhoods are likely to reflect the fact that the earliest speech processing mechanism is concerned with phonetic/indexical information where salience, prosody and the search for word boundaries play a key role in processing, hence biasing processing such that detail is more likely to be coded at word onset position, where most often the stress will be placed, and where a word boundary occurs.

3.1.2.2 Lexical representations

From an emergent perspective the nature of lexical representations is therefore inextricably linked to the organisational structure of the lexicon. Further evidence which supports the claims for the restructuring and increased specification of *lexical* level representations over development and with increasing vocabulary knowledge comes from gating and spoken word recognition tasks (Garlock et al., 2001; Walley et al., 2003), word learning tasks (Storkel & Hoover, 2006) and studies of phonological awareness (De Cara & Goswami, 2003). Metsala and Walley (1998) suggest that as neighbourhoods of similar words develop then more detailed representations are needed to distinguish between the different words. Within this "Lexical Restructuring Model" (LRM), the process of lexical reorganisation is a long one and different items are differentially specified depending upon their familiarity and neighbourhood density.

The evidence for these claims comes from a series of experiments which manipulate ND, age of acquisition (AoA) and word frequency in two "spoken word recognition tasks"(Garlock et al., 2001). The authors suggest that the tasks, gating tasks and real-word repetition in the clear and in white noise, tap the children's sensitivity to sub-lexical information and their ability to use this to recognise spoken words. The tasks were completed by young children (μ= 5;06), older children (μ= 7;06) and adults. Spoken word recognition was found to be influenced by ND and AoA for all groups such that early aquired words from dense neighbourhoods were advantaged in the spoken word recognition tasks. The differences in performance between early acquired words from dense neighbourhoods as opposed to those from sparse neighbourhoods decreased with age suggesting that the process of increased specification in the representation of words from sparse neighbourhoods was still ongoing in those children included in this experiment. The children's performance on word recognition tasks for this group of words (early acquired/sparse) was also found to contribute to variance in phonological awareness scores in these children.

The assumptions made by the lexical restructuring model and other developmental models (Elbro *et al.*, 1998; Fowler, 1991) are supported by results from a number of different experimental paradigms. For example a recent word learning study with 3 year old and 4-5 year old children (Storkel & Hoover, 2006) showed that younger children's ability to learn new words was affected by the ND and PP of whole words but not parts of words whereas older children were sensitive to these variables for both whole and part words. This therefore suggests a greater degree of segmentation in the lexical representations of older children.

De Cara and Goswami (2003) investigated the effect of ND on the performance of 5 year old pre-reading children in phonological awareness tasks. The children were split into two groups, those with a high vocabulary age and those with a low vocabulary age. The high vocabulary age group were sensitive to ND effects demonstrating better performance on words from dense neighbourhoods than those from sparse. The performance of the low vocabulary age group however was unaffected by the ND of the stimulus words. Hence these results support the lexical restructuring model's claim that words from dense neighbourhoods are more segmental in their representation and that this segmentation is highly correlated with vocabulary growth.

A caveat to this claim is that phonological awareness tasks could be performed at the phonological level of processing with no reference to the lexical level of processing and so it is possible that it is the PP of the stimuli not their ND which is pertinent to this experimental paradigm. As infants with no lexical knowledge have been shown to be sensitive to the PP of words (Jusczyk, 1997a; Jusczyk et al., 1994) it is possible that these effects are independent of lexical knowledge. That is, as argued by Coady and Aslin (2004):

> "what remains unclear is whether sensitivity to phonotactic information...... is affected by the words in the lexicon or whether it is determined solely by the first order distributional information contained in the native language input independent of its sequential packaging in words". (p. 188).

However, the relationship between these results and the vocabulary knowledge of the participants cannot be ignored. That is, it is likely that the process of lexical restructuring not only creates changes in representation at the lexical level but also makes the phoneme more accessible and manipulable at the phonological level of processing. A further point of note regarding studies conducted by Goswami and colleagues is that they suggest that the process of lexical restructuring, which is powered by vocabulary growth, produces representations which are segmented to the level of the onset + rime, and that restructuring to the level of the phoneme only occurs as a product of literacy development (De Cara & Goswami, 2002, 2003; Ziegler & Goswami, 2005). However Walley et al. (2003) suggest that phoneme awareness is a direct product of lexical restructuring and is a pre-curser to rather than a by product of literacy.

3.1.2.3 Phonemic representations

Direct evidence that *phonemic* level knowledge and representations arise as products of the lexical restructuring process is rare, however results from non-word repetition experiments have been cited as evidence for this claim. The influence of long term language knowledge on non-word repetition performance has been recognised by many researchers (Baddeley, 2003; Dollaghan *et al.*, 1995; Gathercole, 1999; Howard & van der Lely, 1995; van der Lely & Howard, 1993). In a series of recent experiments Munson and colleagues have demonstrated the effect of PP on non-word repetition and in addition have found that the influence of PP diminishes with age and vocabulary knowledge (Edwards *et al.*, 2004; Munson *et al.*, 2005a; Munson et al., 2005b; Munson *et al.*, 2005c). They suggest that the development of phonological units as separate representations from the lexical items in which they occur is influenced by lexical development and is continuing to be elaborated even up to the age of 13 years (Munson et al., 2005b). That is, they found an advantage for accuracy and fluency of production for high frequency sequences over low frequency sequences but that this difference became smaller as vocabulary knowledge increased. This finding could be interpreted in one of two ways, either larger vocabulary size predicts the development of robust and manipulable representations of phonemes at the phoneme level which can then support speech processing, or children with larger vocabularies have had increased motor practice for low frequency sound sequences and their increased fluency and accuracy represents facilitation at the level of motor programming. In order to test these alternative explanations the authors compared low frequency sound sequences (e.g. /gd/) to zero frequency sequences (e.g. /jɑʊ/; /pw/), that is, those sequences which are attested in English to those which are not. They hypothesised that if increases in vocabulary knowledge facilitated production of zero-frequency sound sequences then improvements in motor frequency could influence performance but could not *fully* explain the data. Indeed their results showed increased accuracy of zero-frequency sound sequences with greater vocabulary knowledge hence supporting the former explanation, that phonemic level knowledge and representations are associated with and perhaps driven by vocabulary growth. This association between declining advantage in repetition of high frequency sound sequences (high PP) over low frequency sound sequences (low PP), and vocabulary knowledge has been replicated in subsequent studies (Munson et al., 2005a; Munson et al., 2005b).These results support the findings of DeCara and Goswami (2003) discussed above which also suggest that the process of lexical restructuring creates changes in representation at both the lexical and phonological level. The term "phonological level" has, up to this point been borrowed from adult models of speech processing to imply the level of processing which will eventually develop into the adult phonological level. However, from the above discussions it is obvious that for much of development it is inappropriate and in fact misleading to discuss a "phonological level" or indeed "phonemic representations". For the forthcoming discussions therefore, this level of processing will be termed the 'sub-lexical level' and representations at this level described as 'sub-lexical/phonemic' to better represent the range in degree of specification likely to be present.

3.1.2.4 A developmental model of speech processing

It is apparent from the descriptions above that the child's pathway of development from infant to adult lexicon is a complex one and that the mechanisms available to the child for processing speech differ considerably along the course of development. In the following section I present a new set of models of speech processing summarising current understanding of the nature of the developing lexicon across development. These models synthesise the key elements of a number of models and theories including the lexical restructuring model of Metsala and Walley described above (1998), the research of Goswami and colleagues relating to literacy development and phonological awareness (De Cara & Goswami, 2003; Goswami, 2002; Ziegler & Goswami, 2005), the PRIMIR model (Processing Rich Information from Multi-dimensional Interactive Representations) (Werker & Curtin, 2005), "probabilistic phonology" (Pierrehumbert, 2003) and the work of Vihman and colleagues (Keren-Portnoy *et al.*, in press; Vihman, in press) and Storkel and colleagues (Storkel, 2002; Storkel & Hoover, 2006).

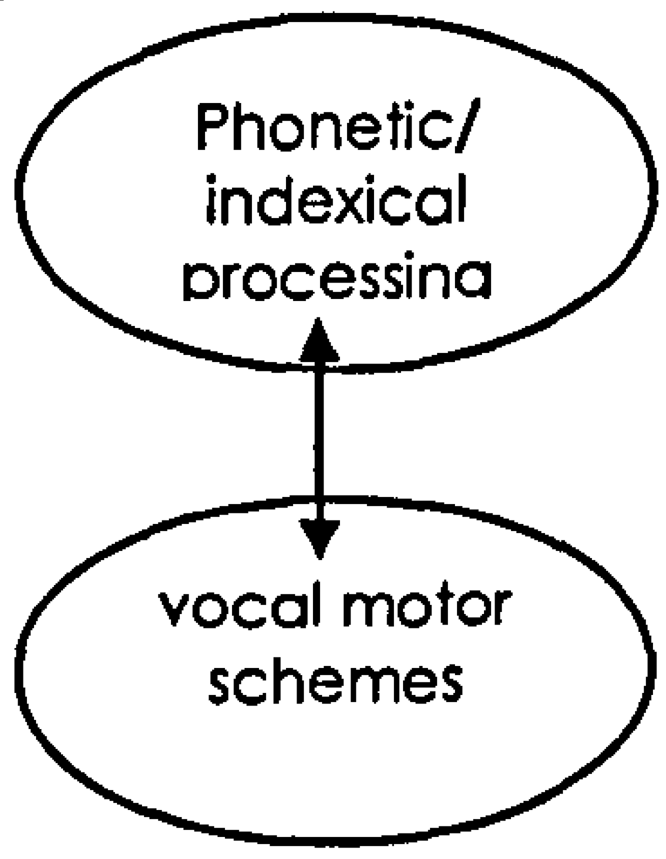
The PRIMIR model (Processing Rich Information from Multi-dimensional Interactive Representations) (Werker & Curtin, 2005) and Pierrehumbert's "Probabilistic Phonology" (Pierrehumbert, 2003) emphasise the interactions between levels of processing both 'in the moment' of processing and over the developmental emergence of the lexicon. Hence children first process speech phonetically and create holistic representations of words, then changes at the lexical level of representation create sub-lexical level representations of syllable, clusters and phonemes; reciprocal influences between these two levels continue to refine the representations of phonemes and lexical representation and the additional influence of grapheme knowledge complete the process of development to the adult model of processing. Importantly, 'in the moment' of processing, speech is processed at all levels which are available to the individual child. Hence understanding the nature of the speech processing mechanism available to the individual child is essential for our understanding of their performance on speech processing tasks.

The developmental models below represent two levels of detail. Figure 3.5 firstly presents a schematic representation of the overall structure and processes of the developing lexicon over four stages of development, pre-linguistic, early vocabulary, later vocabulary and literacy development. Figures 3.6 - 3.10 go on to represent in detail the changes in the lexical and sub-lexical/phonological levels of representation from early vocabulary development to the adult model of processing.

Language development	Structure of the lexicon	Processes

Pre-linguistic

Stage 1

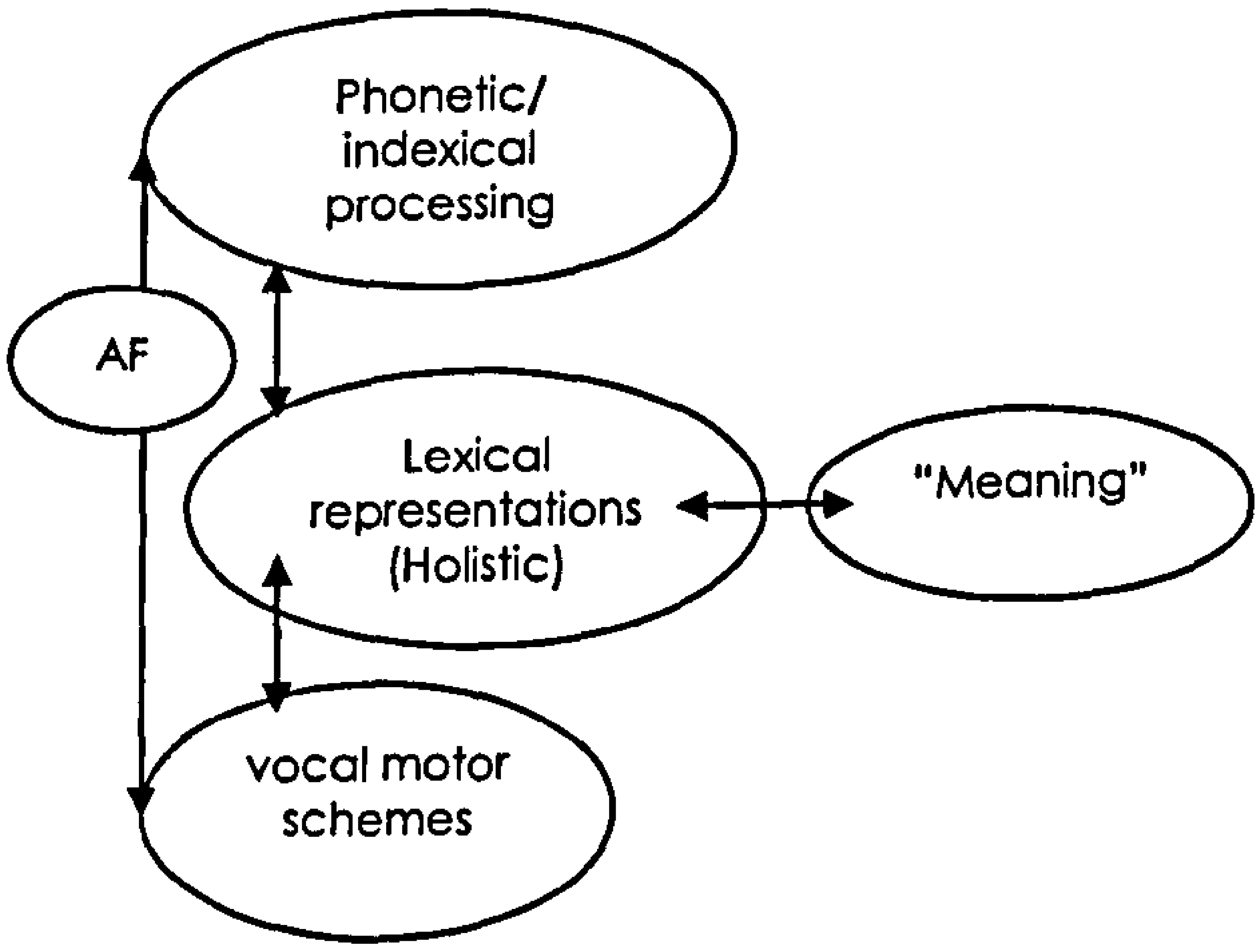


Statistical learning

Links between auditory and motor patterns becoming established through cross-modal mapping

Early vocabulary

Stage 2

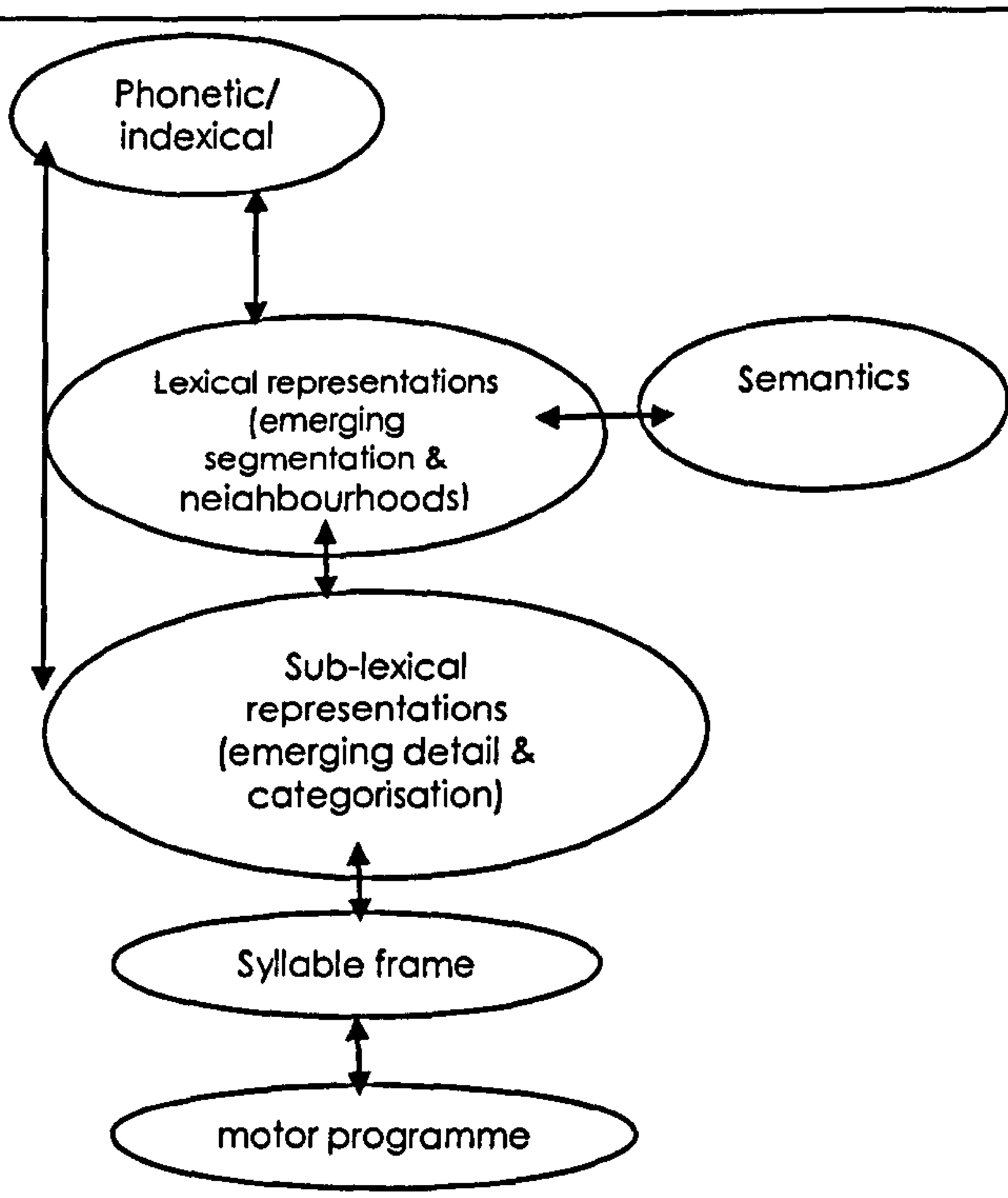


Statistical learning linked to 'meaning' through intention reading and categorisation

Articulatory Filter (AF) heightens the salience of perceived words which match infants vocal patterns

Later vocabulary

Stage 3



Similarity neighbourhoods are emerging at the Lexical level and so representations are restructuring, and producing sub-lexical level of representation which are not yet fully specified phoneme representations

Phonetic/indexical information is used in conjunction with the emerging sub-lexical representations to process speech

The syllable frame is made up of onsets and rime slots

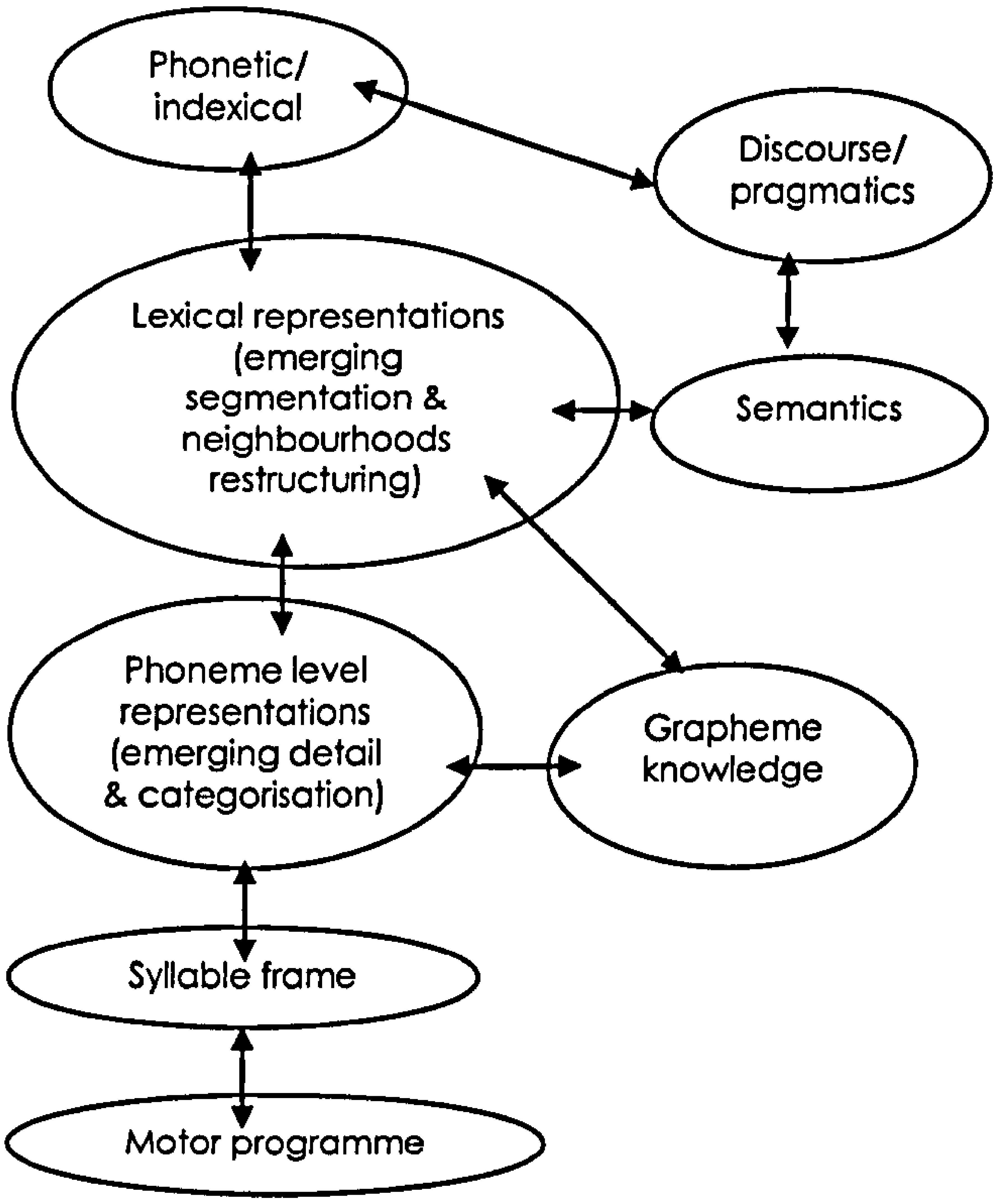
Language development	Structure of the lexicon	Processes
Literacy development Stage 4		Phonetic/indexical information available for processing if necessary but mainly used for sociolinguistic and pragmatic information. Lexical level representations continue to restructure and now also interact with grapheme knowledge. From this restructuring of lexical representation and neighbourhoods, phoneme level representations emerge. These are also directly influenced by emerging grapheme knowledge The syllable frame now made up of onset vowel coda slots.

Figure 3.5. Structure and processes in the emerging lexicon

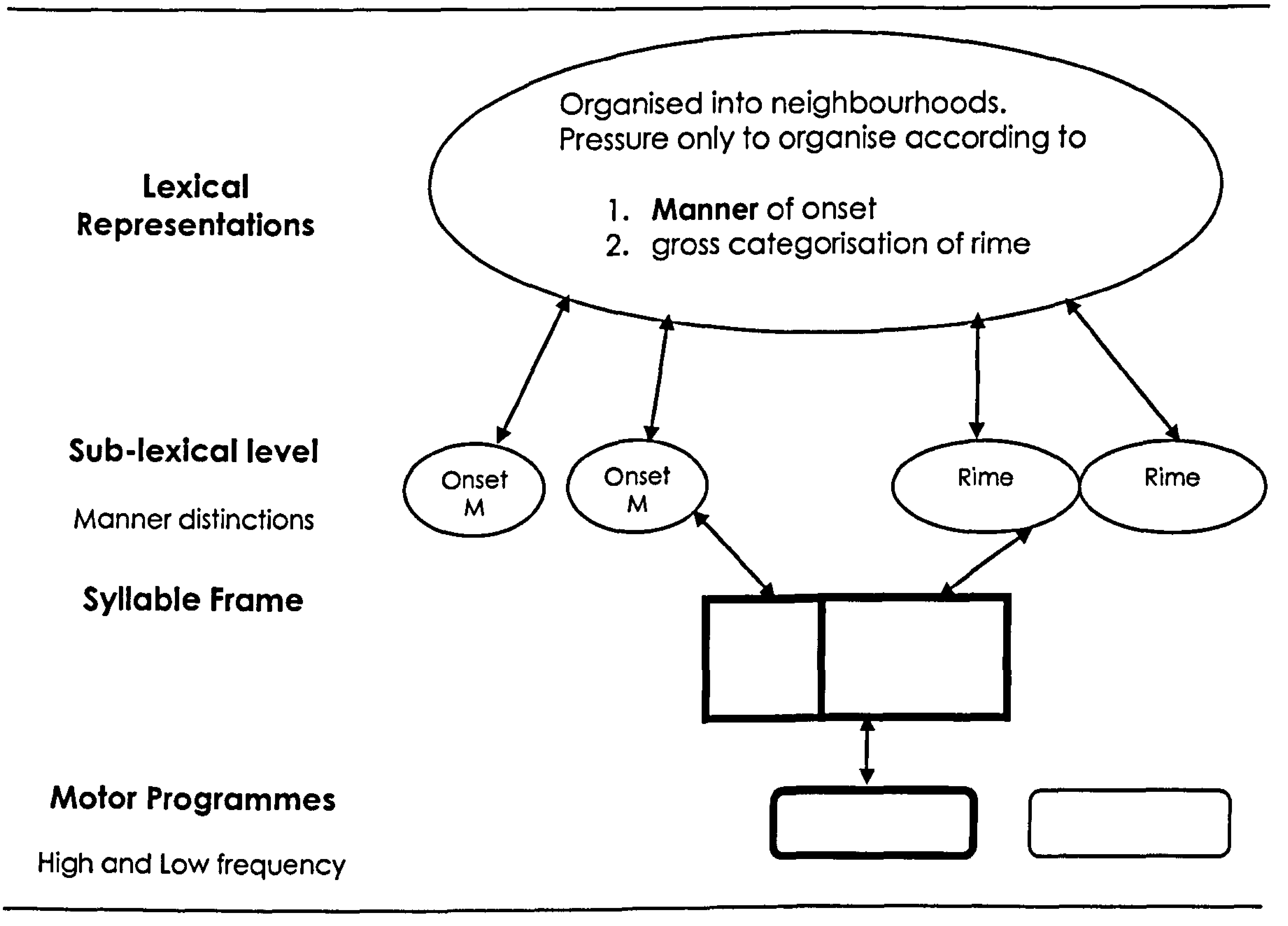


Figure 3.6. Structure and nature of lexical and sub-lexical level representations in Early Vocabulary Development: Stage 2

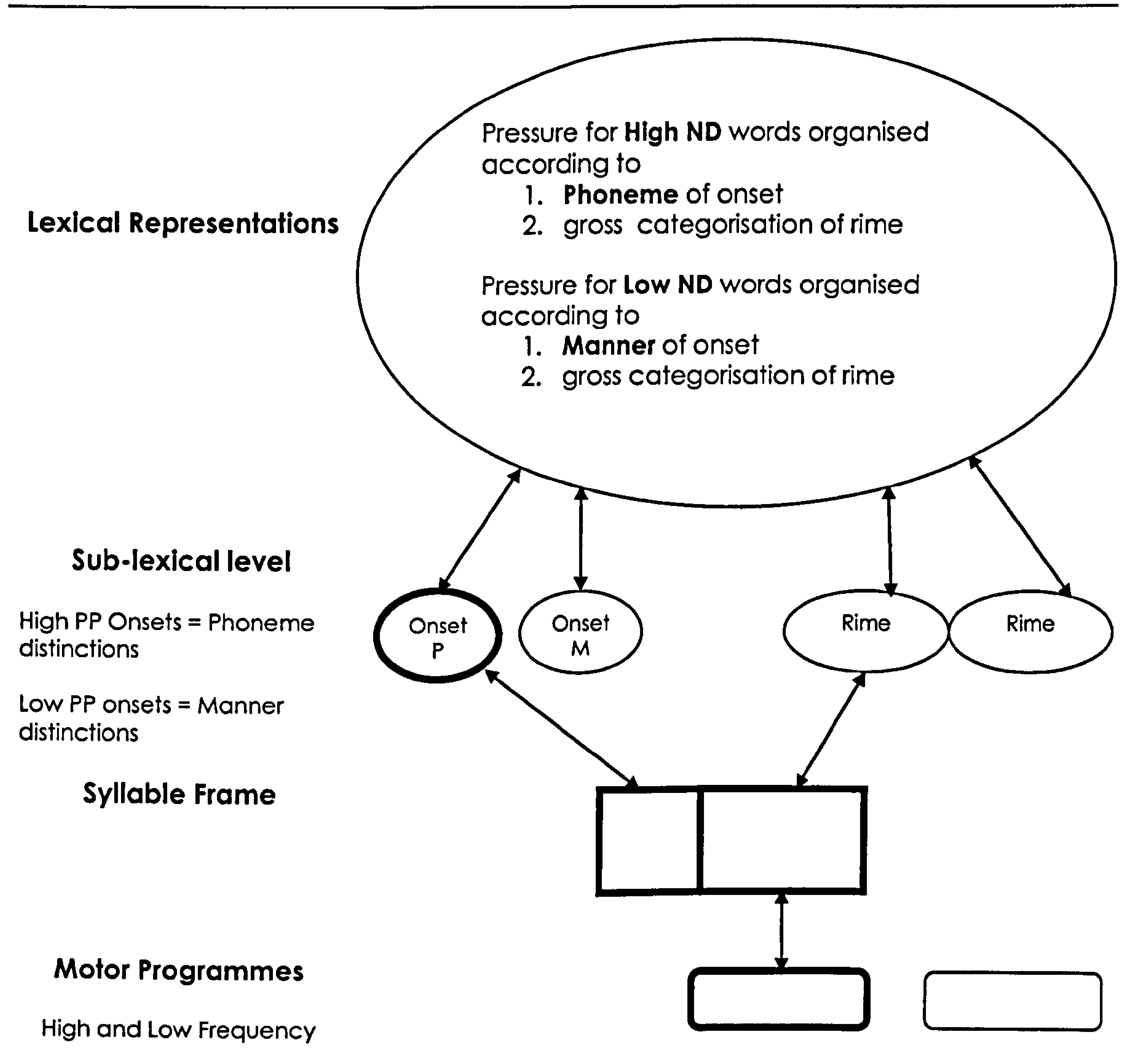


Figure 3.7. Structure and nature of lexical and sub-lexical level representations in Later Vocabulary Development: Stage 3.1

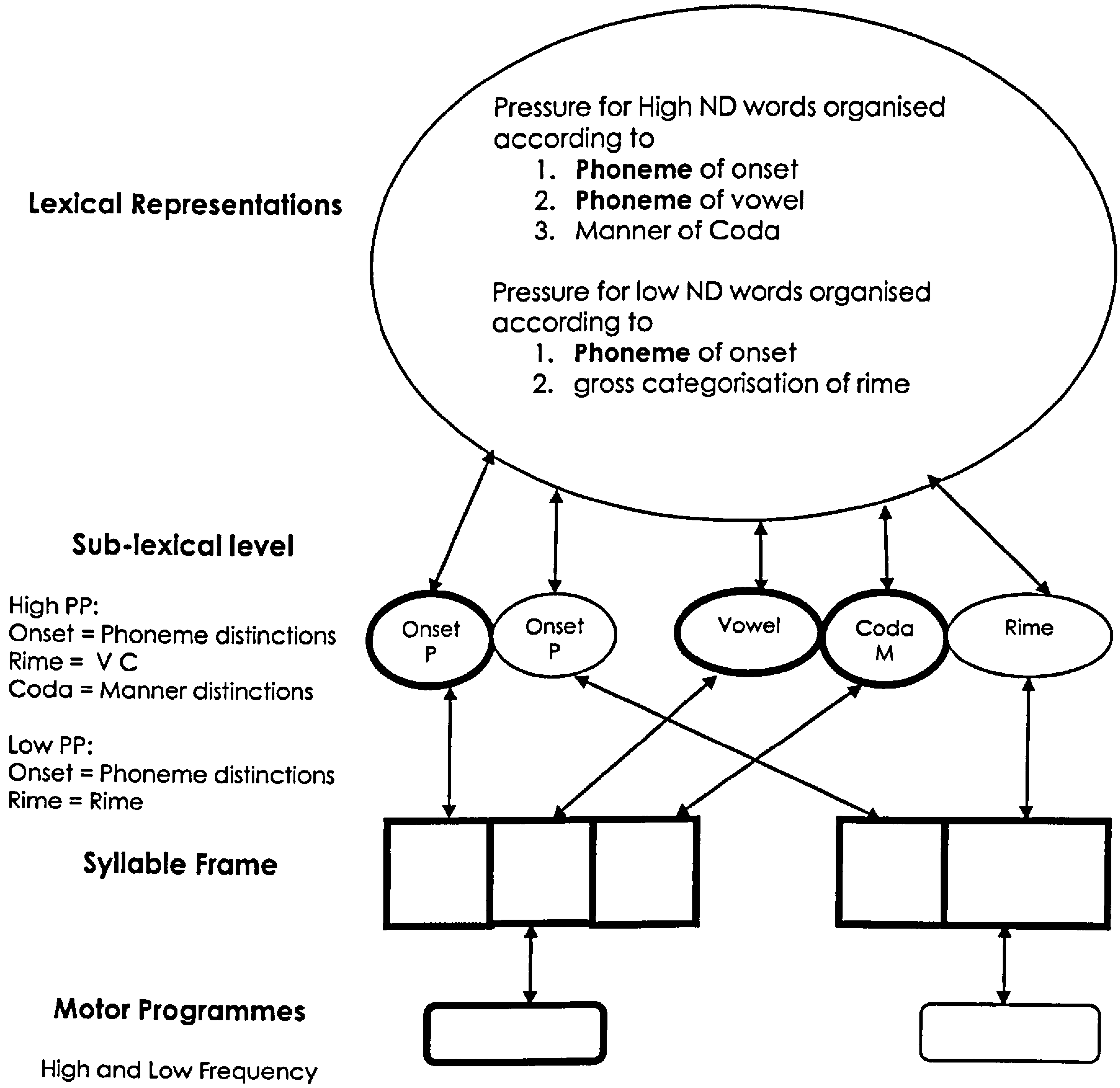


Figure 3.8. Structure and nature of lexical and sub-lexical level representations in Later Vocabulary Development: Stage 3.2

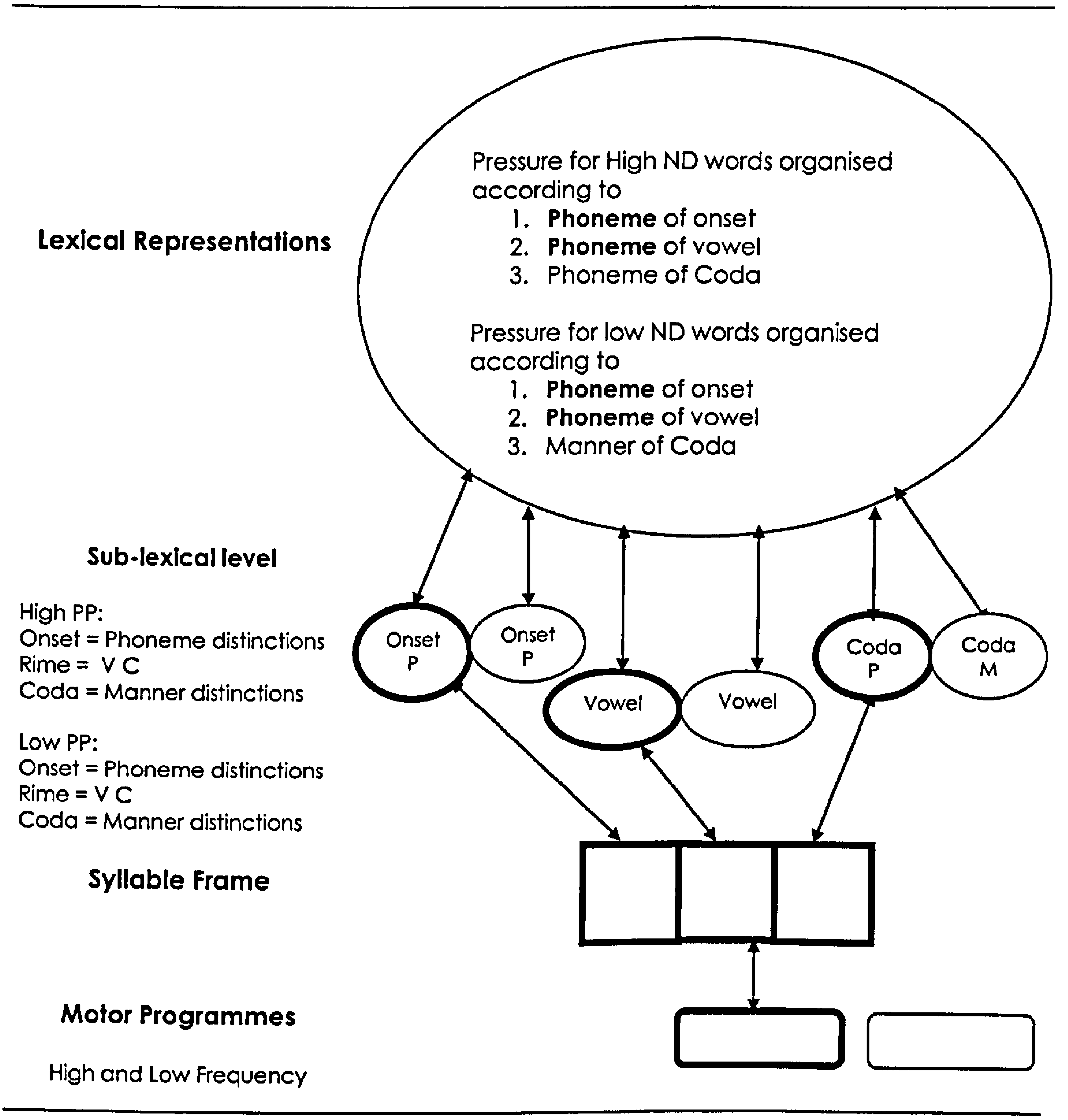


Figure 3.9. Structure and nature of lexical and sub-lexical level representations during Literacy Development: Stage 4.1

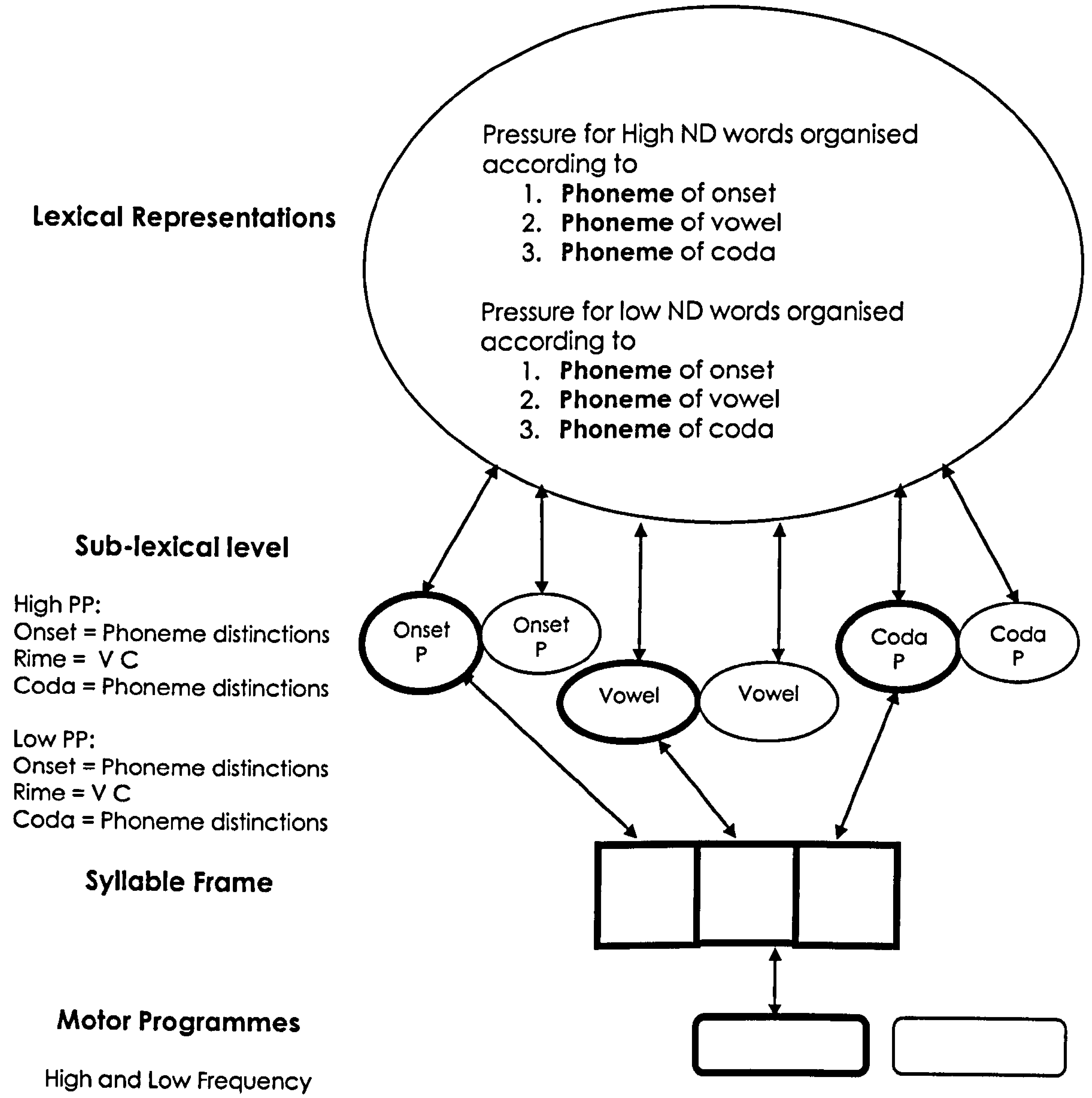


Figure 3.10. Structure and nature of lexical and sub-lexical level representations during Literacy development (approaching the adult model): Stage 4.2

In order to conceptualise and represent the complexities of a dynamic emerging system some oversimplifications necessarily occur and should be borne in mind when interpreting the models above. Firstly the process of emergence is not 'staged' as implied above but rather is a continuous process moving in an incremental and continuous way through the stages described. Secondly, within stages 3 and 4, at any one developmental moment, different parts of the lexicon will be at different sub-stages of the restructuring process depending on the nature of the neighbourhoods which are being formed. Thirdly, it is not clear from current research findings at exactly which point of segmentation/specification development would stop without the acquisition of grapheme-phoneme knowledge and so the delineation between stages 3 and 4 is necessarily equivocal. Fourthly and crucially, when considering how speech processing tasks are proceeding 'in the moment' of processing it must be remembered that speech is processed at *all* levels which are available to the individual child. This includes the phonetic/indexical level which is represented in the models in Figure 3.5 but which has been omitted from the models in Figures 3.6 – 3.10 merely for purposes of clarity of depiction and so no implication as to the relative importance of the levels of processing should be inferred. A fifth key issue must be acknowledged, and that is that the lexical restructuring model is not universally accepted (Ballem & Plunkett, 2005; Swingley & Aslin, 2000) and there is currently not sufficient research to be certain as to the nature of units of sound which are used to restructure the lexicon along the developmental path to the adult model. That is, it is as yet uncertain whether (for example) manner of articulation always takes precedence in initial restructuring of consonants, whether this criteria for categorisation is constant in all syllable and word positions, and as yet, little is known regarding the precise process of categorisation for rimes and vowels over development.

Finally, and fundamentally, emergent models of development are based upon the premise that the developing brain is a self-organising, connectionist network which responds to input from the environment, learns by creating 'representations' and then re-organises its structure based on that learning. Lexical representations within a connectionist architecture are nodes which connect together all of the knowledge stored in the lexicon about that word. A lexical node has connections to a pre-lexical processor of acoustic input, to the relevant semantic and phonological information for its lexeme and to other lexical nodes (creating neighbourhoods as has been discussed in detail above). Lexical representations themselves therefore do not hold any information regarding the nature of the lexeme and so are not in reality 'representations' in any symbolic sense. This therefore begs the question, if a lexical representation isn't a symbolic representation of a lexeme then how can it restructure? This question has not been addressed by proponents of lexical restructuring models. The answer may be that the lexical restructuring model is an adequate functional description of the processes in the developing lexicon however it does not uncover the nature of the underlying processing mechanism. Hence it provides an adequate description of *psycholinguistic behaviour*, but not of the underlying *psycholinguistic mechanism.* As the structure of a connectionist network is not directly analogous to the behaviour described in the model then an additional level of explanation, linking behaviour to mechanism, is required.

In order to make this link between behaviour and mechanism, the general properties of a connectionist network must be considered. The model above is based upon the properties of networks which process information in parallel such that individual units may receive information from many sources simultaneously. Information is encoded in a distributed way and so behaviour is determined by the global activity of the network, not just a single part of it. Also, networks are "analogy machines" (Plunkett et al., 1997 p. 57) such that novel stimuli are processed according to the nature of the existing representations in the network.

Hence the process of lexical restructuring is a function of changes in the structure of the whole lexicon as a result of additional lexical representations being added to the network. These additional lexical representations will have effects at a number of levels; on processing of pre-lexical acoustic-phonetic input through feedback from the lexical nodes such that if two nodes are now competing for recognition then greater acoustic phonetic detail will need to be processed[2]; on processing at the sub-lexical level both 'in the moment', in a similar way to that described above for acoustic-phonetic processing, and also over development through the creation of sub-lexical representations (phonemes, syllables, rimes) in order to distinguish between competing word forms and so create a more efficient processing mechanism than a phonetic-acoustic level operating in isolation; on processing at the lexical level through excitatory and inhibitory links between the nodes which also feed activation to the sub-lexical level. Hence the restructuring process is a description of the effect which changes in the number and nature of neighbours connected to the given lexical node exert on processing at the phonetic and sub-lexical levels of processing. Hence the level of specification of a given lexical representation does not refer to an abstract representation of a lexeme being depicted in greater and greater detail, but rather to the number of neighbours with which it has to compete for recognition and access, the nature of the similarities between itself and its neighbours and the nature of the sub-lexical representations it is connected to. Further work is needed to describe an emergent connectionist network which would exhibit the developmental changes in psycholinguistic processing which have been demonstrated experimentally.

Vitevitch (2008) applied graph theory to consider the nature and organisation of words in the lexicon and how that structure might influence the acquisition and retrieval of word-forms.

[2] Note that whether or not feedback from the lexical to the pre-lexical level occurs in adults and whether it is necessary or helpful remains an area of controversy (Munson et al., 2005b). However data from adult processing cannot be directly applied to the developing speech processing system (Magnuson *et al.*, under review; McQueen *et al.*, 2009).

This analysis was not intended to create a model of language processing but rather was an attempt to describe the nature of the organisational structure of an adult lexicon in terms of "a simple yet mathematically precise model" (Vitevitch, 2008 p. 409). Vitevitch does, however go on to consider what developmental process may lead to the formation of the structure he describes. He concludes that the model of "growing network" which best fits the results of his analysis of the characteristics of the lexical network is the "randomly grown network" described by Callaway *et al.* (2001). Vitevitch suggests that the process of lexical restructuring may drive the creation of new links between two pre-existing, previously unconnected lexical nodes as more detail is added to the lexical representation. I would like to argue for the direction of causality to be reversed, that lexical restructuring is driven by the creation of new links in the network. In the "randomly grown network" of Calloway and colleagues, new connections are placed between randomly chosen pairs of nodes in the network. In this way, as more connections are made between nodes over time then the psycholinguistic behaviour of "restructuring" described above will arise from effects on the global pattern of activity in the network as suggested previously. These randomly generated connections could perhaps be strengthened or weakened by subsequent experience, and so only the connections which support processing (i.e. which lead to efficient identification or access of the appropriate lexical node perhaps through "small world" effects in the network) may become stronger. Hence only connections which link words which have phonological similarities may remain functional and those linking completely unrelated words may reduce in their functionality through lack of use. In this way, the process of lexical restructuring could occur through new connections being *randomly* created and connections only being retained where they support processing, resulting in the formation of phonological neighbourhoods which as previously described, result in the behavioural characteristics described as lexical restructuring.

Despite these caveats and the limitations in the models described in Figures 3.5-3.10, the changes outlined in the nature of the emerging processing mechanism underscore a crucial aspect of an emergent approach to developmental disorders; that children at different developmental stages will approach the same processing task with radically different processing architectures and so individual performance on speech processing tasks must be interpreted with this architecture in mind.

3.1.3 Measuring Lexical Restructuring and the Emergence of Sub-lexical Representations

Based on the models of adult lexical processing and the emerging lexicon described above, the task chosen to measure lexical restructuring and emerging sub-lexical/phonemic knowledge was a non-word repetition task comparing accuracy of repetition of high PP to low PP non-words. The premise was that the reducing difference in accuracy over development between these sets of non-words provides a measure of the emerging availability to processing of phonemic representations which are separate from lexical representation. Phonemes and phoneme sequences with high PP will become more specified in their sub-lexical level representations and available for production as single phonemes in a number of syllable positions at a younger age and/or smaller vocabulary size than those with low PP due to their increased frequency and neighbourhood density in the child's lexical level of representation. These better specified sub-lexical level representations provide a more efficient method of encoding and storing a novel non-word for repetition and hence provide a processing advantage over low PP non-words. As the child moves through stages 3 and 4 (above) the advantage reduces as low PP sounds and sound sequences also become represented more fully at the sub-lexical level. This closing gap therefore can be seen to represent the greater specification of lexical level representations and the availability of sub-lexical level representations.

Non-word repetition tasks do have, however, a long and controversial history and the debate continues as to exactly what is being measured by this task (Coady & Evans, 2008). It is generally now acknowledged that non-word repetition is "influenced by a cascade of sensory cognitive and motor processes" (Gathercole, 2006). This cascade must be considered when interpreting and designing non-word repetition tasks.

Numerous studies involving children with LI have demonstrated that this group of children have severe deficits in non-word repetition accuracy, particularly for longer non-words (Bishop, North and Donlan 1996, Montgomery 1995, Ellis Weismer *et al* 2000, Gray 2003, Montgomery 2004, Edwards and Lahey 1998, Conti-Ramsden and Hesketh 2003, Norbury *et al* 2002, Briscoe *et al* 2001, Dolloghan and Campbell 1998). Indeed claims have been made as to its status as a marker for LI (Bishop *et al.*, 1996). The source of these difficulties in children with LI is an area of contention and evidence has been provided for and against deficits in auditory processing, perceptual analysis, phonological storage, recall and speech-motor output processes (Coady & Evans, 2008). Most influentially a deficit in phonological storage (previously termed the phonological loop) has been posited and much research based upon this premise (Gathercole, 2006).

The following will therefore describe how the non-word repetition task used in this study relates to each of the sub-skills of processing used in speech recognition and production together with a rationale for the claim that the chosen experimental task can in fact measure lexical restructuring and emerging sub-lexical/phonemic knowledge in LI.

It should be noted that the emergent, connectionist models of speech processing invoked here can explain non-word repetition data without recourse to a separate phonological loop or store (Gupta, 2006). However due to the large body of research which advances a deficit in this mechanism in LI and additional evidence of memory impairments in this group, this mechanism will be included in the following discussion.

3.1.3.1 Auditory processing

The experimental task used in this study compares repetition accuracy for high and low PP non-words. Any deficit in auditory processing should affect both sets of non-words equally and so, as conclusions are drawn regarding the nature of processing with respect to the *difference* between high and low PP non-word repetition rather than overall accuracy score, then the influence of auditory discrimination difficulties should be minimised.

3.1.3.2 Encoding

As non-words are heard they activate sequences of representations at the various levels of representation (phonetic, lexical, sub-lexical/phonemic) including lexical representations which share onsets, and rimes with the stimulus non-word (Allopena *et al.*, 1998). Emergent, connectionist models would predict that perceptual analysis will be more efficient, accurate, and resistant to decay and interference where long term knowledge is highly detailed and readily available to support processing. That is, in the moment of processing, phonetic, lexical and sub-lexical representations will be activated. Deficits in phonological encoding have been advanced to explain the non-word repetition deficits found in LI, for example by Bowey in the "phonological sensitivity hypothesis" (Bowey, 2006).

For the child at stage 2 (early vocabulary) encoding of a non-word will be extremely inefficient as it will involve phonetic and lexical encoding only. Hence the child will have to rely on developing a highly detailed on-line phonetic representation of the non-word. Top-down processing support will be unavailable to the child as there is no matching lexical representation and there is no sub-lexical level of representation to map the non-word segments onto and so encode the phonetic detail in the more efficient form of a phonemic code. This detailed phonetic trace will use more resources than a sub-lexical/phonemic encoding and so will be more liable to exceed the child's processing capacity and so accuracy will be compromised. At the lexical level, real words which have some acoustic similarities with the target non-word will also be activated. As the lexical representations are poorly specified this activation will be diffuse and will include words with little resemblance to the target non-word. The diffuse nature of this activation will make it more prone to decay and therefore will provide little support for encoding. At this stage therefore the influence of PP will be limited to an increased salience for the child of high PP sound sequences in perception (Jusczyk et al., 1994). In terms of encoding there should therefore be little or no advantage for high PP non-words.

For the child at stage 3 (Later vocabulary) high PP non-words will have an advantage in encoding over low PP non-words at the lexical and the newly emerging sub-lexical level. At the lexical level, hearing a non-word will activate the real-word neighbours of the non-word. A high PP non-word will usually have more neighbours than a low PP non-word and in adult processing competing representations for high ND words create a diffuse activation which is more prone to decay and interference than for low ND words. In the child at stage 3 however it is proposed that the activation for a low PP (and hence probably a low ND) non-word will be even more diffuse than the high PP/ND non-word. That is, onset phonemes found in high ND words will be represented as phonemes in the lexical representation and so a high PP onset (e.g. /p/) will activate all of the representations of words beginning with /p/. Onset phonemes found in low density words will be represented in terms of their manner only and so a low PP onset (e.g. /θ/) will activate all of the representations of words beginning with a fricative. This more diffuse activation is more prone to decay and interference and so provides less top down support for encoding than is available from the neighbours activated for the high PP non-word. This contrast of concentrated versus diffuse activation will be mirrored at the newly emerging sub-lexical level such that a high PP non word (e.g. /pɛd/)

would be activating representations of /p/ + rime and a low PP non-words (e.g. /hɔɪb/) would be activating all fricative onsets + rime.

As the child moves through stage 3 and into 4 low PP non-words catch up with high PP non-words in terms of the specification of onsets at the lexical and sub-lexical levels however a further advantage then develops for high PP non-words. At the lexical level, representations of high ND words begin to segment the rime into vowel-coda representations. This again has the effect of concentrating activation to fewer real word neighbours, decreasing the decay and interference and so providing more top-down support for encoding than would be available for low PP non-words. That is, as stated above, when the beginning of a word is heard the set of words which share the same initial sound are activated, and then as more of the word is heard activation of the non-overlapping words reduces or is suppressed to smaller and smaller subsets of candidate words until the uniqueness point is reached and only one word is identified. In a system where rimes are not segmented into vowel-coda combinations, and so vowels have not been categorised to the level of detail of the phoneme, the whole word would need to be heard for the number of candidates activated to decrease rather than decreasing steadily on a phoneme by phoneme basis. Once again the less segmented representation would imply more diffuse activation and hence less availability of top-down support.

At the sub-lexical level this contrast of concentrated versus diffuse activation will be mirrored such that a high PP non word (e.g. /pɛd/) would be activating representations of /p/ + /e/ + /d/ and a low PP non-words (e.g. /hɔɪb/) would be activating all /h/ + all diphthong-stop combinations.

As the child moves through stage 4, lexical and sub-lexical representations of high and low PP words and phonemes become equally well specified and so the advantage for high PP words in encoding diminishes.

This experimental task therefore directly taps the use of top-down processing support and can be conceptualised as a measure of the use and quality of long term knowledge in the lexicon for encoding.

3.1.3.3 Phonological storage

Emergent connectionist models conceptualise storage of a non-word for repetition as the set of activated sub-lexical/phonological representations activated by encoding. Hence a copy of the non-word is not held in a separate loop for processing, rather the representation *is* the set of connections with perhaps a separate encoding of the serial order of the sequence of activations (Gupta, 2006). Hence storage can be conceptualised as activated long term knowledge and so will be more accurate, and resistant to decay and interference where this knowledge is highly detailed. Where sub-lexical/phonemic representations do not exist which correspond to the non-word being 'stored', a number of similar representations will be activated. This distributed activation will therefore be weaker and involve more competitors than a highly specified and accurately encoded representation. Weaker activation implies faster decay and more competition implies greater interference.

Gathercole (2006) suggests that a separate influence of phonological storage capacity exists over and above the quality of phonological processing. In support of this claim she cites the characteristic increase in non-word repetition deficit in LI with lengthier words. This heightened length effect in children with LI in comparison with TD children, however can be explained without conceptualising 'capacity' as separate from phonological processing. That is, if the child has limited support of long term knowledge available at the level of encoding, as described above, the poorly encoded representation for repetition will be more prone to decay and interference. To accurately repeat a longer non-word, encoded representations need to resist decay and interference for longer periods of time than shorter non-words and so, where decay and interference is occurring, longer words will be more sensitive to their effects. Hence the heightened length effect in LI may reflect poorly encoded representations which then decay rapidly and/or suffer from interference before the child is able to repeat the non-word, whereas efficiently encoded representations remain active for long enough for the whole word to be accurately repeated. Hence inefficient encoding *results* in the child having a limited phonological storage 'capacity' but capacity and phonological processing are not in reality separable from one another (Bowey, 2006).

The experimental task presented here is able to examine both explanatory frameworks as it contrasts high and low PP for one, two, three and four syllable non-words. As comparisons can be made between high and low PP non-words then the relative influence of storage *capacity* and efficiency of phonological processing can be explored. A range of word lengths was included for a number of reasons. Firstly, it allowed the storage capacity hypothesis to be considered. Secondly it was anticipated that the differences between high and low PP non-words would be small and so by stressing the processing system with longer words, the sensitivity of the task was increased. The shorter words were included to increase cooperation with the task through the increased probability of success and as a method for considering the influence of motor-speech processes.

3.1.3.4 Retrieval

Retrieval of the non-word involves re-combining the activated phonemes or syllables in the correct order into a frame ready for output processing. Success at this stage is predicted by the processes above of encoding and storage but in addition may be influenced by redintegration (Hulme *et al.*, 1997; Thorn *et al.*, 2005). This process occurs where an incomplete trace of the stimulus is retrieved. Redintegration then 'cleans up' the degraded trace by making a 'best guess' as to the identity of the missing phonemes or syllables based on long term lexical knowledge (for real words) and knowledge of the phonotactic patterns of the language (for non-words) (Gathercole *et al.*, 1999a; Stokes et al., 2006). Once again the child with a smaller, more poorly specified lexicon and thence limited sub-lexical level representations will be less able to use sub-lexical knowledge of phonotactic patterns to clean up incomplete traces of non-words. That is, redintegration for non-words involves the child filling in gaps in the degraded trace by guessing the identity of the missing sounds based upon the most likely sound to occur in that context as predicted by the identity of the retained sounds in the trace and the phonotactic patterns of the language. The child with limited sub-lexical representations will have less knowledge of the phonotactic patterns of the language with which to make this guess and fewer phoneme level segments, represented independently from their syllable or rime contexts, which can be slotted into any gaps. High PP non-words will always have an advantage in the process of redintegration as a 'best guess' will necessarily invoke the most frequent sounds in a given context. Where sounds in the non-word have a low PP then knowledge of likely sounds within a low PP context will be necessary for redintegration to occur. Hence an increase in the availability of redintegration for low PP non-word processing will occur over development as more knowledge of low PP sequences is represented at the sub-lexical level and more low PP phonemes are segmentally represented and so available to be slotted into an incomplete trace. Hence at stages 1 and 2 of the developing lexicon described in Figures 3.5-3.10, the process of redintegration will not be available to support non-word processing (although it may be for real word processing) but will emerge at stage 3 with a significant high PP advantage which will then reduce over stages 3 and 4. The experimental task used here should be sensitive to these effects.

3.1.3.5 Speech-motor output processes

There are two issues relating to speech-output motor processes which must be addressed if this task is to be seen as a valid measure of emerging sub-lexical/phonemic knowledge in LI. Firstly, are any differences in performance observed between TD children and those with LI related to the poorer speech-motor output processes often found in the latter group and secondly, are any differences found between the high and low PP non-words related only to greater motor practice for more frequent sound sequences rather than to any changes in lexical and sub-lexical representation.

With reference to the first question, the effect of any associated phonological/speech-motor output difficulties in the children with LI were minimised using the following strategies; the non-word repetition stimuli contained only early developing consonants (m n p b t d k g s f w j and h) (2;06-3;06) (Grunwell, 1985); a modified version of the DEAP phonology screen was administered and a scoring system applied taking into account the sound substitutions observed in the screen (Dodd et al., 2002); and scores were calculated as percentage phonemes correct (PPC) rather than numbers of words right/wrong. In addition, as conclusions are drawn regarding the nature of processing with respect to the *difference* between high and low PP non-word repetition rather than overall accuracy score, then the influence of phonological/speech-motor output difficulties should be minimised. That is, if it can be assumed that any phonological/speech-motor output difficulties will affect high and low PP non-words to a similar degree, it is possible to argue that by considering the *difference* between these scores the influence of phonological/speech-motor output skills can be removed from the measure. It is, however also possible that any such difficulties could in fact be differentially affected by PP and so although they can be minimised they cannot be entirely ruled out.

With reference to the second question, that any differences found between the high and low PP non-words could be explained purely by greater motor practice for more frequent sound sequences than to any changes in lexical and sub-lexical representation. The models described above do acknowledge the influence of frequency on the motor programme level of speech processing however as cited previously, vocabulary knowledge has been shown to facilitate the production of zero-frequency sound sequences (/pw/) and so an explanation based only on increased motor fluency can not fully explain the differences between high and low PP non-words (Edwards et al., 2004). Hence the differences in high and low PP words evince differences in processing at all levels of the speech processing model.

3.1.3.6 Biases in processing

In the models described above the fact that processing happens at all levels of representation simultaneously has been emphasised. However, in adult processing, as detailed previously, it has been demonstrated that the nature of the speech processing task can bias processing so that the effects of one level predominate (Vitevitch & Luce, 1998; Vitevitch et al., 1999). In the developing system it is possible that analogous biases may exist or that the architecture of the processing mechanism being used by the child could create other biases which change over development. Hence, where the sub-lexical level of processing is 'new' to the processing mechanism the sub-lexical bias for non-word repetition described by Vitevitch and colleagues may not be present but will emerge over development. Hence the child at this stage may predominantly use lexical level representations to support processing and so be more prone to the effect of interference from neighbours than the child who can bias processing to the sub-lexical level.

In summary, this novel non-word repetition task measures the processes which are influenced by emerging lexical and phonological knowledge (encoding, storage, retrieval) whilst minimising the possible confounds (auditory processing, speech-motor output) and hence provides insights into the nature of the underlying speech processing mechanism with respect to phonetic, lexical and sub-lexical processing.

3.1.4 What this study adds

Edwards and colleagues (2004) have demonstrated the validity of a non-word repetition task comparing high and low PP as a measure of lexical restructuring and sub-lexical/phonemic knowledge with TD children. Further to this work Munson and colleagues (2005b) have demonstrated its usefulness with children with LI aged between 8 and 13 years and found that children with LI in this age range did not differ from their vocabulary matched peers on the non-word repetition task. In addition the advantage for high PP non-words attenuated with vocabulary knowledge in the same way as in TD children.

This study aims to add to our understanding of the process of lexical restructuring and the development of sub-lexical/phoneme level representations in LI in three ways; by applying a *longitudinal* case-series methodology; by examining the skills of *younger* children with LI (aged 5- 6 years) and those "at risk" of LI (aged 3-4 years) and by devising a developmentally appropriate non-word repetition task for this age group and children with co-morbid phonological output difficulties.

Ultimately this study aims to shed light on the question; do children with LI have poorer access to sublexical/phonemic representations and if so can this be entirely explained by their limited vocabulary knowledge or does and additional impairment exist? The premise being that a narrowing gap over development between scores for high and low PP non-word repetition reflects changes in the nature of the emerging lexicon such that restructuring at the lexical level and emerging sub-lexical/phonemic representation will cause the gap between high and low PP non-words to narrow over time. By comparing the relationship between high and low PP non-words over development in TD children and those with LI it may therefore be possible to determine whether changes in the developing lexicon are proceeding in a similar manner in both groups of children. In TD children the process of lexical restructuring and the emergence of sublexical/phonemic representations is thought to be driven by increases in vocabulary knowledge so, it may be that any differences in processing identified in the LI group is simply a product of having a smaller lexicon. Hence comparisons between the groups regarding the nature of the relationship between high and low PP non-word repetition scores over development will be made with respect to both age and vocabulary knowledge. In this way it will be possible to determine whether any identified impairment can be entirely explained by limited vocabulary knowledge or whether an additional impairment exists. To this end the following research questions have been posited.

1. With respect to age, do the children with LI differ from the TD children in their non-word repetition ability?
2. With respect to age, do the children with LI differ from the TD children in terms of their rate of progress for high and low PP non-words and in the nature of the relationship between high and low PP repetition over development?
3. With respect to vocabulary knowledge, do the children with LI differ from the TD children in their non-word repetition ability?
4. With respect to vocabulary knowledge, do the children with LI differ from the TD children in terms of their rate of progress for high and low PP non-words and in the nature of the relationship between high and low PP repetition over vocabulary development.

5. Can longitudinal cross-sectional trajectories of development be described with respect to age and vocabulary knowledge and are there qualitative differences between the groups.

Finally, as identified in Chapter 1, this study seeks to consider individual differences in language development in children with LI based on the premise that such analyses may provide a rich source of data as to how the language processing system is 'put together' in LI. Within an emergent system "slight differences in the relative rate, strength or timing (...) of the component achievements can result in relatively significant differences between individuals in behavioural outcomes" (Marchman & Thal, 2005 p. 150). Hence by examining individual longitudinal trajectories it may be possible to elucidate the degree and nature of heterogeneity of the LI trajectory, to describe and consider the influence of timing and the sequence of emergence of skills and compare this to typical development. This study therefore posits the following questions with respect to individual developmental trajectories:

1. Can longitudinal individual trajectories of development be described with respect to age and vocabulary knowledge

2. Do qualitative differences exist between individuals and if so what is the nature of this heterogeneity?

3. How do these patterns relate to typical development?

3.2 Method

This experiment utilises data from a number of tasks included in the test battery for the larger longitudinal case-series study described in Chapter 2. Comprehensive details regarding participants, data collection timelines and overall study protocol are given in Chapter 2. Detailed information regarding the specific measures used in this experiment are detailed below.

3.2.1 Measures

3.2.1.1 Vocabulary measures

The children were tested using the Expressive One Word Picture Vocabulary Test (EOWPVT) (Brownell, 2000a) and the Receptive One Word Picture Vocabulary Test (ROWPVT) (Brownell, 2000b). EOWPVT raw scores were chosen as the vocabulary measure for this experiment as expressive vocabulary has been shown to be a stronger predictor of developmental changes in linguistic abilities than receptive vocabulary (Marchman & Bates, 1994). Raw scores were used as they provide a more sensitive method for comparison between TD and LI groups than standard scores.

3.2.1.2 Phonology screen

The Phonology Assessment subtest of the DEAP (Diagnostic Evaluation of Articulation and Phonology) (Dodd et al., 2002) was completed in order to make allowances when scoring the non-word repetition task for phonological substitutions used in the child's spontaneous speech. In addition to the 50 items of the published test, 11 items were added by the author, specifically for use when scoring a sentence repetition task which was part of the wider test battery not reported here. These items were also included in the current analysis as they provided additional exemplars for the phonemes /g/, /h/, and /b/ in word initial position (see Appendix 3).

3.2.1.3 Non-word repetition task

3.2.1.3.1 Task presentation

The child was told "we are going to say some made up words. The words are "funny" words but you should try to say them just like me". The child was allowed to choose an age appropriate reward game and was then asked to copy the adult's models. After five responses the child chose a reward item. One repetition of the stimulus was allowed if the child requested repetition, did not respond or if they were distracted during the presentation of the word. Every effort was made to complete all of the items, and the task was stopped only when a child refused to attempt 4 items consecutively.

3.2.1.3.2 Stimuli

The non-word stimuli were created using the following method. A range of CVC and CV non-words were identified in the CELEX syllable inventory (Baayen *et al.*, 1995) which contained only early developing consonants (m n p b t d k g s f w j and h) (2;06-3;06) (Grunwell, 1985).The probability of the onset nucleus coda sequence was calculated using the following formula:

For a given syllable $C_1V_1\,C_2$

n = total number of different syllables in English

x = number of syllables beginning with C_1

y = number of the x group of syllables which then go on to have V_1

z = number of the y group of syllables which then go on to have C_2

The phonotactic probability was calculated as $\log \frac{x}{n} + \log \frac{y}{x} + \log \frac{z}{y}$

This calculation incorporates the probability that C_1 is the onset of the syllable, and the probability that C_2 is the offset.

A normal distribution of the log transformed probabilities was created such that a value of 0 represented the mean of the distribution and +/- 1 represented one SD from the mean. These calculations allowed for 'high' and 'low' PP to be easily identified.

Two sets of 10 words for each syllable length, (1, 2, 3 and 4 syllables), were then created which were matched by number of different phonemes, stress patterns and CVC structure. One set of non-words contained only high phonotactic probability syllables and another set contained only low phonotactic probability syllables.

These calculations were triangulated by calculating the PP of the candidate non-words using Vitevitch's online "Phonotactic Probability Calculator" (Vitevitch & Luce, 2004).These calculations were compared to the means and standard deviations for positional segment and biphone probabilities for each word length presented by Storkel in 2004 (see Appendix 4). High PP words were accepted if their positional segment probability was at or above the mean and if the biphone probabilities were as close as possible to the mean for that given word length. Low PP words were accepted where positional segment and biphone probabilities were at least (and usually much more than) 1 SD below the mean for the appropriate word length. There was one exception, the non-word /jænauf/ which does fall below the mean for 2 syllable words using Vitevich's calculation method, but is less than one SD below for both metrics. The probabilities for the individual syllables calculated using the CELEX based calculations fall well below the mean (see Appendix 4).

The stress pattern of the non-words was chosen as the most common pattern for that particular word length and was held constant at each syllable level. The resulting non-words are presented in Table 3.3 and the PP calculations presented in Appendix 4.

A range of word lengths was included for a number of reasons. Firstly, it allowed the storage capacity hypothesis to be considered. Secondly it was anticipated that the differences between high and low PP non-words would be small and so by stressing the processing system with longer words, the sensitivity of the task was increased. Finally the shorter words were included to increase cooperation with the task through the increased probability of success for the child and as a method for considering the influence of motor-speech processes.

Phonotactic Probability	Syllable length			
	1	2	3	4
High	nɪs	‘hɪsɛm	‘tɪsəpɛd	hɪsə’sibaɪn
	sɛm	‘hɪnɛs	‘sosəpɛd	sɪnə’teɪpɛd
	hɛs	‘teɪnɛs	‘hɪnəsɛm	hɪsə’teɪsɛm
	pɛd	‘sonɪs	‘sotəbaɪn	tɪsə’sɛbaɪn
	baɪn	‘sɛbaɪn	‘hɪsəsɛm	hɪnə’teɪnɛs
Low	hɔɪb	‘johɔɪb	‘jogaʊhɔɪb	jogu’gaʊhɔɪb
	jaʊt	‘gujaʊt	‘gujæjaʊt	hɔɪgaʊ’jænaʊf
	naʊf	‘jænaʊf	‘hɔɪjænaʊf	gaʊgu’johɔɪb
	gib	‘gaʊmɔɪg	‘jojægib	hɔɪjæ’jogib
	mɔɪg	‘hɔɪgib	‘gujohɔɪb	johɔɪ’jænaʊf

Table 3.3. Non-word repetition task stimuli

3.2.1.3.3 Task design

The stimuli were split into levels differing in the number of syllables. Within the levels the high and low PP non-words were presented in a random order (Appendix 5). Repetitions of phonemes within an individual non-word were kept to a minimum however some repetition was necessary in order to fulfil all of the criteria outlined above. Therefore the number of different phonemes per word was controlled such that, the number, totalled over the 5 stimuli at each word length was equivalent for high PP and low PP non-words.

The task was transcribed in broad phonemic terms in real time and also digitally recorded (Edirol R-09). The child's responses were then re-transcribed using the recordings together with the real-time transcriptions to support the most accurate transcription possible. Scoring was based on these final transcriptions.

3.2.1.3.4 Scoring

The DEAP Phonology Assessment was analysed and tokens identified for the consonants used in the non-word repetition task which were used in monosyllabic words and in a singleton context. Tokens from polysyllabic words were avoided to reduce possible effects of articulatory assimilations (e.g. yellow → /lɛlo/) or unstressed syllable deletion (e.g. tomato → /mɑto/). All target vowel tokens were also identified. Any substitutions or omissions used by the child were noted and the non-word repetition task scored in the light of the analysis such that any errors in the repeated non-words which coincided with speech sound substitutions present in the DEAP Phonology Assessment were scored as correct.

For each non-word the total number of errors was tallied (an error being a substitution, deletion or addition) and the proportion phonemes correct score (PPC) calculated ((Number of phonemes in target word – number of errors) / Number of phonemes in target word). This score was chosen so as to allow for comparisons to be made between words of different lengths and also as a more sensitive measure of non-word repetition accuracy than a right/wrong scoring approach.

This scoring approach was generally unambiguous except where the syllable structure of the repeated non-word had not been retained either through omission or addition of whole syllables. In this event individual phoneme scoring proceeded after aligning the syllable sequence produced by the child to the target using vowels repeated as the syllable anchors (as described by Dollaghan and Campbell (1998)). In this way a judgement was made as to which syllable in the target non-word was the most likely being attempted by the child. If the "vowel anchoring" approach did not readily create a match then the syllables with the highest number of shared phonemes was chosen as the most likely match.

3.3 Results and Discussion

The results will be presented with reference to the research questions previously outlined. The data collected in this study comprised a cross-sectional data set from 37 TD children aged between 37 and 62 months, and 13 individual longitudinal data sets of four separate Data Points, from children with LI aged between 40 and 81 months at the study's outset. In order to answer the research questions the data was considered in two ways, as *cross-sectional developmental* trajectories (Thomas et al., 2009) and as *individual longitudinal* trajectories. The results and discussion relating to the cross-sectional longitudinal trajectories are presented below and those relating to the individual trajectories presented in sections 3.3.3 and 3.3.4.

3.3.1 Cross-sectional developmental trajectories: Results

In order to consider the data from the children with language impairment (LI) as cross-sectional trajectories it was necessary to remove the issue of autocorrelation of the four measures taken from the same individual. To this end, four separate cross-sectional data-sets were created from the LI data from each of Data Points 1-4.

Analysis regarding the nature of change in respect to both age and vocabulary knowledge was planned with vocabulary knowledge measured using the Expressive One-Word Picture Vocabulary Test (EOWPVT) (Brownell, 2000a).

Results were very similar across the data sets and so the following presents results only for Data Points 1 and 4, providing a description of the trajectory of development across the full age-range of the study.

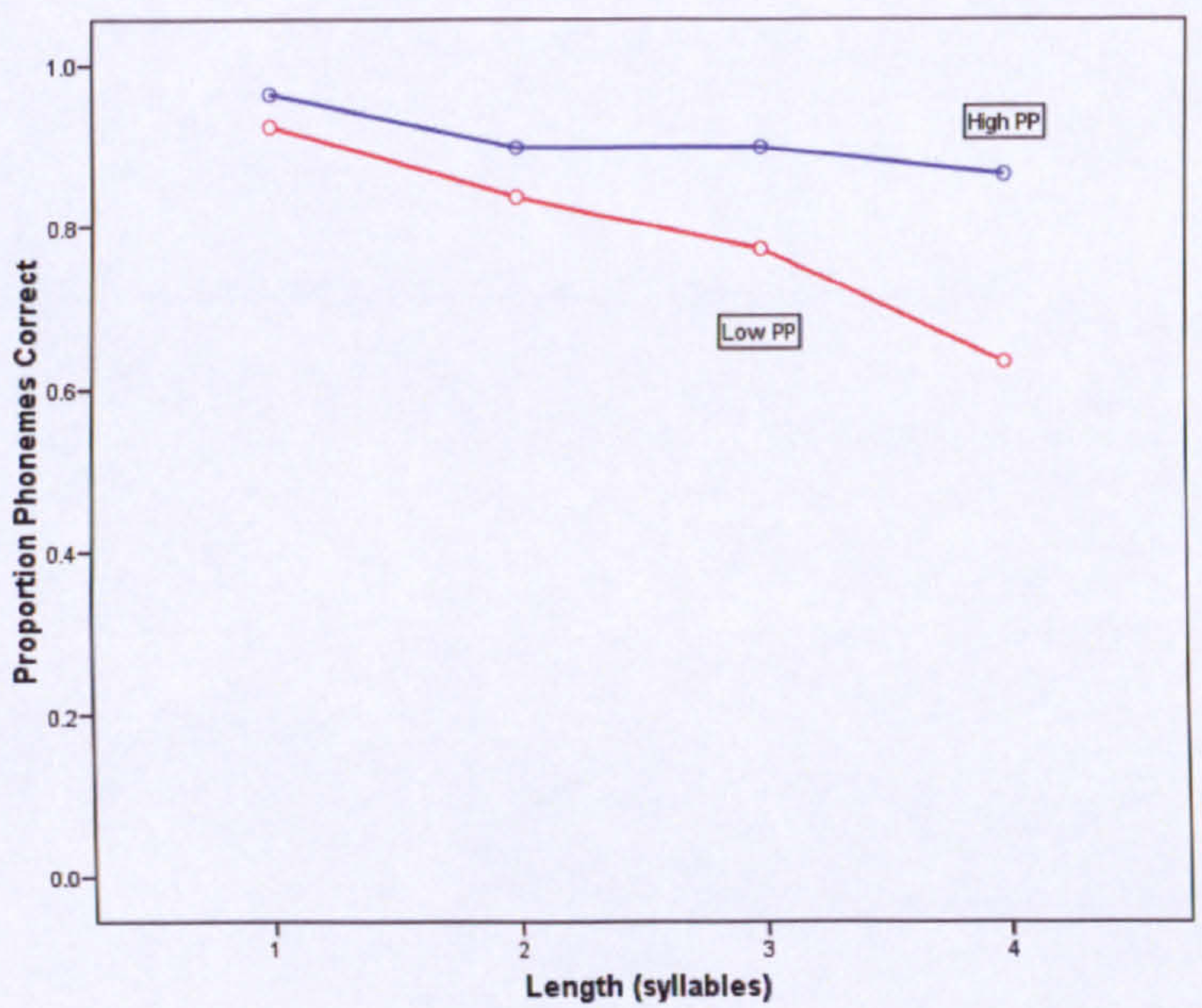
3.3.1.1. With respect to age, do the children with LI differ from the TD children in their non-word repetition ability?

Two 2*4*2 mixed ANCOVAS were completed, for data sets 1 (age range 40 – 81 months) and 4 (age range 55 – 96 months) (TD age range 37 – 62 months). The within subjects factors were PP, with two levels, high and low, and length with 4 levels, 1, 2, 3 and 4 syllables. The between subjects factor was group and the covariate was age in months. The complete set of results from this analysis is presented in Appendix 6.

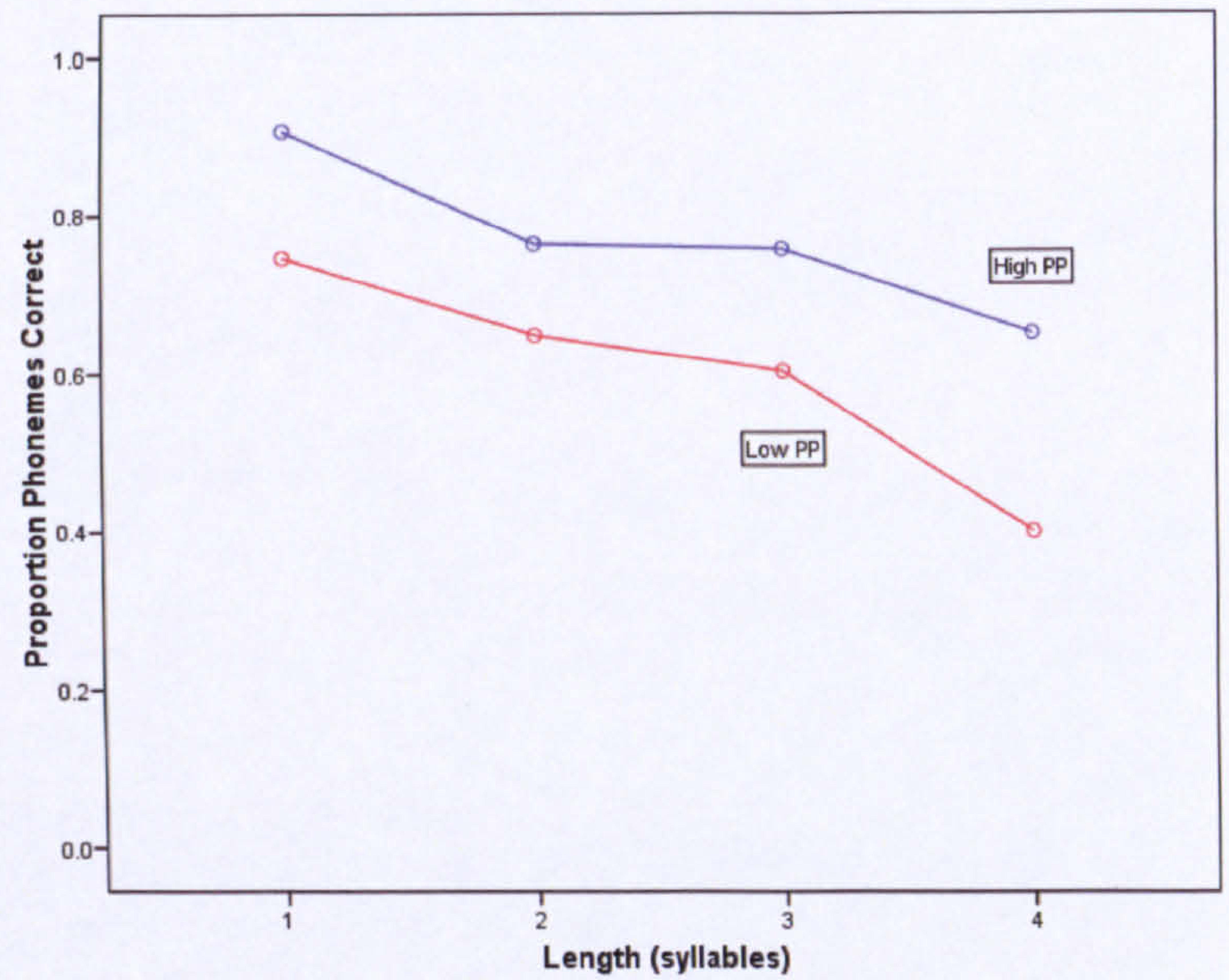
There was a significant main effect of group at both Data Points 1 and 4 [Data Point 1: $F(1, 43) = 19.94$, $p < .01$, partial $\eta^2 = .30$; Data Point 4 $F(1, 46) = 19.94$, $p < .01$, partial $\eta^2 = .30$] demonstrating that, as has been found in many previous studies, the LI group were significantly poorer in their ability to repeat non-words than TD children when compared with respect to age.

There was a significant main effect of length [Data Point 1: $F(3, 129) = 55.63$, $p < .01$, partial $\eta^2 = .56$; Data Point 4 $F(3, 138) = 89.25$, $p < .01$, partial $\eta^2 = .66$]. In many previous studies this length effect is found to differ between groups such that increasing length has a greater effect on repetition accuracy in children with LI than TD children. This was not the case at Data Point 1 as the length x group interaction was not significant [$F(3, 129) = 1.18$, $p = .32$, partial $\eta^2 = .027$] however 3 of the youngest children with LI refused to repeat 4 syllable non-words and this may have contributed to the result. At Data Point 4 the length x group effect was significant [$F(3, 138) = 33.38$, $p < .01$, partial $\eta^2 = .20$].

The PP x Group interaction was significant at Data Point 4 [$F(1, 46) = 5.76$, $p = .02$, partial $\eta^2 = .11$] but not at Data Point 1 [$F(1, 43) = .45$, $p = .51$, partial $\eta^2 = .01$] demonstrating that with respect to age the children with LI were disproportionately affected by the PP of the non-words, being poorer at low PP non-word repetition, but only at the later stages of the trajectory studied here.

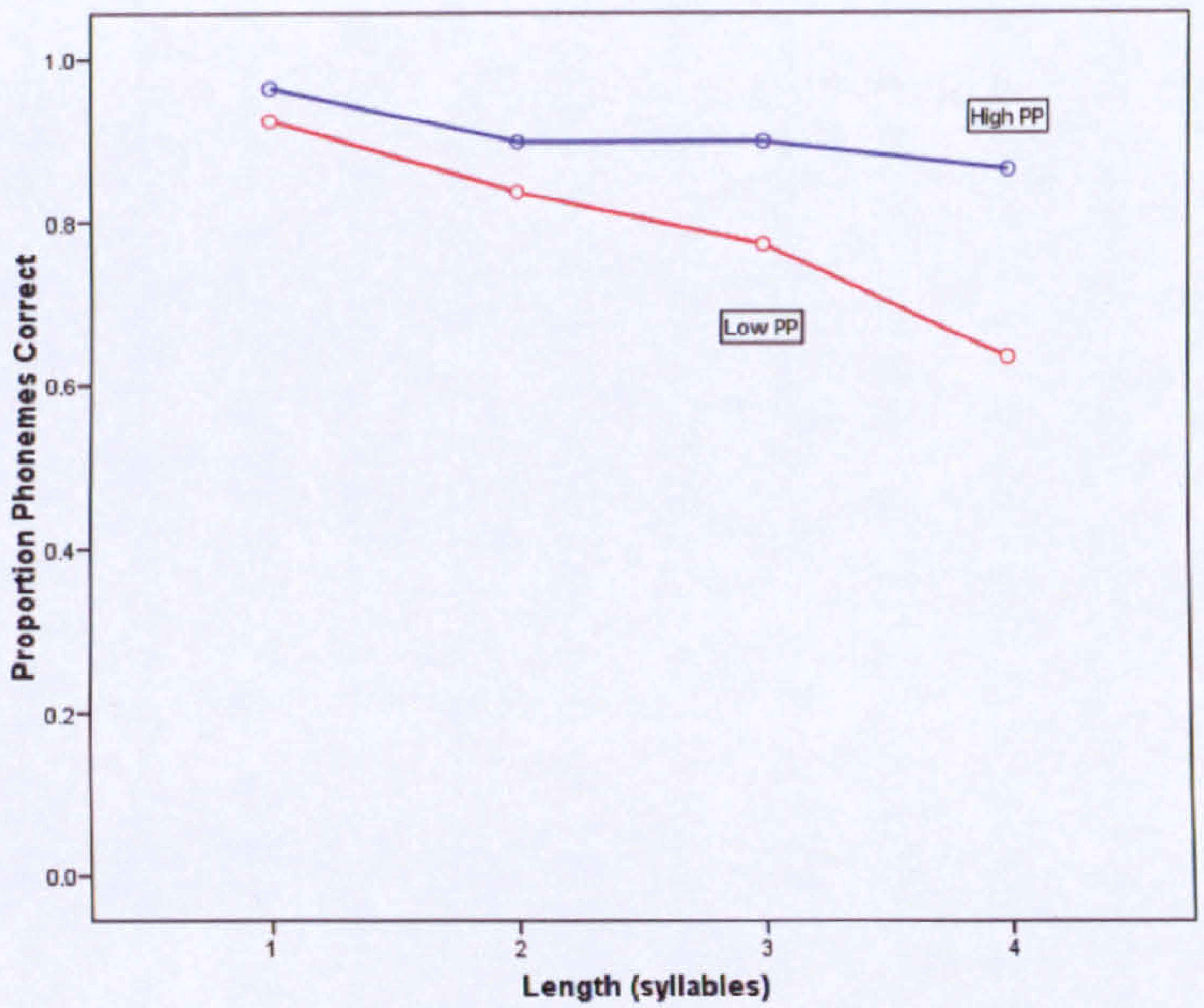


TD Group

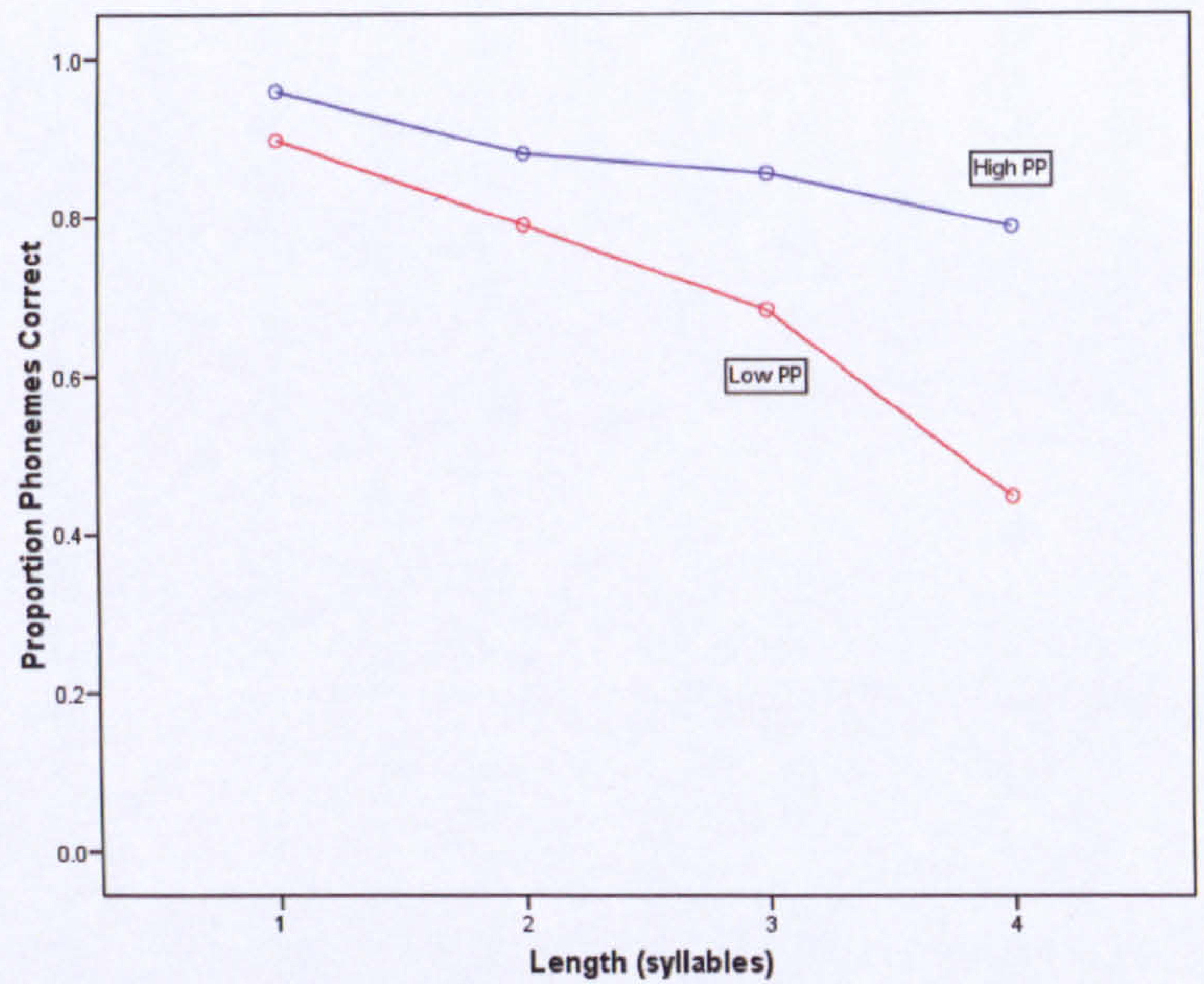


LI Group DP 1

Figure 3.11. Comparing the Effect of Length and Phonotactic Probability on Non-word repetition TD and LI Groups (Data Point 1)



TD Group



LI Group DP 4

Figure 3.12. Comparing the Effect of Length and Phonotactic Probability on Non-word repetition TD and LI Groups (Data Point 4)

3.3.1.2 With respect to age, do the children with LI differ from the TD children in terms of their rate of progress for high and low PP non-words and in the nature of the relationship between high and low PP repetition over development.

As the focus of this study is the effect of PP on non-word repetition, the scores across lengths were collapsed yielding one overall score for high PP and one for low PP non-word repetition ability. Using these two measures as the dependant variables, the following analyses were completed.

In order to consider the nature of the relationship between high and low PP scores for each group over development, one-way repeated measures ANCOVAs comparing high and low PP non-word repetition with respect to age, were completed for the TD group and the LI group at Data Points 1 and 4.

Results of the one-way repeated measures ANCOVA for the TD group comparing high and low PP non-word repetition with respect to age demonstrated the following pattern. The TD children were significantly affected by PP such that low PP non-words were less accurately repeated than high PP non-words [Significant main effect of PP: $F(1, 35) = 36.18$, $p < .01$, partial $\eta^2 = .51$]. The children improved with age [Significant main effect of age: $F(1, 35) = 40.18$, $p < .01$, partial $\eta^2 = .53$] and the gap between high PP and low PP narrowed across development such that low PP scores improved more rapidly than high PP scores [Significant interaction PP x Age: $F(1, 35) = 5.01$, $p < .03$, partial $\eta^2 = .13$] (Figure 3.13).

It is possible that the interaction between PP and age may simply be a function of ceiling effects for the high PP non-words rather than reflecting a truly significant interaction. To test this, the high and low PP scores for 3 and 4 syllable non-words only were compared using a 2 way within subject ANCOVA with age as the covariate. The rationale for this approach was that very few children were at ceiling for these longer words and so, if an interaction was present between PP and age for these words then it could be seen to be independent of ceiling effects. Indeed the interaction between PP and age for 3 and 4 syllable words was significant, $F(1, 35) = 4.53$, $p = .04$, partial $\eta^2 = .12$.

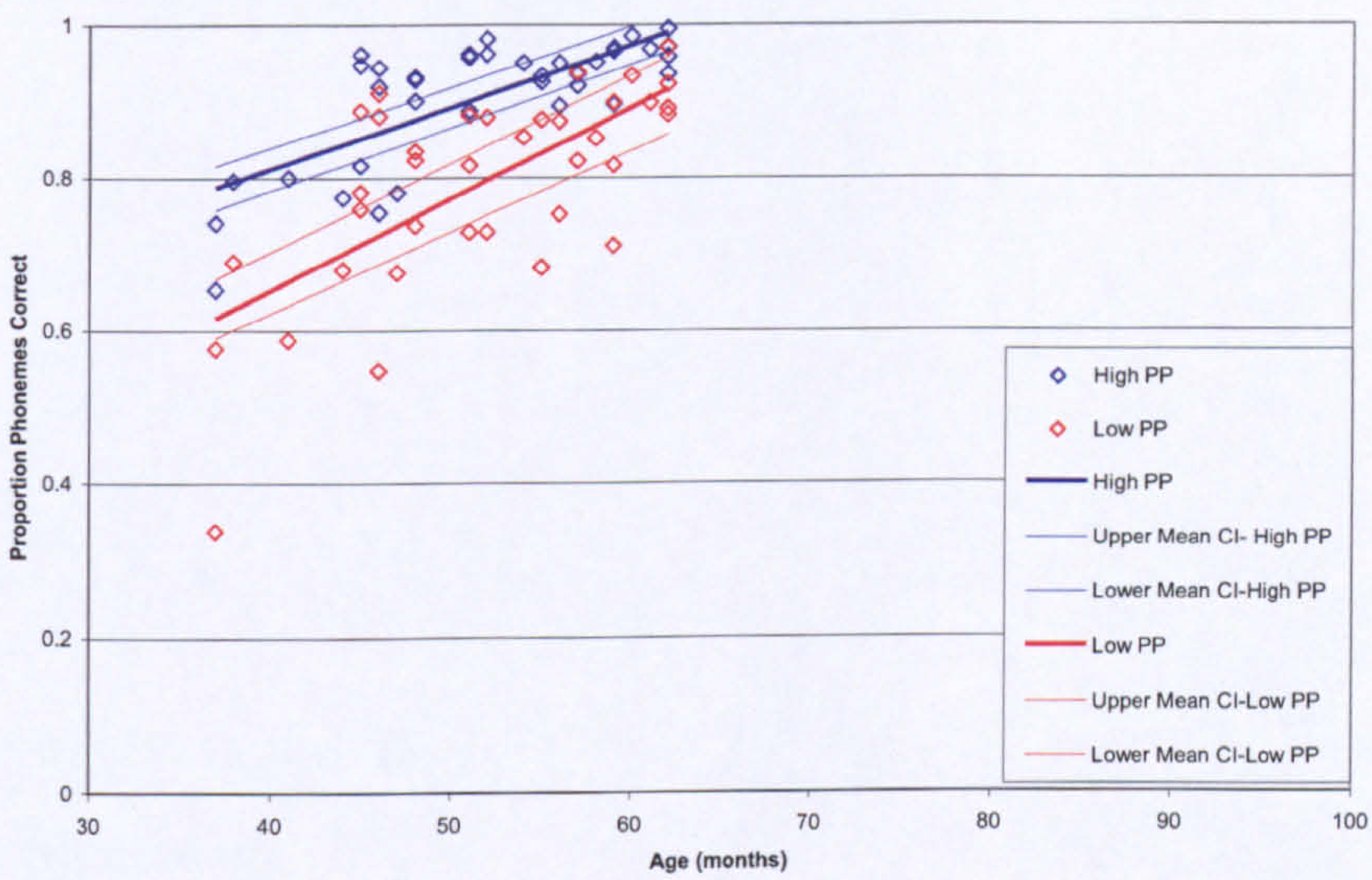


Figure 3.13. TD children: Relationship between high and low PP non-word scores with respect to age

Results of the one-way repeated measures ANCOVA for the LI group comparing high and low PP non-word repetition with respect to age demonstrated the following pattern. As was found for the TD children, the LI group were significantly affected by PP such that low PP non-words were less accurately repeated than high PP non-words [Significant main effect of PP: Data Point 1: $F(1, 11) = 8.77$, $p =.01$, partial $\eta^2 = .44$; Data Point 4: $F(1, 11) = 40.52$, $<.01$, partial $\eta^2 = .79$]. The children also improved with age at data point 1 [Significant main effect of age: $F(1, 11) = 19.41$, $p <.01$, partial $\eta^2 = .64$] (Figures 3.14, 3.15).

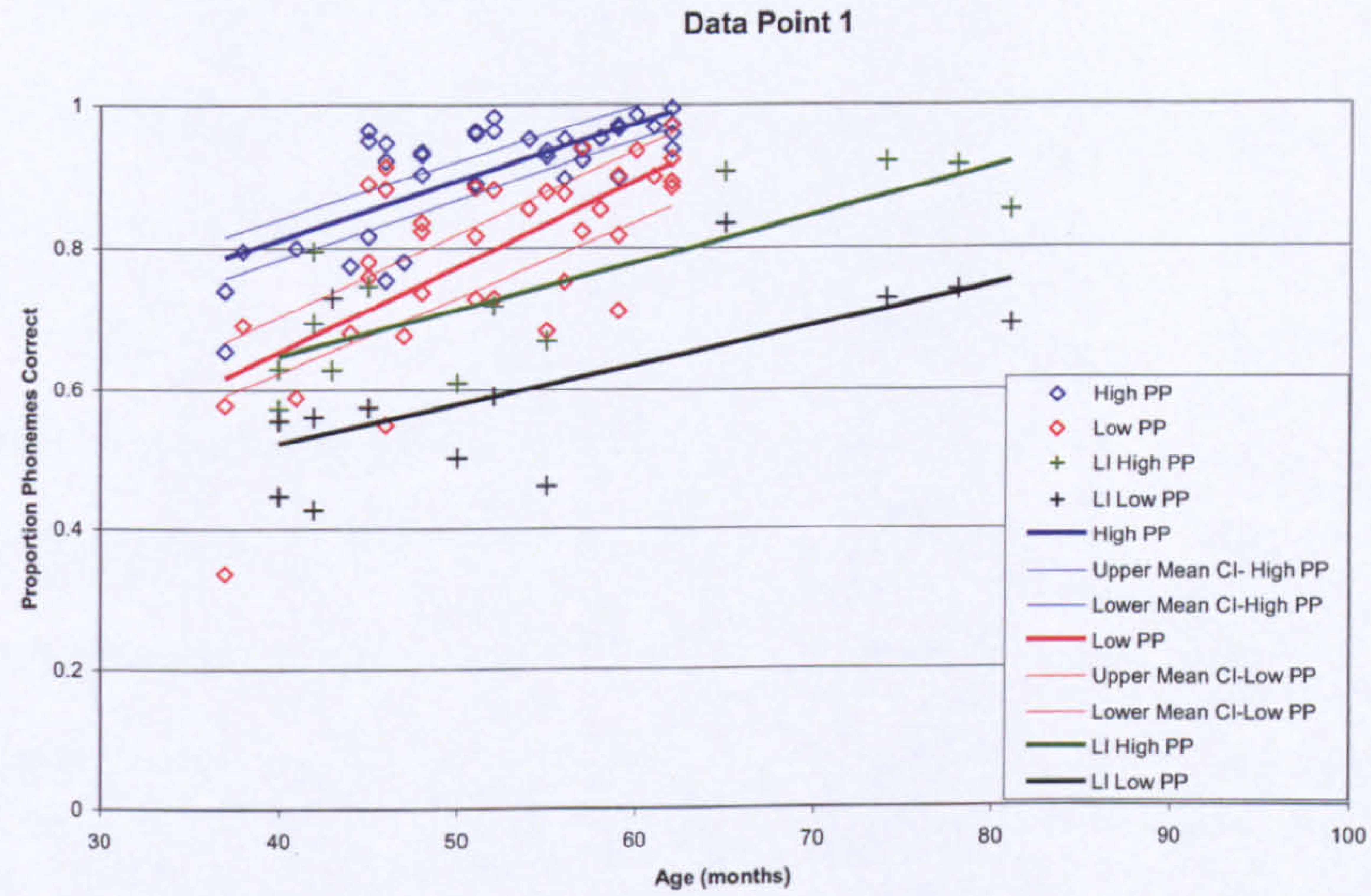


Figure 3.14. TD and LI group Data Point 1: Relationship between high and low PP non-word scores with respect to age

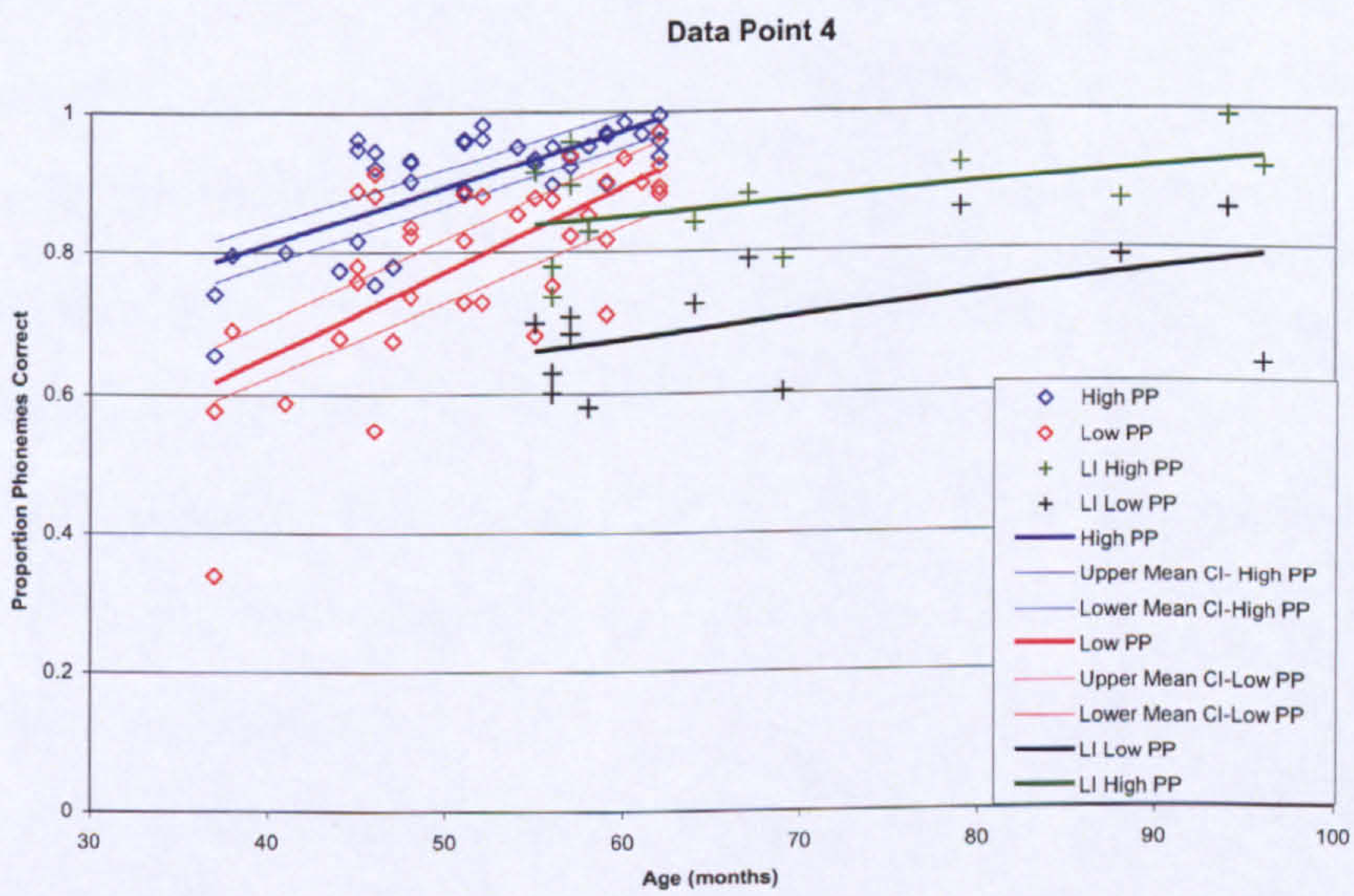


Figure 3.15. TD and LI group Data Point 4: Relationship between high and low PP non-word scores with respect to age

The LI group differed from the TD group however in two respects. Firstly the children were no longer reliably improving with age at Data Point 4 [$F(1, 11) = 40.43$, $p = .06$, $\eta^2 = .29$]. This result suggests that there may be an 'artificial ceiling' in the ability of LI children to improve in non-word repetition or a pause in progress at this particular point in development. This plateau in development will be explored further when considering the qualitative differences between the trajectories of the groups.

Secondly the gap between high PP and low PP non-word repetition scores did not narrow across development in the LI group as occurred in the TD group [PP x Age: Data Point 1: $F(1, 11) = .22$, $p = .65$, $\eta^2 = .02$; Data Point 4: $F(1, 11) = .42$, $p = .53$, $\eta^2 = .04$]. This closing gap in the TD trajectories can be seen as representing lexical restructuring and the emerging specification and availability of sub-lexical level representations. As this narrowing is not occurring in the LI group it suggests that lexical and sub-lexical representations may not be developing in the same way as in the TD group. However, sub-lexical representations emerge from lexical level representations and so this slower specification of sub-lexical processing could simply reflect the fact that the LI group have smaller lexicons. In order to determine whether the slower specification identified here arises *purely* as a result of having smaller lexicons or whether an additional impairment, perhaps in the process of abstracting sub-lexical level representations, exists further planned comparisons with respect to vocabulary knowledge will be presented.

In order to test whether this difference between the groups in the nature of the relationship between high and low PP across development was statistically significant, mixed ANCOVAs were completed. The within subjects factor was PP, the between subjects factor was Group and the covariate was Age. If the observed difference between the groups regarding the presence or absence of narrowing in the gap between high and low PP scores over development, is statistically significant then the 3 way interaction PP x age x group should reflect this. This interaction approached significance at Data Point 1 [$F(1, 46) = 3.68$, $p = .06$, $\eta^2 = .07$] and was significant at Data Point 4 [$F(1, 46) = 1.76$, $p = .04$, $\eta^2 = .19$].

In order to consider whether the groups differed in their abilities to repeat high and low PP non-words over development, one-way between group ANCOVAs comparing LI and TD group scores for high and low PP non-word repetition at Data Points 1 and 4 with age as a covariate were completed.

The results indicated that the LI group were poorer than the TD group for high PP non-words with respect to age [Data Point 1: $F(1, 46) = 28.19$, $p < .01$, $\eta^2 = .38$; Data Point 4: $F(3, 46) = 13.93$, $p < .01$, $\eta^2 = .23$] and for low [Data Point 1: $F(1, 46) = 6.81$, $p = .01$, $\eta^2 = .13$; Data Point 4: $F(3, 46) = 17.80$, $p < .01$, $\eta^2 = .28$].

The rate of improvement over development also differed between the groups such that the slower progress of the LI group was reflected in the significant group x age interactions for both high and low PP non-words at Data Point 4 [High PP: $F(1, 46) = 11.23$, $p < .01$, $\eta^2 = .20$; Low PP: $F(1, 46) = 9.81$, $p < .01$, $\eta^2 = .18$].

At Data Point 1, however the LI group were developing more slowly in their ability to repeat low PP non-words [$F(1, 46) = 4.65$, $p = .04$, $\eta^2 = .09$] but the group x age interaction was not significant for high PP non-words[$F(1, 46) = .70$, $p = .41$, $\eta^2 = .02$]. This difference between Data Points 1 and 4 will be explored further when considering the qualitative differences between the trajectories of the groups.

In summary therefore the LI group were significantly poorer than the TD group with respect to age in their abilities to repeat both high and low PP non-words. They were also developing more slowly in this ability, and the narrowing of the gap between high and low PP non-words with development found in TD children was not present in this group of children with LI.

In order to determine whether these differences simply reflect the fact that the LI group have more limited lexical knowledge the above comparison were repeated with respect to expressive vocabulary scores.

3.3.1.3 With respect to vocabulary knowledge, do the children with LI differ from the TD children in their non-word repetition ability?

Two 2*4*2 mixed ANCOVAS were completed, for data sets 1 (vocabulary score range 17 - 59) and 4 (vocabulary score range 27 - 69) (TD vocabulary score range 27- 67). The within subjects factors were PP, with two levels, high and low, and length with 4 levels, 1, 2, 3 and 4 syllables. The between subjects factor was group and the covariate was expressive vocabulary raw score. The complete set of results from this analysis is presented in Appendix 6.

When non-word repetition scores were compared with respect to vocabulary knowledge the differences between the groups were no longer significant [Main effect of group: Data Point 1: $F(1, 43) = .018$, $p < .893$, partial $\eta^2 = .00$; Data Point 4 $F(1, 46) = 1.026$, $p = .32$, partial $\eta^2 = .02$]. Hence it would appear that the difference between the groups in overall non-word repetition accuracy reflects the more limited lexical knowledge of the children with LI.

There was a significant main effect of length [Data Point 1: $F(3, 129) = 24.66$, $p < .01$, partial $\eta^2 = .37$; Data Point 4 $F(3, 138) = 38.78$, $p < .01$, partial $\eta^2 = .48$]. However the length x group interaction was not significant [Data Point 1: $F(3, 129) = .733$, $p = .53$, partial $\eta^2 = .02$; Data Point 4: $F(3, 138) = .334$, $p = .80$, partial $\eta^2 = .01$]. That is, once vocabulary knowledge is taken into account, the increased sensitivity to the length of the non-words found in the LI group with respect to age is no longer present. This finding therefore supports the contention that the more marked length effect found in children with LI could be explained without recourse to a limitation in the phonological loop. Rather, the length effect can be explained by the limited support of long term knowledge during encoding, compounded by a subsequent deficit in storage through increased decay and interference of these poorly encoded representations (Bowey, 2006). Storage in the model presented here being conceptualised as a set of activated representations within a connectionist network rather than a copy of those representations within a phonological loop.

The Group x Vocabulary interaction was significant at Data Point 4 [$F(1, 46) = 5.38$, $p = .03$, partial $\eta^2 = .11$] suggesting that the children with LI were not improving in their overall non-word repetition scores as their vocabulary knowledge increased whereas the TD children were.

The PP x Group interactions were not significant at either Data Point 1 or 4 [Data Point 1: $F(1, 43) = .122$, $p = .73$, partial $\eta^2 = .003$; Data Point 4: $F(1, 46) = .05$, $p = .82$, partial $\eta^2 = .001$] demonstrating that with respect to vocabulary knowledge the children with LI were not disproportionately affected by the PP of the non-words.

The PP x Group x Length x Vocabulary effect at Data Point 4 was significant and subsequent ANCOVA analyses demonstrated a significant Group x PP x Vocabulary interaction for two syllable non-words only (see Figure 3.16). Such a result may indicate that the children's processing is influenced by the prosody of the non-words and that this factor interacts with PP differently between the groups.

As can be seen from Figure 3.16 the children with LI are not poorer than the TD children at repeating two syllable non-words when compared with respect to vocabulary knowledge, but demonstrate a widening gap between the high and low PP trajectories with vocabulary growth rather than the narrowing found in the TD children.

It is suggested that perhaps there is something about the prosodic structure of the 2 syllable words which prompt the children with LI to use a very immature phonetically based processing bias when their vocabulary knowledge is small, and that this type of processing does not favour wither high or low PP (described previously as 'Stage 2' of lexical development). At this stage the processing architecture consists of a phonetic level, a lexical level containing only holistic representations, no sub-lexical level of processing, and motor output processes comprised of vocal motor schemes which have emerged from babbling. It is possible therefore that it may demonstrate very little difference between high and low PP non-word repetition. That is, at the lexical level the holistic lexical representations will not provide top-down support for either high or low PP non-words, and, the absence of a sub-lexical level of processing for either high or low PP non-words means that neither will experience a processing advantage. As vocabulary knowledge grows it appears that a high PP advantage emerges, perhaps indicating that for 2 syllable words, the development of sub-lexical representations emerges later than for other prosodic structures in children with LI.

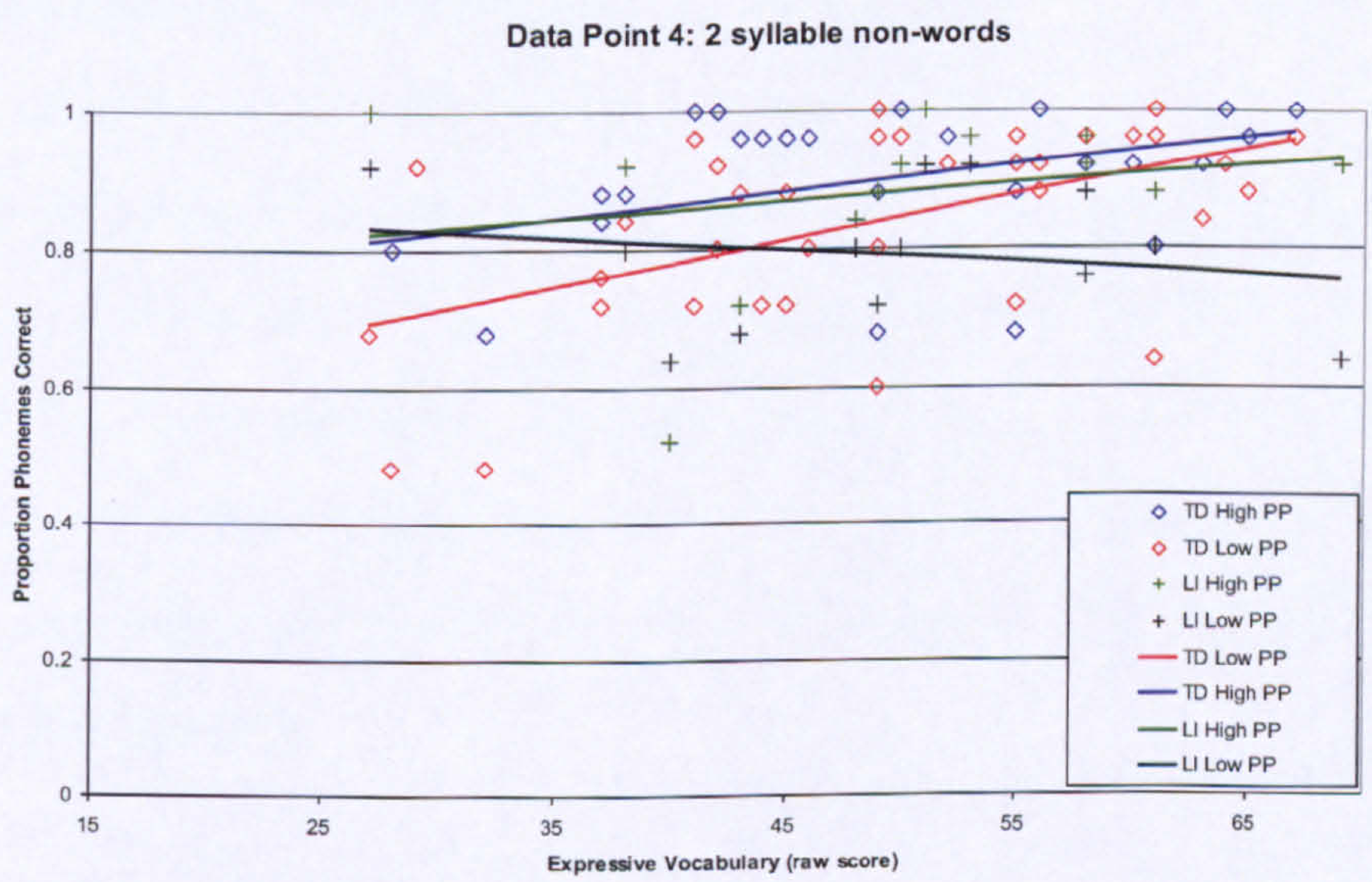


Figure 3.16. Group x PP x Vocabulary Interaction for 2 syllable words Data Point 4

3.3.1.4 With respect to vocabulary, do the children with LI differ from the TD children in terms of their rate of progress for high and low PP non-words and in the nature of the relationship between high and low PP repetition over vocabulary development.?

In order to consider the nature of the relationship between high and low PP scores for each group with respect to vocabulary knowledge, one-way repeated measures ANCOVAs comparing high and low PP non-word repetition with respect to vocabulary, were completed for the TD group and the LI group at Data Points 1 and 4.

Results for the TD group reflected those found with respect to age. The TD children were significantly affected by PP such that low PP non-words were less accurately repeated than high PP non-words [$F(1, 35) = 45.17$, $p < .01$, partial $\eta^2 = .56$]. The children improved as vocabulary knowledge increased [$F(1, 35) = 25.74$, $p < .01$, partial $\eta^2 = .19$] and the gap between high PP and low PP narrowed as vocabulary knowledge grew such that low PP scores improved more rapidly than high PP scores [$F(1, 35) = 8.41$, $p = .01$, partial $\eta^2 = .19$]. Once again, it is possible that the interaction between PP and vocabulary may simply be a function of ceiling effects for the high PP non-words rather than reflecting a truly significant interaction. As for the analysis with respect to age for ceiling effects the high and low PP scores for 3 and 4 syllable non-words only were compared using a 2 way within subject ANCOVA with vocabulary as the covariate. Once again, as for age, the interaction between PP and vocabulary for 3 and 4 syllable words was significant, [$F(1, 35) = 8.10$, $p < .01$ partial $\eta^2 = .19$] (Figure 3.17).

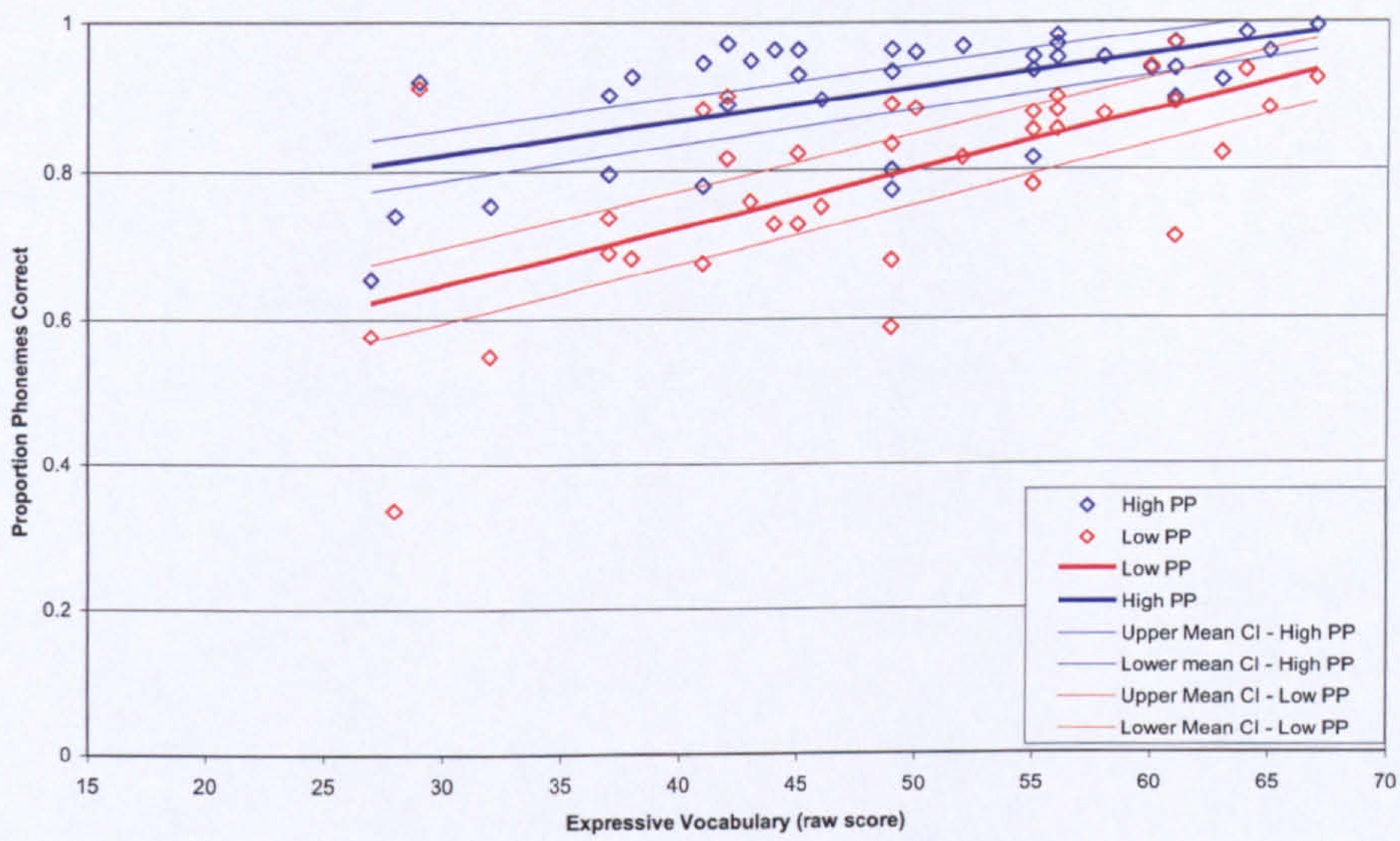


Figure 3.17. TD children: Relationship between high and low PP non-word scores with respect to vocabulary

Results of the one-way repeated measures ANCOVA for the LI group comparing high and low PP non-word repetition with respect to vocabulary demonstrated that the main effect of vocabulary was not significant such that the LI group's repetition scores did not improve as would be predicted by their vocabulary knowledge [Data Point 1: $F(1, 11) = .26$, $p = .62$, $\eta^2 = .02$; Data Point 4: $F(1, 11) = .06$, $p = .87$, $\eta^2 = .01$] (Figures 3.18, 3.19).

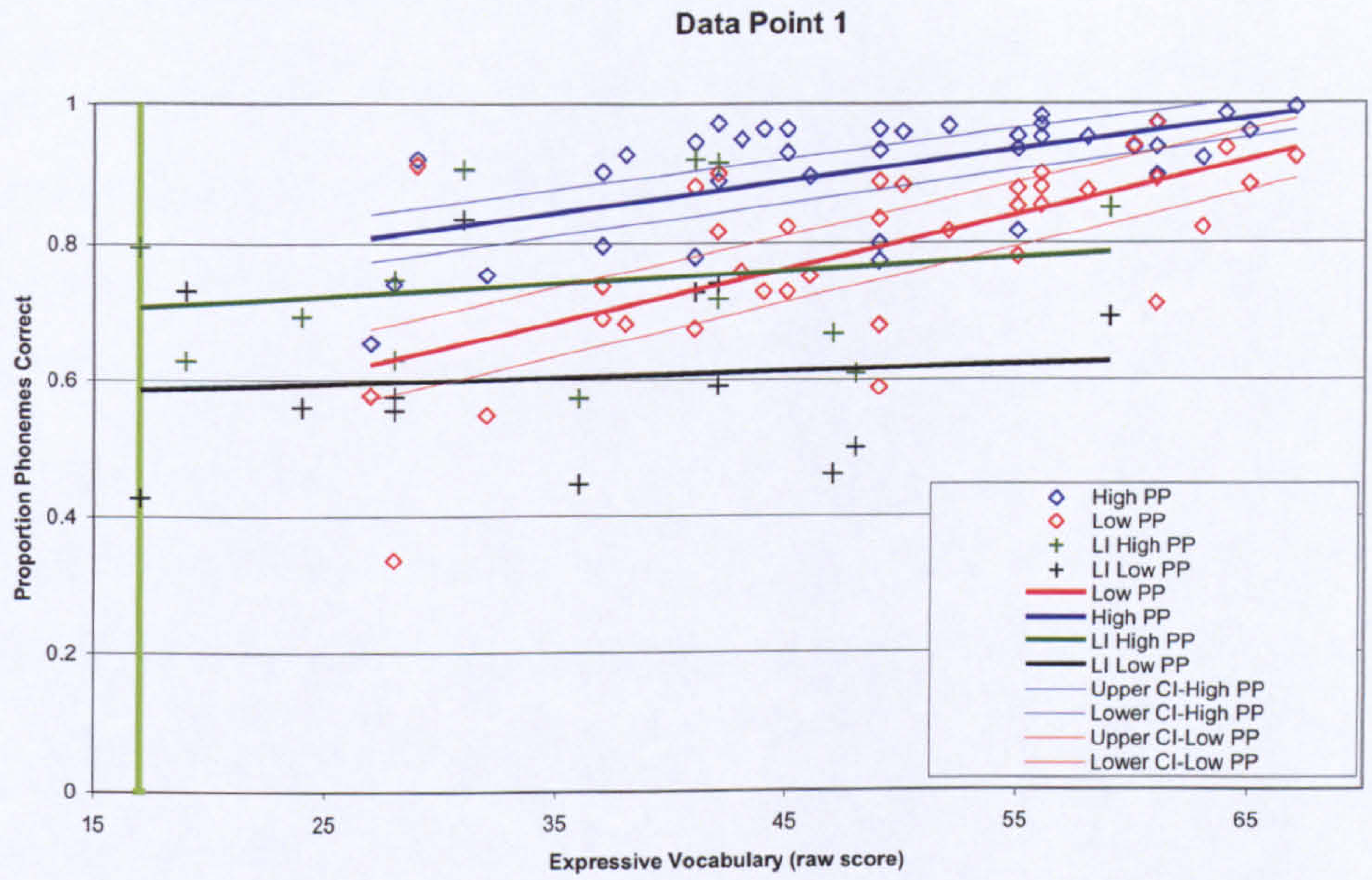


Figure 3.18. TD and LI group Data Point 1: Relationship between high and low PP non-word scores with respect to vocabulary

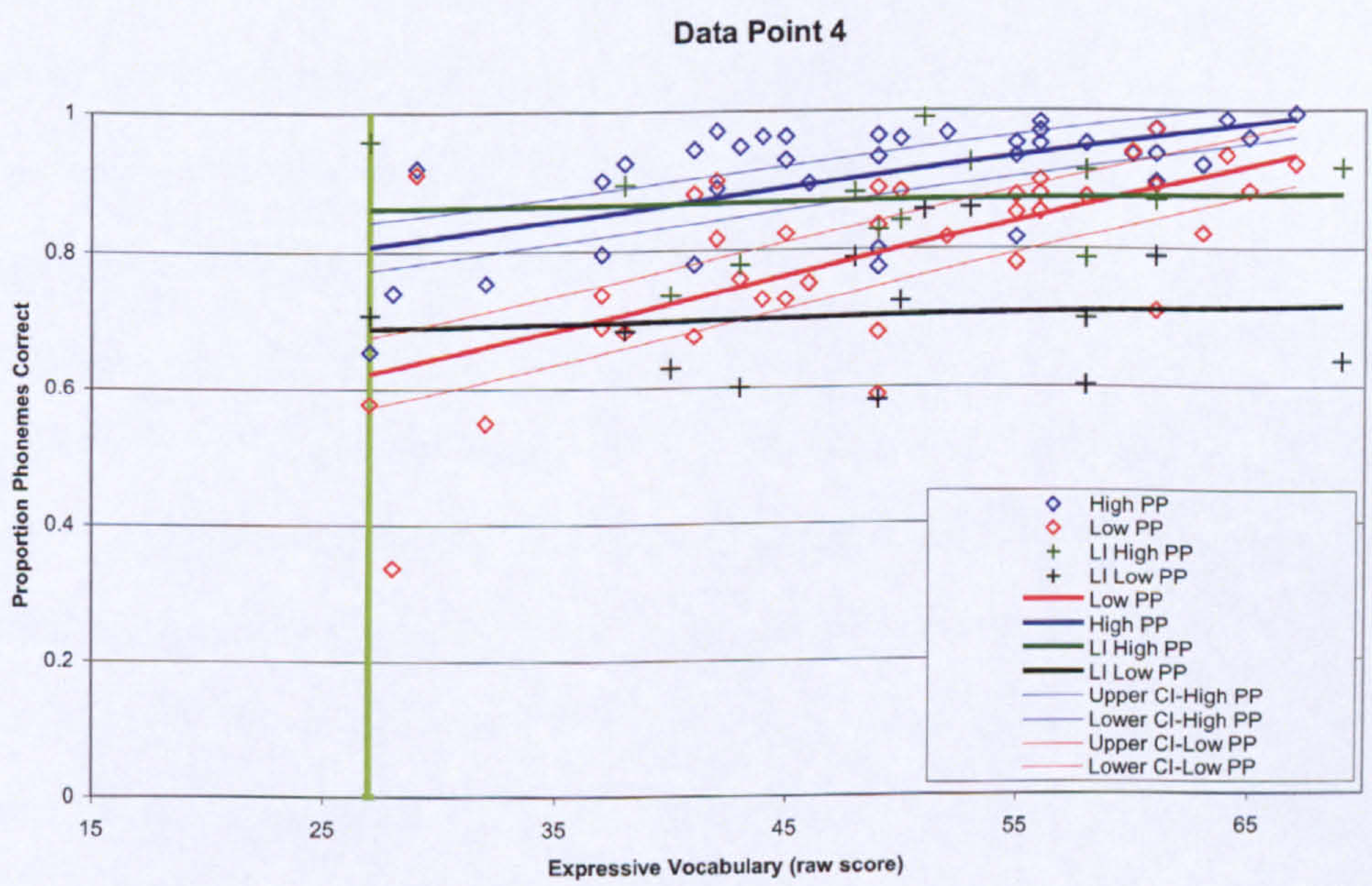


Figure 3.19. TD and LI group Data Point 4: Relationship between high and low PP non-word scores with respect to vocabulary

The main effect of PP was not significant at Data Point 1 such that the repetition scores for high and low PP non-words were not significantly different, although the result did approach significance [$F(1, 11) = 4.81$, $p = .051$, $\eta^2 = .30$]. This result will be explored further when considering the qualitative differences between the trajectories of the groups. At Data Point 4 however the children with LI were significantly poorer at repeating low PP non-words [$F(1, 11) = 12.55$, $p = .01$, $\eta^2 = .53$].

The narrowing of the gap between high PP and low PP non-word repetition scores as vocabulary knowledge increases evident in the TD trajectories, was not evident in the LI group [PP x Vocabulary: Data Point 1 $F(1, 11) = .13$ $p = .73$, $\eta^2 = .01$; Data Point 4: $F(1, 11) = .06$, $p = .81$, $\eta^2 = .01$].

As described with reference to comparisons with respect to age, this finding suggests that the lexical and sub-lexical representations of the LI group are not developing in the same way as in the TD group. In addition, as this difference persists even when the vocabulary knowledge of the two groups is taken into account, it would appear that this slower specification of lexical and sub-lexical representations does not arise purely as a result of the smaller vocabularies of the LI group, but that an additional impairment, perhaps in the process of abstracting sub-lexical level representations, exists.

In order to test whether this difference between the groups in the nature of the relationship between high and low PP across vocabulary development was statistically significant, mixed ANCOVAs were completed. The within subjects factor was PP, the between subjects factor was Group and the covariate was Vocabulary. If the observed difference between the groups regarding the presence or absence of narrowing in the gap between high and low PP scores as vocabulary knowledge increases is statistically significant, then the 3 way interaction PP x vocabulary x group should reflect this. This interaction was significant at Data Point 1 [$F(1, 46) = 3.41$ $p = .04$, $\eta^2 = .13$] but was not significant at Data Point 4 [$F(1, 46) = 1.72$, $p = .20$, η^2

=.04]. This result may relate to the nature of the relationship between scores and vocabulary knowledge for this data set and will be discussed further with reference to characterising the nature of the developmental trajectories.

In order to consider whether the groups differed in their abilities to repeat high and low PP non-words as their vocabulary knowledge increases, one-way between group ANCOVAs comparing LI and TD group scores for high and low PP non-word repetition at Data Points 1 and 4 with vocabulary as a covariate were completed.

The results indicate that, once vocabulary knowledge is taken into account, the LI group were not significantly different from the TD group for either high PP non-words [Data Point 1: $F(1, 46) = .79$, $p = .38$, $\eta^2 = .02$; Data Point 4: $F(1, 46) = 1.07$, $p = .31$, $\eta^2 = .02$] or for low [Data Point 1: $F(1, 46) = .26$, $p = .62$, $\eta^2 = .01$; Data Point 4: $F(1, 46) = .75$, $p = .39$, $\eta^2 = .02$].

The rate of improvement however did differ between the groups for low PP non-words. That is, the LI group were significantly slower in their development for repeating low PP non-words than is predicted by their vocabulary development [Group x Vocabulary: Data point 1: $F(1, 46) = 4.76$, $p = .03$, $\eta^2 = .09$; Data Point 4: $F(1, 46) = 5.17$, $p = .03$, $\eta^2 = .10$].

The rate of improvement for high PP non-words was not significantly different between the groups [Group x Vocabulary: Data point 1: $F(1, 46) = 1.21$, $p = .28$, $\eta^2 = .03$; Data Point 4: $F(1, 46) = 3.76$, $p = .06$, $\eta^2 = .08$].

In summary therefore the LI group were not significantly different in overall repetition accuracy from the TD group when vocabulary knowledge was taken into account. However their ability to repeat low PP non-words was developing more slowly than predicted by their vocabulary knowledge and the pattern of a narrowing gap between high and low PP non-words as vocabulary knowledge found in TD children, was not present in this group of children with LI.

Once again these results support the suggestion that the lexical and sub-lexical representations of the LI group are not developing in the same way as in the TD group and that these differences cannot be fully explained by the smaller vocabularies of the LI group.

3.3.1.5 Can longitudinal cross-sectional trajectories of development be described with respect to age and vocabulary knowledge and are there qualitative differences between the groups.

From the above ANCOVA analyses it is obvious that there are differences in the nature of the developmental trajectories with respect to age and vocabulary knowledge. In order to explore these trajectories further the OLS linear regression coefficients were considered and compared with respect to age and with respect to vocabulary.

Linear regressions were used to characterise the trajectories and make comparisons as this was seen to be the most valid approach for the given data. That is, cross-sectional data may create a number of possible shapes of growth trajectory, some linear, some curvilinear, however, crucially, it is not valid to infer the shape of individual change from the shape of the average change. That is, the shape of the means (the cross-sectional growth trajectory) is not necessarily the same as the mean of the shapes (the mean shape of change across individuals) (Singer & Willett, 2003). Hence in order not to make claims which cannot be supported by the data or method of analysis, descriptions and comparisons have been limited to those characteristics which can be legitimately inferred from the data, that of onset, allowing for consideration of the presence or absence of delay, and rate. Hence OLS regressions were chosen as providing us with the means for analysis which is most appropriate for the data.

Where OLS regressions did not provide a reliable fit to the data the reasons for this were explored in a number of ways. Firstly the presence and influence of any outliers was assessed, secondly the possibility of non-linear models providing a better fit to the data were considered and thirdly the nature of the null-trajectory was explored using a rotation method (Thomas et al., 2009).

To make meaningful comparisons between the OLS linear regression coefficients for the two groups it was necessary to re-scale the age and vocabulary variables for both the LI and the TD groups. This was in order to make fair comparisons regarding the presence or absence of delay. The results were considered with respect to three key considerations.

1. Whether the regressions could be seen as a reliable fit to the data, and, where this was not the case, to explore the possible causes of this result.

2. To determine the presence or absence of delay by considering whether or not the confidence intervals for the intercept values overlapped in the two groups; an overlap indicating no significant differences in onset and the absence of overlap, indicating the presence of delay.

3. Whether there is evidence of meaningful age-related change as indicated by whether the gradient confidence intervals were above zero.

3.3.1.5.1 Characterising the trajectory with respect to age

Results from the ANCOVA analyses above demonstrated a number of differences between the developmental trajectories of the TD and LI groups. The following will summarise those differences for Data Points 1 and 4 and go on to identify the additional information which the OLS regression analyses provides.

3.3.1.5.1.1. The TD Trajectory

The TD group trajectories demonstrated a significant difference between high and low PP scores such that high PP non-words were produced more accurately then low. The TD children improved in their repetition abilities with development and the gap between high and low PP scores narrowed as the children's ability to repeat low PP non-words 'caught-up' with that of high PP non-words (Figure 3.13).

The LI group differed from the TD group at both Data Point 1 (age range 40 – 81 months) and 4 (age range 55 – 96 months).

3.3.1.5.1.2. The LI Trajectory: Data Point 1

At Data Point 1 (LI age range 40-81 months), similar to the TD group, the LI group demonstrated a significant difference between high and low PP scores such that high PP non-words were produced more accurately than low and score for both high and low PP were improving with age. The high PP non-word repetition scores were developing at a similar rate to the TD children but the low PP non-words were developing more slowly and the narrowing gap between high and low PP scores apparent in the TD group was not evident in the LI group (Figure 3.14).

Additional information regarding the nature of the trajectories was obtained through the consideration of the OLS regressions for high and low PP with respect to age for the two groups as described above.

The regressions were a reliable fit to the data (Table 3.4). The LI group were delayed at the onset of the trajectory in their PP non-word repetition ability, as the intercept for this trajectory falls below the lower bound of the TD intercept for high PP. Hence the youngest children in the LI group demonstrated a delay in their high PP non-word repetition skills. For low PP non-word repetition skills however the LI group intercept fell within the bounds of the confidence interval for the TD group intercept. Hence the youngest children in the LI group were not delayed in their low PP non-word repetition skills. In addition, in the LI group, the confidence intervals for high and low PP scores at intercept overlapped, suggesting no real difference in repetition abilities between high and low PP non-words for the very youngest children with LI.

PP	Group		B	Confidence Intervals Lower Bound	Confidence Intervals Upper Bound	R^2	*p*
High	TD	intercept	.811	.755	.846	.540**	<.01
		gradient	.008	.006	.011		
	LI	intercept	.647	.581	.713	.651**	<.01
		gradient	.007	.003	.010		
Low	TD	intercept	.652	.590	.714	.455**	<.01
		gradient	.012	.007	.017		
	LI	intercept	.522	.434	.611	.428**	.02
		gradient	.006	.001	.010		

*p < .05. **p < .01.

Table 3.4. Regression coefficients and confidence intervals (scores x age). Data centred on LI youngest age Data Point 1.

Additional information gained from the Regression Analysis is that the scores of both the TD children and the children with LI at Data Point 1 are meaningfully related to age and that the youngest children with LI may not be affected by PP in the same way as the youngest TD children.

That is, at the outset of the trajectory, for the youngest children in the LI group it appears that there is no significant difference between high and low PP non-word repetition scores. This result should be interpreted with caution due to the low number of children in this age group (3 years; N = 6) and the likely variability in performance in children of this age. This is consistent with their being at stage 2 of the model of the developing lexicon previously described. At this stage the processing architecture consists of a phonetic level, a lexical level containing only holistic representations, no sub-lexical level of processing, and motor output processes comprised of vocal motor schemes which have emerged from babbling. This model predicts that a child at this level will demonstrate very little difference between high and low PP non-word repetition. That is, at the lexical level the holistic lexical representations will not provide top-down support for either high or low PP non-words, and, the absence of a sub-lexical level of processing for either high or low PP non-words means that neither will experience a processing advantage. It is therefore possible that the youngest children with LI were processing the non-words using this very immature system.

Why then were the high PP non-words for this, the youngest group of children with LI (at the outset of Data Point 1) delayed in comparison to the TD group but the low PP non-words were not? This can be explained if the assumption is made that the TD children at the outset of this Data Point have just moved to using sub-lexical rather than phonetic processing (i.e. are at Stage 3.1 of lexical development rather than Stage 2). If this is the case the TD children would be processing low PP non-words with the processing architecture which most disadvantages their production whereas the children with LI would be using inefficient phonetic processing which would depress both their high and low PP scores equally. This therefore would result in little difference between the scores of the groups for low PP non-words as both groups would be processing these non-words in a similar way. For high PP non-words however the TD group would be beginning to have sub-lexical level representations available to support high PP non-word repetition whereas the LI group would still be using inefficient phonetic processing, resulting in significantly poorer repetition scores than the TD group.

3.3.1.5.1.3. The LI Trajectory: Data Point 4

At Data Point 4 (LI age range 55-96 months) the LI group were developing more slowly than the TD group for both high and low PP, there was no narrowing in the gap between high and low PP over development and the children were not reliably improving with age (Figure 3.15).

The additional information regarding the nature of the trajectories obtained from the OLS trajectories was as follows. Both the regression for low PP score x age and for high PP x age in the LI group were not a reliable fit to the data. Cook's D values suggested that one Data Point may have been an outlier in the LI low PP regression. Excluding this outlier did produce a reliable regression ($R^2 = .562$, $p < .01$) however there were no a-priori reasons to exclude this Data Point. The possibility of a non-linear model providing a better fit to the data was explored but no curvilinear models were significant. Inspection of the graphs (Figure 3.15) and the regression coefficient would suggest that the LI children were no longer reliably improving in their repetition skills with age. That is the bounds of the confidence intervals for the gradients of the OLS trajectories span zero such that there is no reliable improvement in score with age.

To test this assumption statistically, the rotation method was applied to the regressions to attempt to discriminate between a 'zero trajectory' reflecting a plateau in skill development, and a trajectory reflecting no significant relationship. The differences to the R^2 after rotation were trivial [High PP: Original data; $R^2 = .221$, $F(1,11) = 3.113$ $p = .105$; Rotated data; $R^2 = .038$, $F(1,11) = .43$, $p = .524$][Low PP: Original data; $R^2 = .257$, $F(1,11) = 3.806$ $p = .077$;

Rotated data; R^2 =.302, $F(1,11) = 4.770$, p = .052] Hence this model suggests that for this data set the LI children's scores for high and low PP non-words do not have a systematic relationship with age.

Additional information gained from the Regression Analysis is that there is no systematic relationship between age and non-word repetition scores in this trajectory for older children (LI age range 55-96 months). Hence the children with LI are not improving as would be predicted by their age.

3.3.1.5.1.4. The LI Trajectory

Consideration of both LI trajectories suggests that over the age range 40 to 96 months the children have two distinct trajectories, one for high and one for low PP non-words. For high PP non-words the LI group are delayed in their repetition score at 3 years old but their rate of progress is equivalent to the TD children up to approximately 4;06- 5;00 years of age. From this age however the non-word repetition ability of the children with LI appears no longer to have a systematic relationship with age. Hence the children do not continue to improve to ceiling as would be expected and so a plateau or pause in their development appears to occur. For low PP non-words the LI group are not delayed in their repetition score at 3 years (at the onset of Data Point 1) and are equally good at high and low PP non-word repetition at this age. Their rate of progress for low PP non-words however is slower than the TD group and an advantage for high PP non-words does emerge over the whole trajectory. This is suggestive that for low PP non-words the pattern of development is best described as an almost flat and extremely slow trajectory. This extremely slow progress is meaningfully related to age up to approximately 4;06- 5;00 years of age. From this age once again the non-word repetition performance of the LI group has no systematic relationship with age. Hence, in children with LI it would appear that the development of segmented lexical and sub-lexical representations for low PP sound combinations is extremely slow and again plateaus or pauses in development between the ages of 4;06 and 8 years.

				Confidence Intervals			
PP	Group		B	Lower Bound	Upper Bound	R^2	*p*
High	TD	intercept	.933	.912	.954	.540**	<.01
		gradient	.008	.006	.011		
	LI	intercept	.839	.781	.896	.221	.105
		gradient	.002	-.001	.005		
Low	TD	intercept	.832	.796	.868	.455**	<.01
		gradient	.012	.007	.017		
	LI	intercept	.661	.588	.733	.257	.077
		gradient	.003	.000	.007		

*p < .05. **p < .01.

Table 3.5. Regression coefficients and confidence intervals (scores x age). Data centred on LI youngest age Data Point 4.

3.3.1.5.2 Characterising the trajectory with respect to vocabulary

3.3.1.5.2.1 TD Trajectory

The TD group trajectories (vocabulary score range 27- 67) demonstrated a significant difference between high and low PP scores such that high PP non-words were produced more accurately then low. The TD children improved in their repetition abilities with increasing vocabulary knowledge and the gap between high and low PP scores narrowed as the children's ability to repeat low PP non-words 'caught-up' with that of high PP non-words (Figure 3.17).

OLS trajectories for the TD group produced a reliable fit to the data demonstrating meaningful improvement as vocabulary knowledge increased [High PP: $R^2 = .351$, $F(1,36) = 18.928$, $p < .01$; Low PP: $R^2 = .409$, $F(1,36) = 24.193$, $p < .01$].

3.3.1.5.2.2 LI Trajectory

The LI group differed from the TD group at both Data Point 1 (vocabulary score range 17 - 59) and 4 (vocabulary score range 27 - 69) in terms of the absence of a narrowing in the gap between high and low PP non-words as vocabulary knowledge increases suggesting that the sub-lexical representations of the LI group are not developing in the same way as in the TD group.

The rate of improvement in non-word repetition differed between the groups for low PP non-words but not for high PP non-words. Hence the development of sub-lexical representations for low PP non-words seems particularly problematic for the LI group.

At Data Point 1, once the influence of vocabulary knowledge was considered, the LI group did not differ significantly in their overall ability to repeat high and low PP non-words although low PP non-words were developing more slowly than high PP words. This may reflect the lack of a high PP advantage in the very youngest LI group members due to the very immature processing architecture described previously.

The OLS trajectories for the LI group with respect to vocabulary did not produce a reliable fit to the data [High PP; Data Point 1: $R^2 = .035$, $F(1,11) = .399$, $p = .54$; Data Point 4: $R^2 = .003$, $F(1,11) = .034$ $p = .86$] [Low PP; Data Point 1: $R^2 = .009$, $F(1,11) = .095$, $p = .76$; Data Point 4: $R^2 = .007$, $F(1,11) = .072$, $p = .79$].

At Data Point 1 Cook's D values ruled out the influence of any outliers as being the cause of this result. At Data Point 4 Cook's D values suggested that one Data Point may be an outlier in the LI low PP regression. Excluding this outlier did produce a reliable regression ($R^2 = .371$, $p = .036$) however there were no a-priori reasons to exclude this Data Point. The possibility of non-linear models providing a better fit to the data was explored but no curvilinear models were significant.

In order to attempt to discriminate between a 'zero trajectory' reflecting a plateau in skill development, and a trajectory reflecting no significant relationship between vocabulary development and non-word repetition skill development, the rotation method was applied to the regressions. The results suggested that for the LI group there is no systematic relationship between non-word repetition scores and vocabulary knowledge for this data set either for high PP non-words [Data Point 1: $R^2 = .028$, $F(1,11) = .319$, $p = .583$; Data Point 4: $R^2 = .034$ $F(1,11) = .384$, $p = .548$] or for low [Data Point 1: $R^2 = .035$, $F(1,11) = .394$, $p = .543$; Data Point 4: $R^2 = .253$, $F(1,11) = 3.728$, $p = .08$].

These results may shed light on the finding that the 3 way interaction (PP x vocabulary x group) was significant at Data Point 1 but was not significant at Data Point 4. That is, the absence of a systematic relationship between non-word repetition scores and vocabulary knowledge in the LI group makes the interpretation of this interaction difficult.

Taken together, the results suggest that the lexical and sub-lexical representations of the LI group are not developing in the same way as in the TD group. As this difference persists even when the vocabulary knowledge of the two groups is taken into account, it would appear that this slower specification of lexical and sub-lexical representations does not arise purely as a result of the smaller vocabularies of the LI group, but that an additional impairment, perhaps in the process of abstracting sub-lexical level representations, exists. In addition the rate of improvement in non-word repetition differed between the groups for low PP non-words but not for high PP non-words. Hence the development of lexical and sub-lexical representations for low PP non-words seems particularly problematic for the LI group.

In summary therefore the development of non-word repetition skills in the LI group is not related to vocabulary development in the same way as for TD children. Children with LI are slower to develop their skills in repeating low PP non-words than would be predicted by their vocabulary knowledge and their overall non-word repetition ability appears to reach an artificial ceiling or pause in development such that they do not reach the level of facility demonstrated by the TD group or predicted by their vocabulary knowledge. For TD children sub-lexical level processing and vocabulary develop interactively and influence each other productively. In LI children this does not appear to happen and their sub-lexical representations are not *directly* related to vocabulary knowledge. The source of these differences will be explored below.

3.3.2 Cross-sectional developmental trajectories: Discussion

The goal of this study was to explore whether new insights regarding the nature of the lexical impairment in LI could be found through the application of a longitudinal case-series methodology which considered the relationship between vocabulary growth and the emergence of sub-lexical/phonemic representations over time in typically developing children (TD) and those with or "at risk" of developing LI. The ultimate aim was to attempt to shed some light on the question; do children with LI have poorer access to sub-lexical/phonemic units *purely* as a result of having smaller lexicons or does an additional impairment, exist? The key findings to emerge from the analysis of the cross-sectional trajectories were as follows. Firstly, that the LI group were significantly poorer at non-word repetition than their age matched peers but that once the level of vocabulary knowledge of the two groups was accounted for, there were no significant group differences in overall non-word repetition performance. Through the application of a developmental perspective and methodology it was possible to identify group differences in the *nature of the trajectories of development* of non-word repetition skills. That is, in the relationship between the trajectories of development for high and low PP words, such that the children with LI did not demonstrate a closing gap between high and low PP scores; in the rate of change of low PP scores, such that the children with LI were improving more slowly than would be predicted by their level of vocabulary knowledge; in the overall shapes of the trajectories, such that the scores of the children with LI for both high and low PP non-words plateaued at a level below ceiling; and in the nature of the relationship between vocabulary growth and changes in non-word repetition abilities, such that for the TD children these abilities were closely related but for the children with LI this was not the case. What then do these results tell us about the nature of the developing lexicon in children with LI?

3.3.2.1 A deficit in schema abstraction

These results would appear to suggest that non-word repetition performance in children with LI is limited both by their existing level of vocabulary knowledge, which predicts *overall* processing capacity and hence *overall* non-word repetition ability, but also by a difficulty in abstracting sub-lexical/phonemic knowledge from their existing vocabulary knowledge, as indicated by the slowed development in their ability to repeat non-words with low PP and the absence of a narrowing gap between their high and low PP non-word repetition trajectories. Recall that the premise for this claim rests on the assumption that a reducing difference in accuracy over development between high and low PP non-words provides a measure of the emerging availability to processing of sub-lexical/phonemic representations which are separate from lexical representation. Phonemes, sub-lexical segments and phoneme sequences with high PP will become more specified in their sub-lexical level representations and available for production as single phonemes in a number of syllable positions at a younger age and/or smaller vocabulary size than those with low PP due to their increased frequency and neighbourhood density in the child's lexical level of representation. These better specified sub-lexical level representations provide a more efficient method of encoding and storing a novel non-word for repetition and hence provide a processing advantage over low PP non-words. As the child's lexicon and hence speech processing mechanism develops the advantage reduces as low PP sounds and sound sequences also become represented more fully at the sub-lexical level. This closing gap therefore can be seen to represent the greater specification of lexical level 'representations' and the increased availability of sub-lexical level representations. As the gap is not closing in the children with LI even relative to their level of vocabulary knowledge, then it is possible to infer that children with LI are not abstracting sub-lexical level representations as efficiently as their lexical knowledge would predict and hence may have an additional difficulty, over and above that predicted by their vocabulary knowledge, in the process of abstracting sub-lexical/phonemic schemas from that knowledge.

3.3.2.2 A deficit in PWM or general processing capacity

These results challenge the PWM and capacity limitation accounts of LI in that the overall repetition scores can be explained by the children's level of vocabulary knowledge and that the groups are differentially affected by the PP of the non-words. Hence limited lexical knowledge limits processing capacity through reduced 'top down' support for processing but, in addition, these results suggest that the children with LI may also have a speech processing mechanism which is either comprised of degraded linguistic representations or which is structured atypically and hence functions inefficiently. Furthermore, as the group differences lie in the dynamic nature of *change* in processing abilities, it would seem that group differences may lie in the mechanics of neuroconstructivism. That is, if, as described in Chapter 1, learning in a developmental context can be conceptualised as an iterative cycle of uptake –abstraction – re-organisation, then it would seem that the children with LI may have difficulties in at least two of these processes with respect to the developing lexicon; with uptake, as their limited lexical knowledge limits their processing capacity; and with abstraction as they are less able to abstract sub-lexical/phonological knowledge from lexical knowledge than their peers. It is also possible that an impairment may exist in the final stage of the cycle (re-organisation) and certainly the presence of an impairment in the first two stages would, probably imply at least a delay in this stage of the neuroconstuctivist cycle. Gathercole (2006) claims that the increased sensitivity of children with LI to length effects provides evidence of impaired phonological working memory. This claim is challenged on two counts. Firstly the increased sensitivity to length effects of the LI group is not apparent once comparisons are made with respect to vocabulary size, adding support to the claim that length effects can be explained by the nature of long term knowledge and without recourse to a separate phonological loop. Secondly the group differences in the effect of PP on bi-syllabic non-words suggest that it is not just length that matters but also the linguistic features of non-words, such as their prosody. Such findings again implicate the nature of the underlying processing mechanism in the group differences found. Indeed such findings may fit most comfortably with Gathercole's recent claim that "LI is associated with a deficit arising in phonological storage, which will have its greatest impact on lengthy items due to the process of decay"(2006, p. 530), and her recent move away from the terminology of "Phonological Loop" and "Phonological Working Memory" to a "Phonological Storage Hypothesis". However, Gathercole goes on to say "this function is much more challenging for a phonological sensitivity hypothesis, which does not provide a clear explanation of why a lengthy nonword should require greater phonological sensitivity than a shorter stimulus" (2006, p. 530). This sharp distinction between storage and sensitivity is a false dichotomy and one which is challenged by the model presented here. In place of the phonological sensitivity and phonological storage hypotheses for non-word repetition deficits in LI, I suggest that the nature of the speech processing mechanism *as a whole* must be considered, that the deficits found in LI are best conceptualised as resulting from an inefficient speech processing architecture and that the nature and functionality of this architecture change across development in response to changes in the child's existing lexical knowledge and the representations which they have been able to abstract from that knowledge. This explanation brings together the phonological sensitivity and phonological storage hypotheses by acknowledging that encoding of a novel word is affected by the nature of the existing lexicon (phonological sensitivity) and that this in turn affects phonological storage as less well encoded representations will be more prone to decay. In this way phonological sensitivity, through it's effects on encoding and thence storage, *can* explain the heightened length effects found in LI. However rather than making a claim for one explanation over the other the 'inefficient speech processing architecture explanation', argues that, in fact, the two processes are not separable. Furthermore

This 'inefficient speech processing architecture' explanation is based on the premise that it is the function of the system *as a whole* which creates the characteristic non-word repetition deficit in LI. Hence in addition to deficits in encoding and storage, the nature of the inefficient speech processing architecture may also increase the effects of interference during speech processing. Such a deficit has been identified in children with LI and problems with suppression posited as a possible cause (Mainela-Arnold et al., 2008; Seiger-Gardner & Brooks, 2008). Alternatively a lexicon in which sub-lexical/phonemic level representations are not fully specified could create conditions for increased interference. That is, if, as in a TRACE model, the speech processing mechanism has bi-directional excitatory connections between sub-lexical level representations and lexical nodes, in a speech processing system where *phonemic* representations are present, the number of candidate lexical nodes receiving spreading activation from the sub-lexical/phonemic level will reduce more quickly over the time course of hearing a word than in a system where less fine grained sub-lexical level representations are present. Hence, in a system with a less well developed sub-lexical level of representation more lexical nodes will be activated for longer periods and hence will act as potential competitors to the target word for longer periods than in a system with a fully specified phonemic level of representation. Just such an impairment may be in evidence in the current study. That is, it was evident that the children with LI often added complexity to the non-words when repeating them and that these additions often turned a syllable into a real word or created rimes which occur in highly frequent real words (e.g. 'hɪnɛs → 'hɪn**ɛst**; 'sɛbaɪn → 's**ɛbaɪnd**; 'sɛbaɪn → '**sim**baɪm; 'sotəbaɪn → '**sun**təbaɪn). This error data has not yet been formally analysed but may yield insights into how children with LI and TD use their long term lexical knowledge to support processing and whether this use can be conceptualised as a supportive strategy (as in a redintigration) or a hindrance to processing (as in interference). An additional area of deficit may also lie in the nature of prosodic representations (Chiat & Roy, 2007) and the unusual trajectory of influence of PP on the repetition abilities of the children with LI for bi-syllablic non-words suggests an interaction between vocabulary development, the nature of the speech processing architecture and prosodic representations which may warrant further research. This finding will be returned to in due course.

The inefficient speech processing architecture explanation hypothesis here described therefore suggests that the non-word repetition deficit in LI is a complex behaviour which has emerged from a complex set of interactions between numerous sub-systems within the speech processing system. Its nature therefore cannot be understood by looking for one level of breakdown. Rather the whole mechanism must be considered and the behaviour understood in terms of the nature of each of the sub-systems and of their interactions both in the moment and across development and hence, requires researchers to move away from the search for an impaired level of processing to the search for an understanding of the workings of a whole atypical mechanism.

3.3.2.3 An atypical trajectory

In addition to the deficit in schema abstraction identified above, the results suggest an atypical trajectory in the non-word repetition skills of the children with LI. That is early in the children's development (aged 3;04 – 6;09) their abilities demonstrate meaningful improvement with age, however later in the trajectory (aged 4;07 – 8;00) the children with LI appear to reach a premature plateau in their ability to improve and there is no significant relationship between age and performance. Such a pattern, if interpreted in the light of the arguments described above, could suggest that the children with LI have developed a different lexical processing architecture from TD which has proved adequate in the early stages of the lexicon but which plateaus and does not reach the levels of efficiency of the TD children's speech processing mechanisms. This study may therefore provide empirical support for Bishop's suggestion that the child with LI "becomes stuck in immature modes of processing language, which hamper new learning" (Bishop, 2000, p. 139). This plateau in development may therefore be indicative of just such a 'sticking point'. It must be pointed out however that the only other study which considers change in the influence of PP on non-word repetition with respect to vocabulary knowledge in children with LI did not find this plateau in development (Munson et al., 2005b). The most likely source of this difference is that the children with LI in the study by Munson and colleagues were much older than those included here (8;05 – 14;01). If that is indeed the source of difference between the studies then it would appear that this plateau reflects a pause or a 'sticking point' in development which children with LI may be able to overcome but which perhaps requires some other factor to occur to drive this change, for example reaching a critical mass of vocabulary knowledge or a critical level of literacy attainment.

A second aspect of this atypical trajectory is the fact that, unlike the TD children, the progress of the children with LI is not meaningfully related to vocabulary growth. This lack of a relationship between non-word repetition and vocabulary knowledge in children with LI has been found in other studies (Briscoe et al., 2001; Edwards & Lahey, 1998). This 'disconnection' from lexical development in children with LI could arise from a number of sources. As Coady and Evans point out (2008), there may be a statistical explanation such that, because children with LI represent the extremes of the distribution of performance and knowledge, there may be insufficient variance in this distribution to detect the relationship between the variables, a feature which may be further exaggerated by the low numbers of children with LI in this and other studies. However, as demonstrated in the current study, this finding may also represent an inability to use lexical knowledge to create sub-lexical level representations. In this way the child with LI may 'disconnect' the growth in their knowledge of *words* from growth in their knowledge of *sub-lexical/phonemic units.*

It may also be possible that, although the children here have been compared according to the size of their lexicons, differences in speech processing abilities and or biases may mean that the groups are not equivalent in terms of the composition of their lexicons. The following chapter, detailing the word learning abilities of the study participants may shed some light on this explanation.

Finally, there is tentative support for the suggestion that at the very outset of the trajectory described here (3 year old children at Data Point 1) the children with LI may not demonstrate a high PP advantage in their non-word repetition ability. This pattern may perhaps represent the children using phonetic/indexical processing which is independent of lexical knowledge, then, later in development, top-down processing and emerging sub-lexical representations are exploited and so the high PP advantage emerges. It appears that this pattern may also be present for bi-syllabic non-words and at a later point in the trajectory (Data Point 4). This may represent the fact that different parts of the developing lexicon will be at different stages of 'restructuring' at any given moment and that this delayed trajectory for bi-syllabic words may indicate a specific difficulty with this prosodic structure for children with LI.

Further work with young children with TD and those with LI is indicated to uncover whether this absence of sensitivity to PP is real and whether it is ever in evidence in very young TD children. Coady and Aslin (2004) demonstrated that TD children aged 2;06 show a high PP advantage in non-word repetition and suggest that this advantage is a continuity from early infant perceptual biases for high PP combinations. If, therefore it is demonstrated that this sensitivity to PP is always in evidence in TD children but that it is absent in young children with LI then it could perhaps be indicative of an early deficit in statistical learning in this group of children and so point to a potential causal mechanism for the late and slow start into word learning in children with LI.

3.3.2.4 Clinical Implications

The above findings suggest that the nature of the speech processing mechanism in children with LI is such that when learning new words they will have difficulties with at least two of the three stages of learning in the neuroconstructivist uptake-abstraction-reorganisation cycle; with *uptake*, as their limited lexical knowledge limits their processing capacity; and with *abstraction* as they are less able to abstract sub-lexical/phonological knowledge from lexical knowledge than their peers. It is also possible that an impairment may exists in the final stage of the cycle (re-organisation) and certainly the presence of an impairment in the first two stages would, probably imply at least a delay in this stage of the neuroconstructivist cycle. Interventions for children with LI must therefore address these aspects of learning. In order to increase 'uptake', direct teaching of new words may be indicated but more importantly, adaptations to the child's learning environment are recommended to decrease the overall processing load of tasks during new learning and hence support greater uptake of new knowledge. In order to support schema abstraction, direct work on phonological and phonemic awareness are recommended, as is future research to consider whether pattern finding and the process of abstraction itself can be facilitated in young children with LI. With respect to the final stage, reorganisation, further work is needed to determine if, when and how the speech processing mechanism reorganises in typical development, and exactly what the drivers of these changes are in the developing system. That is, whether they are simply triggered by a critical mass of uptake and critical levels of abstraction or whether additional drivers of change are needed. Indeed, it may be that in the TD child such shifts in structure emerge spontaneously from uptake and abstraction processes but that in atypical development additional and perhaps different drivers are needed to effect change. Efficacy studies and microgenetic study designs may uncover such drivers in LI and TD.

3.3.2.5 Conclusions

Children with LI are poorer than their age matched peers at repeating non-words, but their overall processing capacity for such tasks appears to be explained by their existing level of vocabulary knowledge. However they are slower to develop their skills in repeating low PP non-words than would be predicted by their vocabulary knowledge and their overall non-word repetition ability appears to reach an artificial ceiling or pause in development such that they do not reach the level of facility demonstrated by the TD group or predicted by their vocabulary knowledge. For TD children sub-lexical level processing and vocabulary develop interactively and influence each other productively. In LI children this does not appear to happen and the development of their sub-lexical representations are not *directly* related to vocabulary knowledge. A deficit in the ability to abstract sub-lexical and phonological knowledge from lexical knowledge is posited as the mechanism which creates this atypical trajectory and an 'inefficient speech processing architecture' hypothesis advanced to explain the non-word repetition deficits found in LI.

3.3.3 Individual trajectories: Results

The overall goal of this study was to explore whether new insights regarding the nature of the lexical impairment in LI could be found through the application of a longitudinal case-series methodology which considered the relationship between vocabulary growth and the emergence of sub-lexical/phonemic representations over time in typically developing children (TD) and those with or "at risk" of developing LI. The ultimate aim was to attempt to shed some light on the question; do children with LI have poorer access to sub-lexical/phonemic units *purely* as a result of having smaller lexicons or does an additional impairment, exist? The following data analysis seeks to consider individual differences in language development in children with LI and specifically to attempt to elucidate the degree and nature of heterogeneity of the LI trajectory, to describe and consider the influence of timing and the sequence of emergence of skills and to compare this to typical development based on the premise that such analyses may provide a rich source of data as to how the language processing system is 'put together' in LI. The following research questions are therefore posed:

1. Can longitudinal individual trajectories of development be described with respect to age and vocabulary knowledge?
2. Do qualitative differences exist between individuals and if so what is the nature of this heterogeneity?
3. How do these patterns relate to typical development and are they similar to those found in the cross-sectional group trajectories?

Analysis applied two methods, descriptive and statistical. The descriptive analysis involved considering the empirical growth plots for each individual both non-parametrically, by considering the graphical summary of each child's pattern of change, and parametrically, by creating OLS regression trajectories for each child (Singer & Willett, 2003). These trajectories plotted non-word repetition scores, for high and low PP items, against age and vocabulary. For the plots with respect to vocabulary, the missing vocabulary knowledge score (Data Point 2) was imputed using a linear regression (age x vocabulary) for each child. The individual longitudinal trajectories were then compared to each other to consider heterogeneity and among age groups to consider the influence of timing and sequence of emergence of skills. The individual trajectories were also compared to the cross-sectional trajectory of the TD children to consider the nature of any differences from the TD trajectory. It is not possible to say whether the TD children would evince the variety of individual trajectories found in the LI group (Figure 3.20) as only cross-sectional data is available for comparison. The shape of a mean trajectory is not informative as to the possible shapes of longitudinal trajectory which individuals within the TD group may have displayed had longitudinal data been collected. However we can comment on whether the scores of the individual children with LI fall within the 95% CI of the TD children's performance and whether any differences found with respect to age remain when performance is considered with respect to vocabulary knowledge. It is not possible from the graphs to comment on the rate of change in the individual trajectories when compared to the TD children or the nature of the relationship between the trajectories for high and low PP scores.

In an attempt to address this issue the second method of analysis applied was a statistical one and related to the question of the nature of any differences from the TD trajectory. The individuals were compared to the TD children statistically using an approach which combines the use of summary measures of change (Matthews et al., 1990) with Crawford's t-test (Crawford & Howell, 1998). These two approaches are designed, in turn, to cope with the issues of autocorrelation of repeated measures (Matthews et al., 1990) and the problems of increased Type I errors when comparing individuals to small normative samples (Crawford & Howell, 1998). This statistical approach does not completely answer the difficulties in comparing longitudinal data to cross-sectional data. Making inferences about the average rate of change with age for an individual from the rate of change in the averages of a group of individuals with age is obviously not comparing like with like. However such comparisons are intrinsically conservative. That is, the use of TD cross sectional rather than longitudinal data increases the uncertainty about the gradient of the slope. The true variability of the slope for each individual is likely to be less than that estimated by cross-sectional data where variability arises both from differences between the individuals and variability across the age range. Hence, if differences *do* exist between the individual trajectory and the 95% CI of the TD children's performance then these differences are likely to be highly significant. The following results first characterise the trajectories of the children with LI and consider heterogeneity and timing, and secondly, compare the individual trajectories to those of the TD children with respect to age and vocabulary knowledge.

3.3.3.1 Characterising individual trajectories in LI: heterogeneity and timing

Figure 3.20. presents the individual empirical growth trajectories in non-word repetition abilities for high and low PP non-words of the children with LI (labelled as either R-LI (Resolving LI) or P-LI (Persisting LI) as determined by their language status at the end of the study) plotted against time where zero is the start of the study. This allows for consideration of differences in trajectory between individuals (heterogeneity) and across the age range studied (timing). For statistical comparisons to be made regarding similarities and differences in the *shape* of the trajectories multiple waves of data collection would be required and if a data set has few waves (as in this case) then simple models with strict assumptions must be applied, such as assuming that individual growth is linear over time (Singer & Willett, 2003). The following therefore, as it relates to trajectories containing four Data Points, is limited to a

descriptive analysis and so any observations relating to heterogeneity of shape of trajectory must be interpreted with caution.

With respect to the first point, the differences in trajectory between individuals, there is a degree of heterogeneity in the growth trajectories, with most variety in the children aged 3 years at the study's outset. However there are also many similarities between the individuals. All of the children demonstrate a high PP advantage for the majority of their trajectory and most trajectories are suggestive of improving performance with age. The key exception being the oldest group aged 5-6 years at the study's outset. Their trajectories appear to demonstrate the plateauing in performance which was also found in the previously reported group data.

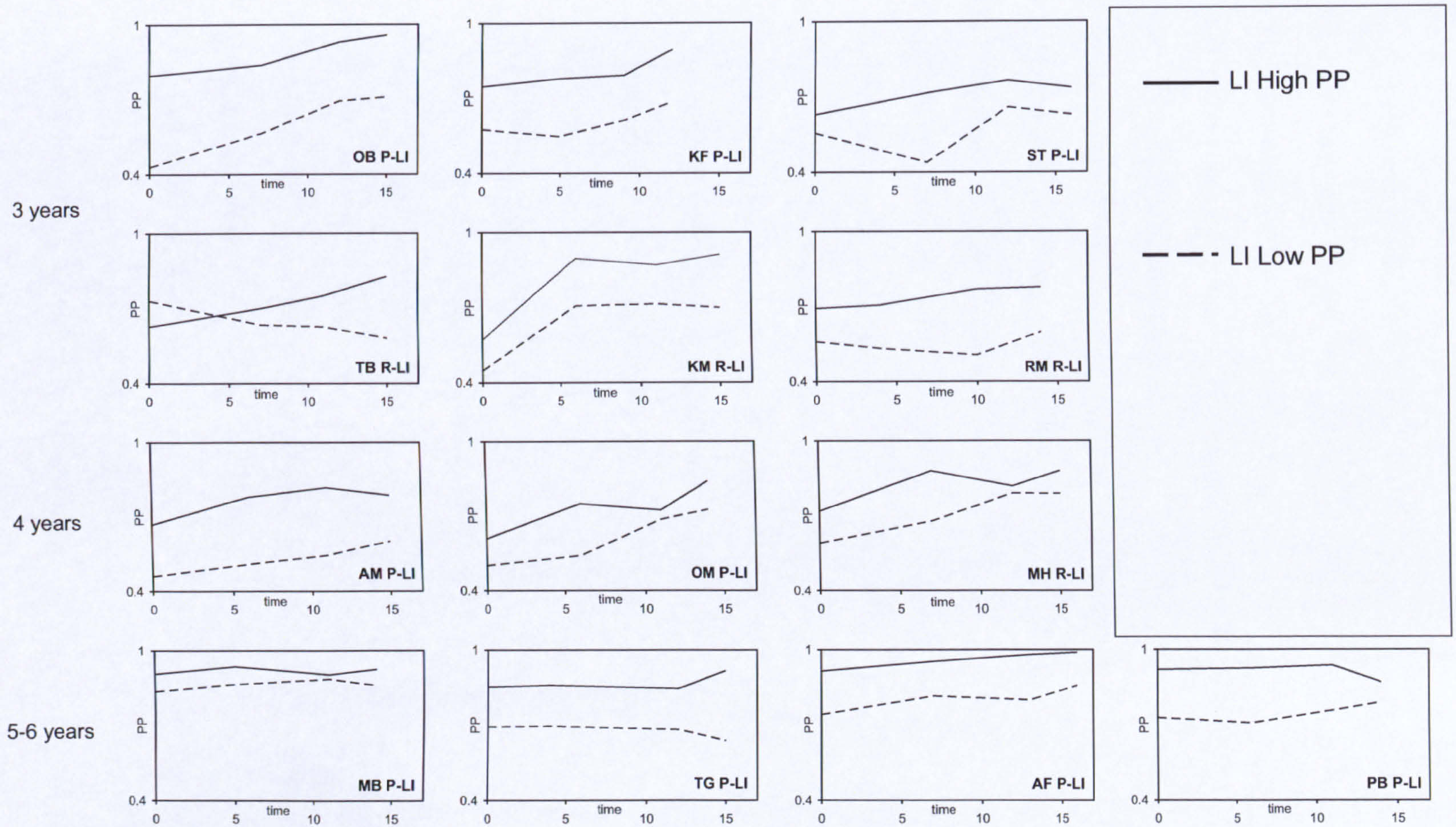


Figure 3.20. Empirical growth plots for High and Low PP scores against time (months) for individual children with LI

The children who were aged 3 years at the outset of the study demonstrate the most heterogeneity with particular variation in the pattern of the low PP trajectory. For example TB's trajectory appears to represent a decreasing score over development and KF, ST and RM's trajectory suggest dips in performance at certain stages in their development. Such heterogeneity may simply be the result of 'noise' in the data. Young pre-school children are much more likely to be unreliable on any experimental task due to variability in attention and motivation. In addition, this age group had the most significant issues with respect to their phonological output abilities (See Chapter 2: Participants, for more detail). Allowances were made for these difficulties (as described in the Methods section) such that any sound substitutions made in a phonological screen were scored as correct in the repetition task, however such allowances make assumptions both of consistency in a child's phonological system and that error patterns are not context sensitive (for example assuming that a consonant in a polysyllabic word will be produced in a similar manner to one in a monosyllabic word). This may not necessarily be the case and so there is an increased probability that for this group of children, their output phonology may add an additional source of variability to their scores.

TB's trajectory is a case in point, at Data Point 1 it appears that non-words with low PP were more accurately produced than those with high. TB had a very severe co-morbid phonological impairment at this point and this could have affected the validity of the scoring of his non-word repetition attempts. In addition to these issues of reliability and validity however, TB's phonological impairment may also have affected his performance through effects on his processing biases or abilities. The influence of children's existing phonological inventories on their word learning has been demonstrated in a number of studies although the results vary over development and depending on their methodology as to whether IN (sounds that are produced) or OUT (sounds that are not produced) are favoured. Whether such biases or constraints influence repetition tasks has not been studied. In addition methods for dealing with differences in children's phonological systems when scoring repetition tasks is a more complex issue than it first appears. Both issues would seem to be potentially fruitful areas for further research.

The children who were aged 4 years at the outset of the study are a relatively homogeneous group, improve in their non-word repetition ability over the course of the study and repeat high PP non-words more accurately than low. It does not appear that low PP scores were catching up with the high PP scores in this age-group. AM appears to be more disadvantaged by low PP than the other 4 year old children.

The 5-6 year old children again are relatively homogeneous. They appear to have reached a plateau in their ability to improve in non-word repetition with the possible exception of AF who may demonstrate a very slow improvement over the course of the study. Again narrowing between high and low PP non-words is not apparent in this group of children and high PP words were always produced more accurately then low. MB demonstrates relatively high scores in non-word repetition ability with very little disadvantage for low PP non-words although there is no obvious improvement over the course of the study.

In summary, with respect to heterogeneity, overall there are many similarities between the individuals with all of the children demonstrating a high PP advantage for the majority of their trajectory and most trajectories improving with age. The greatest heterogeneity is apparent in the 3 year old children but is likely to result from increased variability in this group arising from cognitive and phonological factors. With respect to timing, across the age range the pattern reflects that described by the cross sectional trajectories. That is, both high and low PP scores gradually increase between 3 and 5 years but then appear to plateau, at a level below ceiling between the ages of 6 and 8 years.

3.3.3.2 Comparing individual trajectories in LI to TD trajectories

3.3.3.2.1 Descriptive comparison with respect to age

Figure 3.21 presents the individual OLS trajectories of the children with LI in non-word repetition abilities for high and low PP non-words plotted against age in months. Also plotted for comparison purposes for both high and low PP non-words are: the OLS trajectory of the TD group, the trajectory for the 95th centile of the TD scores, and the trajectory for the 5th centile scores of the TD group with respect to age. In this way comparisons can be made between the trajectories of the TD group and those of the individual's with LI and whether or not the individual's trajectory falls outside of the typical range of scores can be identified. Such comparisons (as described previously) provide a conservative estimate as to whether the children with LI are significantly different from the TD group in terms of their overall performance. Differences between the individuals and the TD group with respect to rate of change and the interaction between high and low PP are presented below with reference to the statistical tests only.

Taking each age group in turn, and beginning with the children aged 3 years at the outset of the study, it is apparent from Figure 3.21 that performance for low PP non-word repetition falls around the 5th centile of the TD group for all of the children with LI, with some degree of variability around this line. Performance for high PP non-words is more variable with three children falling below the 5th centile (RM, ST, TB) one child very close to the 5th centile (KF) and the remaining two children falling within the range expected for their age (OB, KM).

The children aged 4 years at the outset of the study perform more poorly than the 3 year old group with all of the children falling below the 5th centile for both low and high PP non-word repetition, although MH's low PP scores are very close to the 5th centile and these low PP scores appear to move into the range of Typical Development by the end of the study.

The children aged 5-6 years at the outset of the study fall outside of the age range of the TD group. If the TD trajectories are linear, and so can be extrapolated forwards, then it appears that all of the children in this age group do fall below the expected range of performance for their age. One child (MB aged 5 at the outset) would perhaps fall within the typical range at the beginning of his trajectory but his subsequent rate of progress suggests that by the end of the study his scores would also fall outside the typical range for his age.

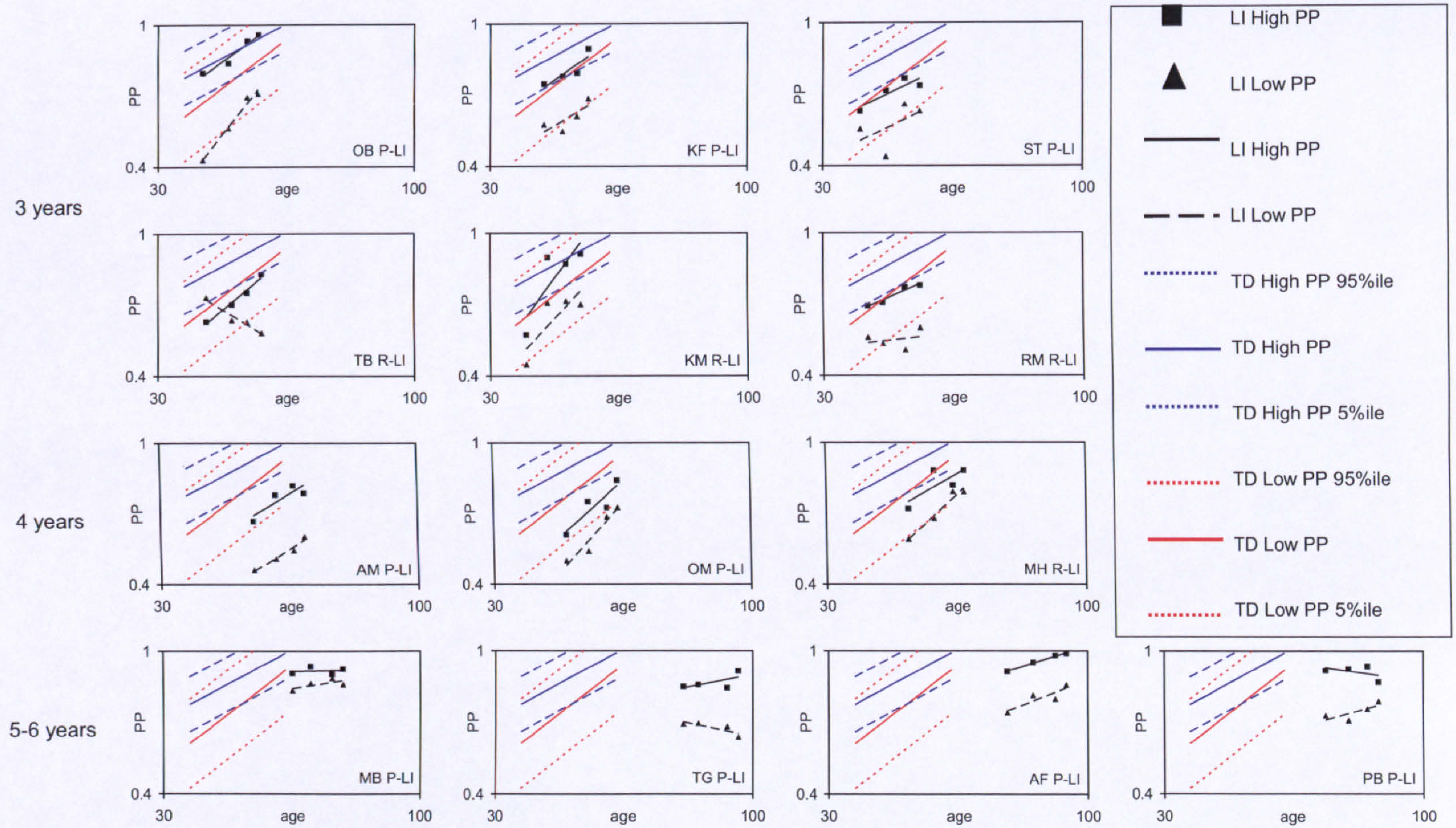


Figure 3.21. High and Low PP OLS trajectories against age (months) for individual children with LI compared to TD children's cross sectional trajectories

3.3.3.2.2 Descriptive comparison with respect to vocabulary

Figure 3.22 presents the individual OLS trajectories of the children with LI in non-word repetition abilities for high and low PP non-words plotted against Expressive Vocabulary raw scores (EOWPVT, Brownell, 2000a). Also plotted for comparison purposes for both high and low PP non-words are: the OLS trajectories of the TD group, the trajectory for the 95th centile of the TD scores, and the trajectory for the 5th centile scores of the TD group with respect to vocabulary scores. In this way comparisons can be made between the trajectories of the TD group and those of the individual's with LI. Such comparisons provide a conservative estimate as to whether the children with LI are significantly different from the TD group in terms of their overall performance.

It is apparent from Figure 3.22 that when making comparisons with respect to vocabulary knowledge, there is a great deal of overlap with the TD trajectories. In fact only 3 children (AM, OM and TG) have scores falling outside of the typical range, AM for both high and low PP, OM for only high PP, and TG only for low PP.

Hence, as was demonstrated in the group comparisons, it appears that, once vocabulary knowledge is considered the children with LI are generally not significantly different from the TD group. The cross-sectional group comparisons previously reported found significant differences between the groups in terms of rate of change in low PP scores with respect to vocabulary knowledge and in the relationship between high and low PP scores across development. The following statistical tests consider whether such differences exist between individual trajectories and the TD cross-sectional trajectory.

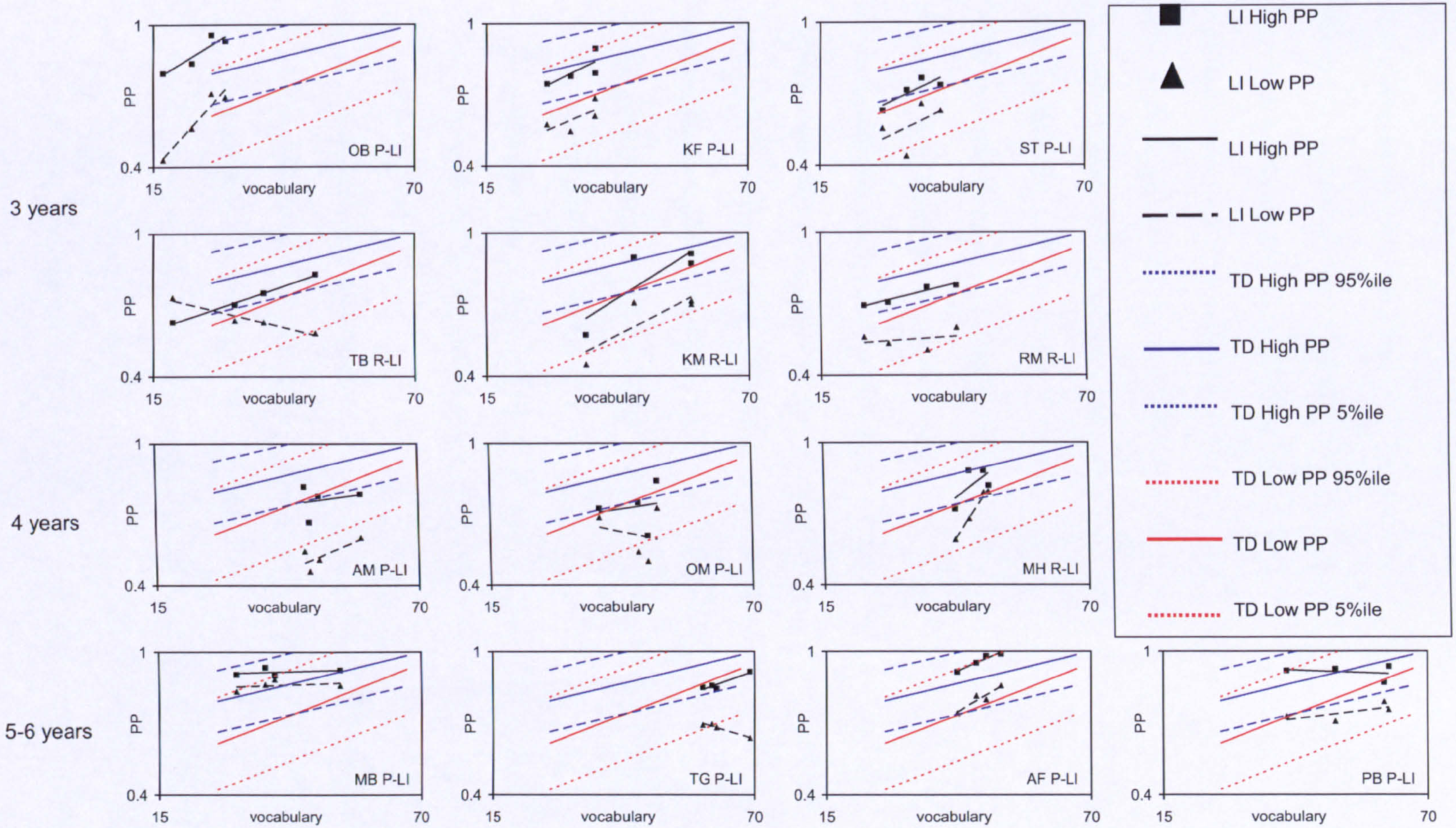


Figure 3.22. High and Low PP x vocabulary OLS longitudinal trajectories for individual children with LI and TD children's cross sectional trajectory

3.3.3.2.3 Statistical comparisons with respect to vocabulary

A statistical analysis was completed in order to consider whether the differences observed between the individuals with LI and the TD trajectory described above were statistically significant and to consider any differences between the rate of change in the trajectories of the individuals with the TD trajectory with respect to vocabulary knowledge and in the relationship between high and low PP scores as vocabulary knowledge develops. To make comparisons between such dissimilar data, that is, in order to compare longitudinal data (i.e. related data) to cross-sectional data (i.e. unrelated data) it was essential to deal with the issue of the auto-correlation of the repeated measures in the longitudinal data set. This issue was addressed by reducing the set of related measures for each child to single summary measures for the factors of interest, and by comparing these newly created single measures with equivalent summary measures for the cross sectional data set (Matthews et al., 1990). Details of the calculations used to derive these measures are found in Appendix 7. The summary measures for the individual children with LI were created as follows:

1. *Total non-word repetition scores*: total percentage phonemes correct (PPC) averaged over the four Data Points.
2. *Difference between high and low PP scores*: total percentage phonemes correct (PPC) averaged over the four Data Points for high PP minus PPC for low PP (i.e. the main effect of PP)
3. *Overall rate of progress with respect to vocabulary knowledge*: the gradient of the slope of change in PPC scores with respect to vocabulary growth averaged across the 40 test items (i.e. the main effect of vocabulary)
4. *The nature of the relationship over development between high and low PP scores:* the difference between the average gradient across the 20 test items of the high and low PP slopes with respect to vocabulary growth (i.e. the PP x vocabulary interaction)

The summary measures for comparison derived from the TD children were the scores which the TD data would predict from the level of vocabulary knowledge of the individual child with LI. The measures were created as follows:

1. *Total non-word repetition scores*: TD population estimates were calculated using multiple regression and scores for the children with LI derived as predicted by their expressive vocabulary knowledge and the distribution of scores in the TD group were then calculated for comparison
2. *Difference between high and low PP scores*: TD population estimates of difference in scores were calculated using multiple regression and scores for the children with LI derived as predicted by their expressive vocabulary knowledge and the distribution of scores in the TD group were then calculated for comparison
3. *Overall rate of progress with respect to vocabulary knowledge*: TD children's rate of progress with respect to vocabulary scores were calculated using linear regressions created from the TD cross-sectional data
4. *The nature of the relationship over development between high and low PP scores:* TD children's difference between the slopes for High PP and Low PP scores with respect to vocabulary scores were calculated using linear regressions created from TD cross-sectional data

The summary measures for each child with LI were compared to the summary measure from the TD group data which the LI child's level of vocabulary knowledge would predict (see Appendix 7 for detail of calculations). Comparisons were then made between these two summary statistics using Crawford's t-test (Crawford & Howell, 1998), a statistical test designed to compare individuals to small normative samples. Crawford's t-test is calculated as $\frac{\mu_1 - \mu_2}{\sigma\sqrt{(n+1)/n}}$ where μ_1 = the mean of the LI individual's scores and μ_2 = the mean score which would be predicted by the individual's expressive vocabulary score based on the TD children's data, and σ = the population standard deviation for the particular summary measure. The population standard deviation was not available for each of the measures and so was imputed from the existing data. Details of the calculations used to derive the standard deviations are provided in Appendix 7.

One tailed t-tests were completed for each of the comparisons due to the nature of the hypothesised difference between the individual children with LI and the TD trajectory. That is, in terms of overall score and rate of progress with respect to vocabulary knowledge, it was hypothesised that the children with LI may perform more poorly than the TD children; with respect to the high PP/low PP difference score it was hypothesised that there may be a heightened PP effect in the children with LI (as suggested by the effect of low PP in the group comparisons) and so would demonstrate a larger high PP low PP difference than the TD group; with respect to the nature of the relationship over development between high and low PP scores, (i.e. the difference in the high and low PP slopes) it was hypothesised that the children with LI would not evince the same closing of the gap between high and low PP scores as was found in the TD group. A closing gap between the trajectories is indicated by a negative score (i.e. as the low PP gradient would be steeper (and so a higher value) than the high PP gradient), hence if the children with LI were not evincing this closing gap, the difference in their high and low PP slopes would be $\geq$ zero. The complete results of the individual t-tests are presented in Appendix 8. Table 3.6 summarises these results for each individual with LI.

Child	Total PPC	High PP Low PP Difference	Rate of progress Total PPC	PP x Vocabulary interaction
OB	.68	.14	.07[a]	.83
KF	.24	.29	.29	.36
ST	.048*	.60	.07[a]	.33
TB	.14	.73	.68	.06[a]
KM	.07[a]	.22	.24	.21
RM	.05[a]	.51	.40	.14
AM	.007*	.06[a]	.54	.63
OM	.03*	.54	.82	.07[a]
MH	.22	.55	.02*	.95
MB	.87	.87	.77	.33
TG	.03*	.06[a]	.77	.01*
AF	.71	.32	.29	.50
PB	.27	.18	.76	.50

* = p< .05 (significant); a = p≥ .05 ≤ .08 (approaches significance)

Table 3.6. p-values from Crawford t-tests (one tailed) for individuals with LI compared to TD children with respect to vocabulary knowledge

Analysis of the total non-word repetition scores (PPC) found that 4 children scored more poorly than would be predicted by their vocabulary knowledge (ST, AM, OM and TG) and that a further 2 children's scores approached significance (KM and RM).

The High PP/Low PP difference (main effect of PP) was not significantly different from the TD group when compared with respect to vocabulary knowledge for any individual with LI although AM and TG's results approached significance.

Rate of progress with respect to vocabulary knowledge only differed from the TD group in 1 case (MH) and approached significance in 2 others (OB and ST). For all three of these children this difference represented *faster* progress than predicted by vocabulary knowledge and therefore may represent a period of significant improvement in their language or phonological skills.

The PP x vocabulary interaction which measures the nature of the relationship over development between high and low PP scores was significantly different from the TD group in one case (TG) and approached significance in two others (TB and OM). This result reflected a widening gap between high and low PP scores over time in these children as opposed to the narrowing gap found in the TD children. All other scores were not significantly different than predicted by the children's vocabulary knowledge.

These results generally concur with the descriptive comparisons made in Figure 3.22 which plot the individual OLS trajectories of the children with LI plotted against vocabulary and compare them to the TD children's cross sectional trajectories and the trajectories of the 95th and 5th centile scores.

3.3.4 Individual trajectories: Discussion

The overall goal of this study was to explore whether new insights regarding the nature of the lexical impairment in LI could be found through the application of a longitudinal case-series methodology which considered the relationship between vocabulary growth and the emergence of sub-lexical/phonemic representations over time in typically developing children (TD) and those with or "at risk" of developing LI. The ultimate aim was to attempt to shed some light on the question; do children with LI have poorer access to sub-lexical/phonemic units *purely* as a result of having smaller lexicons or does an additional impairment, exist? The analysis of individual longitudinal trajectories was included in order to consider individual differences in language development in children with LI based on the premise that such analyses may provide a rich source of data as to how the language processing system is 'put together' in LI. Hence by examining individual longitudinal trajectories it may be possible to elucidate the degree and nature of heterogeneity of the LI trajectory, to describe and consider the influence of timing and the sequence of emergence of skills and compare this to typical development. In this way it was hoped that insights would be gained as to the nature of the developing lexicon in individual children with LI. In order to do this with the available data a novel statistical methodology was devised. The following discussion will therefore, in addition to addressing the research aims of the study, also consider the usefulness of this novel statistical approach and its potential application to future research. The following discusses in turn: heterogeneity and timing in the LI trajectory; comparisons between the individual LI trajectories and the TD trajectory, with specific reference to similarities and differences to the cross-sectional group data; and finally the study design and statistical methodology.

3.3.4.1 Heterogeneity and timing in the LI trajectory

The individual LI trajectories were generally homogeneous, with all of the children demonstrating a high PP advantage for the majority of their trajectory and most trajectories improving with age. Overall, sources of heterogeneity appear to be associated with differences in timing and so to differences in the nature of the emergence of skills at different stages in the developmental trajectory rather than to a large variety of individual differences. That is, two key areas of differences are evident in the trajectories; the plateauing of performance in the group of children aged 5-6 at the study's outset, and the greater variability in performance in the group aged 3 years at the study's outset. The plateau in progress at a level below ceiling was evident in the cross-sectional group data and appears to be present in at least 3 of the 4 children in the oldest age-group. It is important to note that the statistical comparisons between the individual's with LI and the TD trajectory did not suggest that the children with LI were developing more slowly that the TD peers. However these comparisons were made *with respect to vocabulary knowledge* and so it would appear that the plateauing in progress of the individuals with LI may be explained by their rate of progress in vocabulary knowledge. Such a conclusion may be premature however, as the individual trajectories described spanned only a very short developmental period (an average of 14.4 months) and the children with LI were developing their vocabulary knowledge extremely slowly. In this context small differences in the *rate of change* of skills may not be detectable and so this null result may represent a lack of power the data in its ability to detect differences in rates of change which may arise due to the limited time frame of the data collection period.

The variability in the trajectories of the children aged 3 years at the study's outset is likely to relate to cognitive and phonological factors affecting performance. It is also possible however that lexical and phonological processing in this age group may be qualitatively different from the older children and between individuals and that differences in trajectory may exist.

However the current data does not have sufficient power to detect such differences. Further longitudinal work encompassing a broader age range, with more data waves and more participants is required to determine whether such differences result purely from 'noise' in the data or whether they represent individual or developmental differences in the nature of the speech processing mechanism. Such work is necessary if we are to understand fully the nature of the emerging lexicon and the ontogeny of LI.

3.3.4.2 Comparisons between the LI and TD trajectories

The previously reported group comparisons of cross-sectional developmental trajectories found that when the LI and TD groups were compared with respect to vocabulary knowledge, there were no significant differences between the groups in overall non-word repetition scores; that the ability of the children with LI to repeat low PP words was developing more slowly than predicted by their vocabulary knowledge; and that the pattern of a narrowing gap between high and low PP non-words as vocabulary knowledge increased was not evident in the children with LI.

Analysis of individual trajectories allows us to consider whether the above group findings hold true for all of the children with LI. By considering individual differences and the possible causes for such differences it may be possible to create a more detailed and ecologically valid picture of the heterogeneous nature of LI. Indeed, statistical analyses of the individual trajectories suggest that the above group findings do not hold true for all of the individual children with LI.

With respect to overall non-word repetition ability, four of the individual children with LI were significantly poorer than would be predicted by their level of vocabulary knowledge (ST, AM, OM and TG), and a further two children's scores approached significance (KM, RM) (see Table 3.6). This differs from the group results and for these children therefore an additional impairment, over and above that which can be explained by their level of vocabulary knowledge would appear to be affecting their ability to repeat non-words. Looking at the overall profile of analyses for these individual children, there is tentative support for the suggestion that for three of these children, an impairment in sub-lexical/phonological processing is implicated rather than an overall processing capacity limitation and, furthermore that this impairment is more significant than would be predicted by their vocabulary knowledge (see Table 3.7 and Figure 3.23). That is, AM is poorer overall at non-word repetition than would be predicted by her vocabulary knowledge and in addition her 'high PP low PP difference' score approaches significance. This is suggestive that AM may be disproportionately affected by PP and hence that her difficulties with non-word repetition may arise from difficulties in sub-lexical/phonological processing rather than from a processing capacity limitation. For OM, the 'PP x vocabulary interaction' approaches significance suggesting that over development the gap between high and low PP scores is not narrowing as would be predicted by his level of vocabulary growth, hence this is suggestive of difficulties in abstracting sub-lexical/phonemic knowledge across development. For TG this 'PP x vocabulary interaction' is also significant and in addition the 'high PP Low PP difference' score approaches significance. Again these differences suggest that TG's difficulties cannot be explained by his level of vocabulary knowledge and that sub-lexical/phonological processing is implicated as the locus of impairment rather than processing capacity.

ST is the exception as, despite also having poorer overall non-word repetition abilities than would be predicted by his vocabulary knowledge, there is no indication from his other results of a sub-lexical/phonological processing impairment. ST's 'rate of progress' score approaches significance but this result reflects *faster* progress than is predicted by his vocabulary growth. Inspection of ST's trajectory suggests that his abilities fall mostly within the TD range. At

Data Point 2 however, ST's performance for low PP words is poorer than at Data Point 1. It is possible that such a dip in performance may represent variability caused by cognitive, attentional or motivational factors rather than changes in speech processing skills and that this may have caused his overall score to fall outside of the typical range.

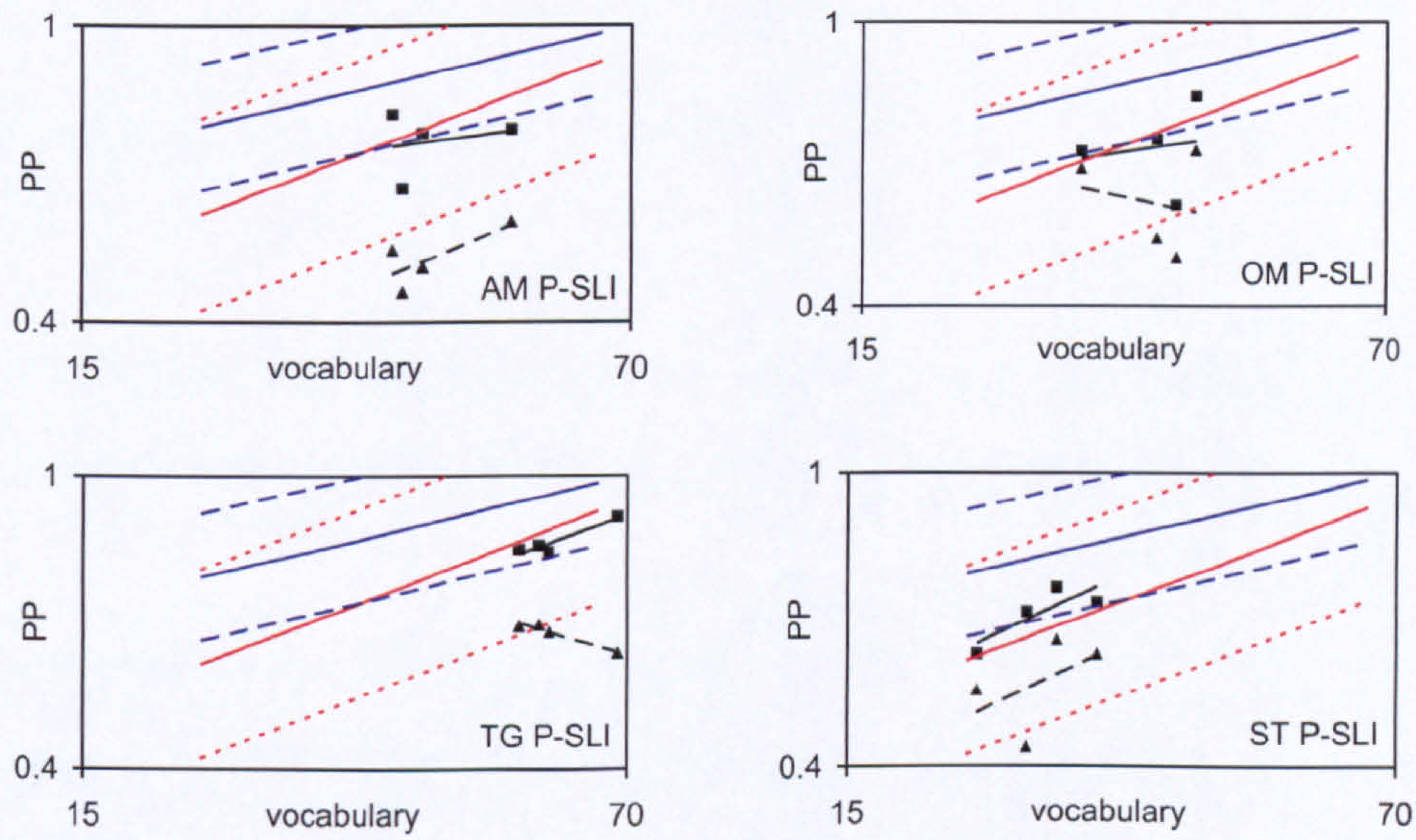


Figure 3.23. Children with LI with poorer non-word repetition scores than predicted by their vocabulary knowledge: longitudinal trajectories and TD cross sectional trajectory

Child	Total PPC	High PP Low PP Difference	Rate of progress Total PPC	PP x Vocabulary interaction
ST	.048*	.60	.07 [a]	.33
AM	.007*	.06 [a]	.54	.63
OM	.03*	.54	.82	.07 [a]
TG	.03*	.06 [a]	.77	.01*

* = $p < .05$ (significant); a = $p \geq .05 \leq .08$ (approaches significance)

Table 3.7 Children with LI with poorer non-word repetition scores than predicted by their vocabulary knowledge: profile of p-values from Crawford t-tests (one tailed)

There is no evidence that KM and RM, whose non-word repetition ability scores approached significance, have sub-lexical/phonological processing difficulties as their scores for 'high PP low PP difference', 'rate of progress' and 'PP x vocabulary interaction' were not significantly different from that which would be predicted by their vocabulary knowledge.

Turning to the remaining key findings from the group comparisons of cross-sectional developmental trajectories, that the ability of the children with LI to repeat low PP words was developing more slowly than predicted by their vocabulary knowledge; and that the narrowing gap between high and low PP non-words found in the TD trajectory was not evident in the children with LI, there is little evidence from the individual statistics to back up these results. That is, only in two cases is there tentative evidence that the children are disproportionately affected by low PP (AM and TG 'high PP low PP difference' approaches significance) and, with respect to the absence of a narrowing gap between the high and low

PP trajectory (PP x vocabulary interaction), only one child is significantly different from the TD trajectory (TG) and two approach significance (TB and OM) (see Table 3.7).

Taken together, these results would therefore appear to suggest that *some children* with LI have difficulties with non-word repetition which is linked to an impairment in sub-lexical/phonological processing (as indicated by either a disproportionate effect of PP on processing or a slower rate of progress in low PP scores than is predicted by their vocabulary knowledge). However, for many children with LI, their difficulties with non-word repetition can be explained by the level of their vocabulary knowledge as there is no evidence of an additional sub-lexical/processing impairment in these children.

Recall that the analysis of the cross-sectional developmental trajectories suggested that the ability of the children with LI to repeat low PP words was developing more slowly than predicted by their vocabulary knowledge and that the narrowing gap between high and low PP non-words found in the TD trajectory was not evident in the children with LI. The individual trajectory analyses, however suggest that these results may either be an artefact of the data analysis technique, or may be true only for some of the children with LI. To take the first suggestion, it would seem premature to dismiss the cross-sectional data findings as erroneous based on the individual trajectories presented here. That is, as it is measures of *change* which were shown to be significantly different between the groups in the cross-sectional trajectories, it is essential to consider the time span across which these changes were measured. That is, the age ranges in the group comparisons were 3;04 to 6;09 and 4;07 to 8;00 (a range of 41 months), and the vocabulary score ranges were 17 to 59 and 27 to 69 (a range of 42 points). In the individual trajectories the time span in months for each individual trajectory averaged 14.4 months (ranging from 12 – 16 months) and the span of vocabulary scores for each individual trajectory averaged 15.2 (with a range of 7 – 30 points). It therefore seems likely that the individual trajectories presented here are not sufficiently long and do not consist of sufficient vocabulary growth for statistical differences in the rate of change to be evident. The second suggestion that the differences found in the group data may reflect patterns of development in some of the individuals studied and not others, may indeed be the case. The pattern of results previously described identifying a small group of children, who present with a pattern of results indicative of a sub-lexical/phonological processing impairment, would go some way to support this. Hence the statistical analysis of the individual trajectories suggests a level of heterogeneity in the results which was not readily apparent from the descriptive analyses. Identifying such heterogeneity is a primary motivation in conducting individual case study analyses as it underlines the need to avoid over-generalisation of group study findings to all children with LI. In addition individual case studies can also uncover differences which may be lost in comparisons of group means. For example, in the present study a group of children appear to have improved in their non-word repetition skills more rapidly than their vocabulary knowledge would predict (OB, ST, MH). Such patterns were not apparent from the group data and may be indicative of a differing trajectory of development. Identifying the nature of differing trajectories is crucial if we are to uncover the differing and perhaps widely varying ontogenetic trajectories of TD and LI and the mechanisms which play a role in the creation of these differing trajectories.

3.3.4.3 Study design and statistical methodology

The current methodology would appear to hold promise for increasing our understanding of LI. Its focus on development increases our understanding of the role of change in the development of impairment and of the changing nature of the processing system. Its focus on individual cases increases our understanding of heterogeneity and avoids both over-generalisation of group findings to all children with LI and the 'washing out' of individual differences which can occur when using statistics focussed on group means.

However it is clear that when considering change at the level of the individual, especially where the individual's developmental trajectory is slowed, as for the children in this study with respect to their vocabulary acquisition, then tracking development for longer time periods than was possible in the current study is recommended, especially if differences in *rate of change* between and within individuals are to be studied. Consideration of the rate of change of skills, and the dynamic interaction between skills over time holds promise as an approach which may increase our understanding of the nature of the developing lexicon and, more broadly of language acquisition in the context both of impairment and typical development. Longer prospective longitudinal studies of language development are therefore needed and such studies have been and are being completed (Bavin *et al.*, 2008; Conti-Ramsden et al., 2009; Roulstone *et al.*, 2002). However most large cohort studies measure language development using standardised tests or parental report measures which assess surface changes in language knowledge and behaviour but which do not tap changes in psycholinguistic processing. In addition the time intervals between observations in these larger studies are often relatively wide and so can identify that the child has moved from skill A to skill B, but do not uncover how the child makes this change. Hence longitudinal studies with frequent observations and carefully designed experimental tasks are recommended. Such a recommendation however is not easily followed as such a study design would be costly, time consuming, liable to participant drop-out and a considerable commitment for the participants involved. Also the time-lag between posing the question and having the data to answer the question could mean that by the time the data is analysed the research field has moved on and both the question posed and the measures used are no longer relevant or meaningful.

Alternatively, the novel statistical approach presented here, allowing individual longitudinal trajectories to be compared to a reference normative cross-sectional trajectory, could provide a compromise methodology which would allow for questions regarding individual longitudinal change to be asked and answered and measures of change piloted in a less resource intensive context. In addition this approach holds promise for addressing the challenge of differentiating between individual developmental change and therapeutic change in intervention studies. That is, by comparing the rate of change in scores of an individual receiving intervention to the rate of change predicted by a cross-sectional comparison group, it would be possible to determine whether the child's progress was significantly faster than that of children not receiving the intervention.

3.3.4.4 Conclusion

This study has a number of important outcomes. Firstly it demonstrates that at least some children with LI are likely to have a sub-lexical/phonological processing impairment which, together with limited vocabulary knowledge, affect their speech processing efficiency. For other children with LI their processing capacity limitations appear to be attributable to their level of vocabulary knowledge, although longer term longitudinal studies may uncover sub-lexical/phonological processing impairments which were not detectable in the current study's time frame. These results call into question the PWM and capacity limitation theory of LI at least for a sub-group of these children, and instead suggest that the nature of lexical and sub-lexical knowledge and change in the processing architecture of the speech processing mechanism may play a crucial role in the development of LI.

Secondly, this study acts as a pilot for the novel statistical methodology of comparing individual longitudinal trajectories to a reference cross-sectional trajectory and has demonstrated its applicability for considering change within an individual and with reference to control data. Such an approach has potential applications for understanding the developmental process without recourse to large scale prospective longitudinal designs and for evaluating the efficacy of interventions within a developing system.

Thirdly, this study demonstrates that the novel non-word repetition measure presented is able to tap changes in speech processing abilities across development and hence may hold promise as a research and clinical tool. Finally, the results demonstrate the 'added value' which considering *change* and *individual difference* bring to our understanding of developmental disorders. Change, as it captures differences between typical and atypical development in the process of neuroconstruction which static designs cannot capture, and individual difference, as it acknowledges, examines and seeks to explain heterogeneity within models of atypical development.

CHAPTER 4

Building a Lexicon in LI: The Process of Word Learning

This chapter presents further empirical longitudinal data which describes the process of lexical development in LI and explores the influence of development, lexical knowledge and phonological processing on the growth and organisational structure of the developing lexicon. Specifically, I present the findings from a fast mapping task which explores the influence of phonotactic probability and neighbourhood density on the fast mapping abilities of children with LI and their Typically Developing (TD) peers. The evidence in the previous chapter suggested that children with LI are less able to abstract sub-lexical level representations from their existing lexical knowledge and so develop inefficient lexical and phonological processing mechanisms. This chapter will consider the similarities and differences between TD children and those with LI with respect to the nature of the influence of phonological and lexical variables on their fast mapping abilities. This will therefore provide evidence as to the possible source of the word learning difficulties found in LI, and provide further insights as to the structure, functioning and nature of developmental change in the lexicons of these two groups of children. The following therefore presents in turn: a review of the current literature relating to the influence of lexical and phonological factors on the word learning abilities of TD children and those with LI; empirical data which describes the trajectory of influence across development of these factors on the word learning abilities of both groups; comparisons between those trajectories; and a discussion of the insights gained regarding the nature of the word learning difficulties found in children with LI.

4.1 Mapping the Trajectory of Word learning Ability in LI

4.1.1 The word learning difficulties of children with LI

Children with Specific Language Impairment have difficulty learning new words (Alt & Plante, 2006; Alt *et al.*, 2004; Gray, 2005; Rice *et al.*, 1994). Most are slow to begin the process of lexical acquisition (Reilly *et al.*, 2009), and their vocabulary test scores fall further behind their peers over development (Stothard et al., 1998). As described previously, this impaired mapping and the resulting late and slow development of the lexicon could be crucial to the ontogeny of LI (Chiat, 2001; Conti-Ramsden, 2003b). Understanding the causes and nature of this word learning impairment could therefore be crucial in the early identification of children with LI and in the design of interventions.

The process of learning a word is complex and begins with "fast-mapping" and continues with a prolonged period of "slow mapping"(Carey, 1987). The fast-mapping process establishes a link between a word and a referent with only minimal exposure and encodes and retains sufficient detail such that, on subsequent presentations of the word and the referent, the child can recognise them and begin the process of slow mapping, where more detail is added to the representation. This process proceeds until the semantic representation of the words resembles adult meaning and may take months or years to complete. Hence with reference to the oft cited estimate that young children learn 10 new words per day (Carey, 1978), Bloom points out, "they might instead be learning one-hundredth of each of a thousand different words" (p. 25).

In addition, processes brought to bear on word learning are complex and involving multiple processing abilities in interaction with the child's existing long term knowledge of the world and of language (Golinkoff *et al.*, 2000). Hence, as the child's knowledge grows, the skills brought to bear, and cues used to support new word learning change. In attempting to identify the source (or sources) of word learning impairment in LI it is essential therefore to consider which processing skills may be impaired and also the influence of development on the availability and use of these skills. Not only will different processing skills be available at different stages in development and so become more or less important in the process of word learning (e.g. literacy in the adolescent, comprehension of syntax in the pre-schooler) but also, within an emergent model of LI, early processing impairments which affect language learning will impact on the nature of the child's long term language knowledge and this, in turn, will alter the nature, efficiency and/or availability of processing skills relevant to word learning across development. It is essential therefore to consider not only the influence of processing skills on word learning in LI but also the influence of development on these abilities as the nature of these impaired processes will change as the child's language develops. Hence, as identified by Thomas (2005), to understand a developmental disorder fully we need to understand both how the early innate mechanisms differ from TD and also how this difference changes the developmental process (Thomas, 2005).

The work of Chiat (2001) and Leonard (2007) suggests that the atypical trajectory of children with LI could involve early phonological and lexical processing impairments, which then lead to deficits in argument structure, syntax and morphology and a limitation in overall processing capacity, and that these, combined with persisting phonological impairments, go on to create literacy difficulties. At each stage of this trajectory therefore, new word learning will be challenging for the child with LI due to the combined and compounding effects of each of these impairments. Indeed cross-sectional data from the participants in this study suggest that the children with LI aged between 3 and 8 years were on average developing their expressive vocabulary skills at half the rate of the TD group (Appendix 9).

The phonological and lexical impairments described at the start of this hypothetical trajectory for LI have been described and demonstrated by many researchers (Bishop, 1997b; Bishop, 2000; Chiat, 2001; Constable et al., 1997; Conti-Ramsden, 2003a; Maillart et al., 2004; Mainela-Arnold et al., 2008; Seiger-Gardner & Brooks, 2008). Such impairments may arise as a result of a later start into word learning as a smaller lexicon is thought necessarily to imply less efficient lexical and phonological processing (Walley, 2005; Werker & Curtin, 2005) or it is possible that an additional impairment may exist which makes the phonological and lexical processing of children with LI less efficient than TD children even with equivalent lexical knowledge.

Two key questions therefore emerge from consideration of this trajectory: first what is the *primary* cause of this late and slow start into word learning for children with LI? And second, are the subsequent lexical and phonological processing impairments entirely explained by limited lexical knowledge, or does an additional impairment exist? This chapter seeks to address these questions through consideration of the first step into word learning, the fast-mapping of a novel word.

With respect to the first of these questions, what is the primary cause of this late and slow start into word learning for children with LI? As previously acknowledged the process of word learning involves multiple skills and cues and the word learning difficulties of children with LI could be caused by an impairment in any one or indeed a combination of these skills. It is beyond the scope of this study to explore all of these possible sources however, a number of possible *'primary impairments'* in LI have been advanced including processing capacity limitations (Ellis Weismer & Evans, 2002; O'Hara & Johnston, 1997), a phonological processing deficit (Bowey, 2001, 2006), a syntactic bootstrapping deficit (van der Lely, 1994), a phonological working memory (PWM) deficit (Gathercole *et al.*, 1999b), and an auditory processing deficit (Tallal, 2000). This study seeks to explore the influence of phonological processing and lexical processing on word learning by considering the influence of phonotactic probability (PP) and Neighbourhood Density (ND) on the fast-mapping abilities of children with LI and their TD peers and to consider changes in their influence across development. In this way the abilities of the children with LI to use their sub-lexical and lexical knowledge to support word learning will be examined and changes in these abilities across development elucidated. The influence of PP will uncover the abilities of the children to use sub-lexical knowledge to support fast-mapping. The influence of ND will uncover the abilities of the children to use lexical knowledge, and overall fast-mapping scores will uncover the influence of PWM and processing capacity. In this way the results of this study will speak to the phonological processing, PWM, and processing capacity explanations for the word learning difficulties found in LI. It must be noted however that this study will explore the word learning abilities of children with LI between the ages of 3 and 7 years. It therefore can only address the causes of the word learning deficit at this particular time point within the developmental trajectory of LI. To identify the initial, innate and primary impairment or impairments prospective longitudinal studies of word learning and speech processing in infants with long term follow up of language learning outcomes are necessary. With respect to the second question: are the lexical and phonological processing impairments found in children with LI entirely explained by their lexical knowledge? As mentioned previously, results of the non-word repetition task described in Chapter 3 suggested that an additional impairment does exist and that it could be in the ability to abstract sub-lexical level representations from lexical knowledge. This chapter will consider whether performance of children with LI on a fast-mapping task corroborates this finding through consideration of the relationship between task performance and vocabulary growth in the two groups, and will consider whether further insights can be gained as to the structure, functioning and nature of developmental change in the lexicons of these two groups of children.

4.1.2 The Influence of PP and ND on Word Learning in Typical Development

4.1.2.1 Experimental studies

Evidence that PP affects word learning in children was first presented by Storkel and Rogers (2000). In this paper they presented experimental data demonstrating a high PP advantage during the fast-mapping of nouns in 10 and 13 year old typically developing children. That is, in a classroom lecture context, the children were more able to learn new words with high PP than those with low PP. Since that time this result has been replicated in younger children aged between 3 and 6 years for nouns (Storkel, 2001) and for verbs (Storkel, 2003). In adults however a *low PP* advantage has been demonstrated (Storkel *et al.*, 2006). Taken together, these results are suggestive that the influence of PP may change across development, moving from a high PP advantage in children to low PP in adults. The results however are difficult to interpret as it is only in the last study, with adult subjects (Storkel et al., 2006) that the ND and PP of stimuli have been orthogonally varied, all previous studies co-varying and therefore confounding these variables.

Although ND and PP are highly correlated separable influences on adult processing have been demonstrated in repetition and same/different judgement tasks such that PP is thought to influence the phonological level of processing and ND the lexical level (Vitevitch & Luce, 1998; Vitevitch et al., 1999). It is important therefore to consider whether such separable influences are in action during word learning and to date it is not possible to say whether ND, PP or an interaction between these variables produced the effects on children's word learning abilities reported in Storkel's studies.

Storkel, et al's study of adult word learning used stimuli which orthogonally varied ND and PP and demonstrated separable effects on adult word learning such that more low PP than high PP words were learned and more high ND than low ND words were learned (Storkel et al., 2006). This study assessed word learning through an expression probe with the proportion of correct phonemes as the dependent variable. The low PP and high ND advantage was evident where both partially correct and totally correct responses were combined. However, further analysis considering partially and totally correct responses separately found that only PP and not ND exerted a significant effect on partially correct responses and only ND and not PP exerted an effect on totally correct responses. Storkel and colleagues suggest that the phonological and lexical levels of representation may therefore influence different aspects of word learning in adults, with low PP acting as a "trigger" to begin new word learning and high ND acting to support the novel representation to "stabilise".

The effect of PP and is thought to occur when the adult recognises that they have heard a novel word and so a "word learning mechanism" is triggered. Low PP words are more easily recognised as novel as they are more readily identified as differing from existing lexical representations than words with high PP. Hence low PP words are more likely to trigger word learning at the first exposure than those with high PP and so the word learning mechanism will be 'on' for more exposures for a low PP word than for a high.

Stabilisation is influenced by ND and is posited to be the result of spreading activation between the novel representation and its lexical neighbours through shared units at the phonological level of representation. This process strengthens links between the lexical representation and the phonological level with fewer exposures to the new word for a word with high ND than for a word with fewer neighbours. Hence words which were totally correct were more likely to have high ND than low ND.

To date, one experimental study has claimed to separately consider the influence of PP and ND on children's word learning (Hollich *et al.*, 2002). This study taught a new word to infants aged 1;05, however, prior to word learning, the infants were exposed to three possible lists of words, a list which contained words which were all neighbours of the target word (the high ND condition) a list which contained very few neighbours of the target word (the low ND condition) or a list which contained no neighbours of the target word (the zero ND condition). The high ND condition being exposure to 12 neighbours of the target word each repeated six times the low ND condition being exposure to 3 neighbours and 9 non-neighbours of the target word each repeated six times, and the zero ND condition being 12 non-neighbours each repeated six times. After list exposure and word learning trials the children's word learning was tested using the split screen preferential looking paradigm. This paradigm tests whether infants demonstrate a preference (in terms of looking time) for the referent of the newly learned word when they hear the word and are presented with two pictures, the target referent and a distracter. The infants only demonstrated a preference for the target in the low ND condition. Hollich and colleagues claim that this demonstrates that the infants had produced a competitive network of lexical representations in the absence of semantic representations during exposure to the list of neighbours. This competitive network then made it more difficult for the child to recognise and learn the novel word. In addition the infants in the zero ND condition also performed more poorly than those in the low ND condition. In fact words were *only* learned in the low ND condition and were not learned at all either in the zero or high ND condition. Hence having *some* neighbours was beneficial for word learning but having *too many* had a negative effect.

Hollich and colleagues (2002) suggested that this result may reflect the influence of PP on the word learning process. That is, hearing the neighbours 18 times (in the low ND condition) affected the phonological level of processing, as no lexical representations were created but a facilitative phonological processing effect occurred, but hearing the neighbours 72 times affected the lexical level of processing such that a competitive network of lexical representations was created.

To test this hypothesis they repeated the experiment exposing the children to each of the word lists only once such that the high ND condition had 12 repetitions of the neighbours and the low ND condition had 3. If the PP of the words was indeed facilitating word learning then it was anticipated that a reversal of the previous result would be observed with the high ND/high PP condition now producing better word learning results than the low ND/low PP condition. This was indeed the case, suggesting that there are separable effects of PP and ND on infants' word learning (a high PP advantage and a low ND advantage) and that these effects are mediated by the amount of prior exposure to similar words.

Taking Hollich's results for infants and Storkel's results for adults together, it therefore would appear that the influence of ND and PP on word learning changes across development moving from a high PP to a low PP advantage and from a low ND to a high ND advantage. The methodologies of these studies however are obviously very different and so must be interpreted with caution. Support for Hollich's findings can be found from the results of a recent experimental study by Swingly and Aslin (2006). This study examined the influence of neighbourhood density on word learning in 18 month old infants. This study considered the phonotactic properties of the novel words but did so only post-hoc and so it is difficult to be entirely sure of the source of their results. That is, they found the infants were unable to learn 'novel neighbours' which were novel words similar to words in the children's lexicons (e.g. tog – a neighbour of dog) but were able to learn novel nonneighbours, that is words which were not similar to familiar words (e.g. meb). Hence low ND appeared to facilitate word learning in these young children. The post-hoc consideration of PP considered whether the PP of the novel neighbours was significantly different from the PP of the nonneighbours. The results of this analysis found differing results depending on the PP metric employed and which stimuli were compared. However, although the authors conclude that their results were unlikely to be caused by differences in the PP of the stimuli, it is not possible to rule these effects out entirely.

Interestingly, Swingley and Aslin, in previous studies of word recognition have found infants aged 18 months of age can discriminate between neighbours and nonneighbours of familiar words (e.g. dog-tog) (Swingley & Aslin, 2000). It would therefore seem unlikely that a poorly specified lexical representation could be the source of the children's difficulties in triggering word learning for a word which has a familiar neighbour. Werker has also found similar apparently contradictory results with 14 month old infants who confuse phonetically similar words when they are linked to objects but can discriminate them when they are not (Werker &

Yeung, 2005). Werker suggests this difference arises from differences in the overall processing demands of the tasks. Swingley and Aslin however suggest that the nature of the child's lexical processing mechanism may be the source of this difference. That is, that very young children may be more likely than older children to see novel neighbours as 'near misses' of words which already exist in their lexicons than older children and so do not trigger word learning for these words. This tendency to view neighbours as near misses occurs because the children are still developing phonological categories from the allophonic and indexical forms which they hear and are representing in their lexicons. Hence they are not able to use strict phonological distinctions in word learning as they do not yet have fully formed phonological categories, and hence a phonological/sublexical level of representation, with which to make these distinctions. They therefore assume, on hearing the word 'tog', that it may be a form of the word dog which this particular individual may produce due to accent or individual differences (indexical information) or that the word initial /t/ may be an acceptable allophonic form of /d/ in this context (phonetic information).

A third explanation of this finding is also possible and is presented by Werker in her PRIMIR model (Werker & Curtin, 2005); that both Werker and Swingley and Aslin are correct. That is, through the emergence of a sub-lexical/phonemic level of representation, improvements occur both in overall processing capacity and in the child's ability to use phonological distinctions to bootstrap word learning. That is, having a phonological/sublexical level of processing decreases the child's reliance on more detailed phonetic encoding hence increasing efficiency, and increases lexical processing specificity through the support of phonological categories with which to distinguish between word forms. Such an explanation would accord with the proposed model of the developing lexicon described in Chapter 3 where the process of 'lexical restructuring' is reframed as changes not in the nature of the lexical representation but rather in the nature of the newly emerging sublexical/phonemic level of representation and in the number and nature of the connections between lexical nodes.

4.1.2.2 Studies of vocabulary composition

Studies of children's vocabulary composition have provided insights into possible word-learning biases across a broader range of development than reported by Hollich and colleagues (2002). Storkel (2004a) considered the influence of ND, word frequency and word length on the age of acquisition of nouns as reported by 1,800 parents using the infant and toddler versions of the CDI (Dale & Fenson, 1996; Fenson et al., 1997), hence covering the age range 12 - 30 months. This analysis revealed that early acquired words in this group of very young children were higher in density, shorter in length and higher in frequency than those learned later. There were however significant interactions between frequency and ND and word length and ND. That is, high ND had an effect only for low frequency words suggesting that increased exposures to a word could override the effect of ND on word learning. The ND x Length interaction revealed an effect of ND only for monosyllabic words. This is likely to be due to the very limited variability in densities of polysyllabic words with the median number of neighbours for words of six phonemes or more being zero (Storkel, 2004b). Hence a high ND bias would appear to exist in very young children's word learning for short, low frequency nouns. Once again this study co-varied PP however and so whether this result is due to PP or ND effects remains moot. Storkel argues that the high ND bias is likely to be present for all words (both high and low frequency) in the first stages of word learning (fast-mapping), that is, when high and low frequency words are on an equal footing in terms of numbers of exposures. Storkel's experimental studies cited above which co-vary PP and ND in fast mapping tasks would appear to bear out that assumption.

Maekawa and Storkel (2006) attempted to tease out possible separable influences of PP, ND, word frequency and word length on children's word learning and possible developmental changes in their influence. This study considered the noun vocabulary use of three children, aged 16, 21 and 22 months in spontaneous language samples from the CHILDES database, over a 1 year period (MacWhinney, 2000). This study found considerable individual differences but word length had a consistent effect across all three children and across the time-span of the study, with shorter words being learned at an earlier age than longer words. It appeared however that the influence of PP may have been changing across development with high PP facilitating the youngest child but for the oldest child ND and frequency were most important with low ND facilitating acquisition. These single case studies point to a possible trajectory of influence across the age range of 16 – 34 months, however it is also possible that they may be measuring individual differences in processing biases rather than a trajectory of changing biases and so further research is needed.

Most recently Storkel (2009) has returned to the exploration of infant CDI data (aged 1; 04 – 2; 06) to consider the separable influences of PP, ND, word length and a range of semantic variables on the age of acquisition of nouns and to consider changes in their influence across development. For semantic variables, Storkel found a changing developmental profile such that words with many semantic neighbours were more difficult to learn in the 1; 04 – 1; 08 age group but were easier to learn in the 1; 10 – 2; 06 age group. For PP, a low PP advantage was demonstrated and this remained stable across the age range studied. For ND Storkel used a lexical composite score combining the effect of ND and word length, as these variables were highly correlated. Results for this score indicated a high ND/short word advantage with the advantage increasing from age1;04 to 1;08 but decreasing from 1; 08 to 2; 06 such that the advantage remained, but was of a much smaller magnitude for the oldest children in the study.

4.1.2.3 The developmental trajectory of influence of PP and ND

The results of both experimental studies of word learning and studies of vocabulary composition are highly suggestive of separable effects of PP and ND on the word learning abilities of young children. They do differ however in terms of the nature of the developmental trajectories of influence of these variables. Storkel's CDI data (2009) suggest that the influence of PP may be stable across development, and that the *relative* influence of ND may change across the age range studied. Overall, the results were very similar to those found for adults (Storkel et al., 2006) and so could therefore represent continuity and stability in the overall influence of PP and ND on word learning over development.

It should be noted however that Storkel's results appear to be directly at odds with those of Hollich and colleagues (2002) .That is, Storkel finds, for children aged 1; 04 – 2; 06, more infants knew words with low PP and high ND than words with high PP and low ND. Hollich's results suggest the opposite pattern, with a high PP and low ND advantage for word learning. Hence it is not yet possible to say unequivocally whether the trajectory of influence of PP and ND is stable or changing across development (see Figure 4.1)

Differences in the chosen methodologies are likely to explain these apparently contradictory findings. Storkel's vocabulary composition data represent the results of long term word learning, the results of Hollich's two experiments however, can be interpreted in two ways; as evidence of the separable influences of ND and PP respectively (as the authors describe) and so, as directly contradictory to Storkel's findings, or as representing the difference between 'word learning' (in the first experiment) and fast mapping (in the second). That is, perhaps the methodology used cannot truly claim to manipulate PP and ND separately, rather PP and ND are co-varied and differences in the resulting effects may be due to their joint influence at different stages of the word learning process. If we conceptualise 'word learning' as the process of adding information to a lexical representation where a lexical network of neighbours has already been created for the novel lexical item, then both Hollich's first experiment and Storkel's vocabulary composition analysis could represent 'word learning'. The low PP advantage found in Storkel's data and the low ND/PP advantage found in Hollich's first experiment would then be compatible. Hollich's second experiment would then represent results where no lexical network has been created, thus better representing the process of fast mapping. From this standpoint Storkel's results would appear to represent the result of long term 'word learning' but neither study clearly identifies the separable effects of ND and PP on fast-mapping.

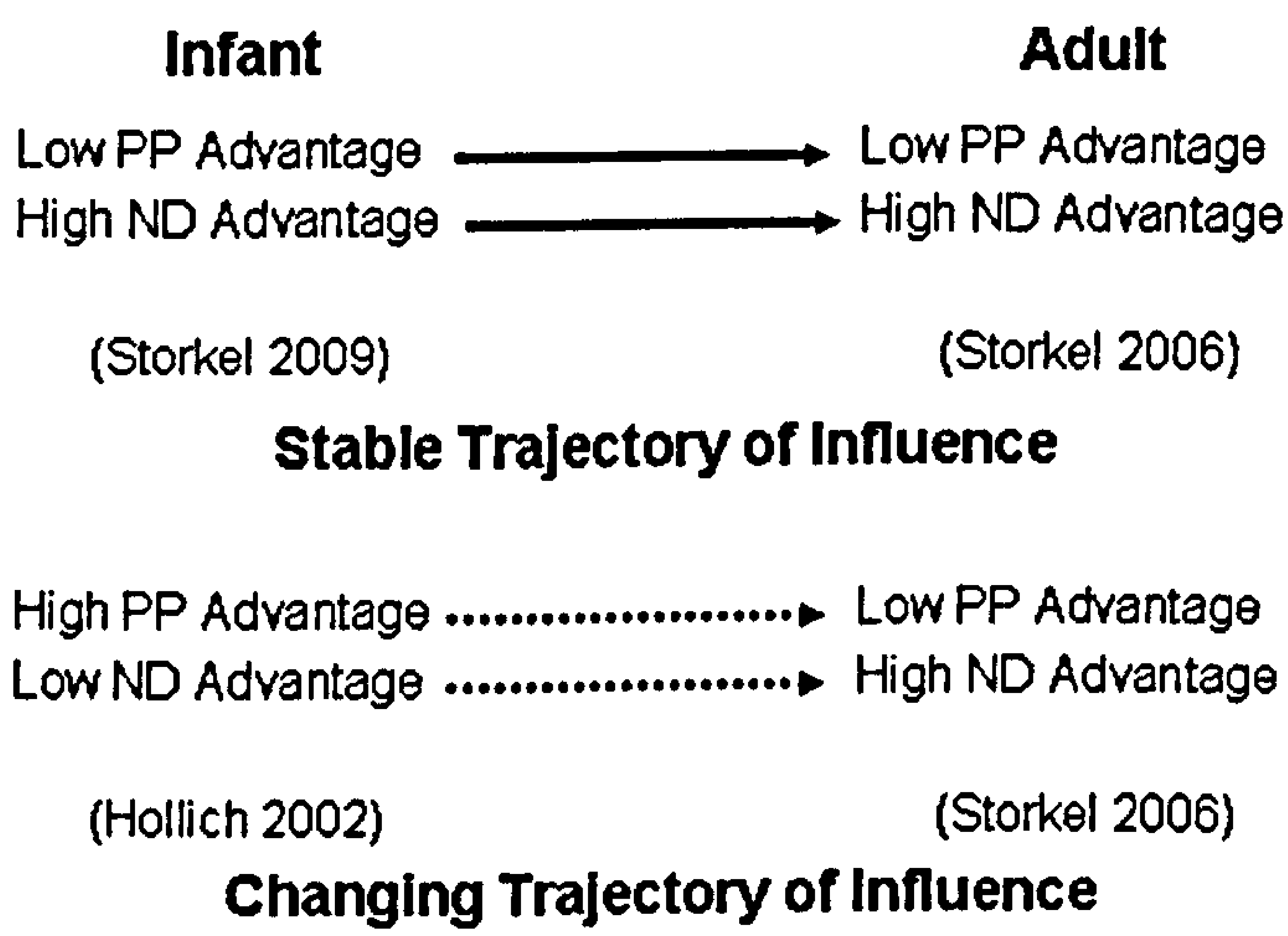


Figure 4.1. Possible trajectories of influence of PP and ND on word learning

As Storkel states "ultimately, additional data are needed from studies that systematically vary these factors while examining learning of words fully crossed in phonotactic probability and neighbourhood density to more clearly determine when and how each variable influences word learning by infants" (Storkel, 2009, p. 314).

This study will answer Storkel's call for direct experimental evidence through examining the fast mapping abilities of TD children with stimuli which vary PP and ND orthogonally and in addition will consider changes in their influence across development. In this way, whether PP and ND evince a stable or a changing trajectory of influence on the process of fast mapping will also be considered.

4.1.3 The Influence of PP and ND on Word Learning in LI

Despite the number of researchers advocating a phonological processing impairment as a possible source of word learning difficulty in LI there have been very few studies which have directly manipulated phonological variables and considered their influence on the process of word learning in LI. This can partly be explained by the dominance of the PWM explanation of the word learning impairments in LI and the subsequent focus on non-word repetition abilities and their relationship to vocabulary learning, but also because developmentally appropriate and relatively pure measures of 'phonological sensitivity' or 'phonological processing' are difficult to design and there is no accepted methodology for tapping this level of skill or knowledge in young children. As outlined above, the manipulation of PP in experimental stimuli has proved fruitful in tapping phonological processing in word learning in TD children and so would seem to be an appropriate methodology to pursue in children with LI.

Research regarding the nature of lexical impairments in LI has focussed on the concept of holistic, underspecified lexical representation within the framework of the lexical restructuring model (Maillart et al., 2004). Recently however, evidence has been presented that lexical networks in children with LI are more susceptible to interference, and that difficulties with inhibiting competing words may contribute to the processing difficulties of these children (Mainela-Arnold et al., 2008; Seiger-Gardner & Brooks, 2008). Indeed these studies question the notion of 'holistic lexical representations' in LI and rather posit inefficient lexical processing with difficulties arising in suppression and decay of activated representations. As discussed in Chapter 3 these findings, together with a developmental connectionist model of the lexicon, where lexical representations are in fact distributed connections to multiple levels of representation and whose characteristics are derived from the number, weighting and distributions of these connections, would suggest that immature and impaired lexicons are better conceptualised as 'inefficient networks' rather than as being comprised of 'holistic representations'. In this way the impairment would lie in the nature of the representations at all levels, phonetic, phonological and semantic, and in the nature of the connections between those levels and between competing lexical nodes. Examining the influence of ND on word learning in LI could shed some light onto the nature of the development of the lexical network in LI and on its influence on word learning for these children.

To date only one study has considered the influence of PP on the word learning abilities of children with LI and none have considered the influence of ND. Alt and Plante (2006) investigated the influence of PP on children's abilities to learn the lexical labels and the semantic features of novel objects within a fast-mapping paradigm. This study found that overall the children with LI scored more poorly then their TD peers, recognising fewer lexical labels and mapping fewer semantic features about the newly learned referents. In the lexical label probe, where the children where asked to decide whether or not the word they heard was the correct label for a given referent, neither group's performance was affected by the PP of the lexical item. In the semantic feature probe however PP did exert an effect, but only for the children with LI. That is, the children with LI were able to map as many semantic features as the TD group where the novel word had a high PP but mapped significantly fewer semantic features in the low PP condition.

Alt and Plante explain these findings within the limited processing capacity framework of Just and Carpenter (1992). This framework suggests that individuals have a limited overall processing capacity and that during learning there are trade-offs between processing and storage. Hence, a difficult task takes up a great deal of processing capacity and so minimal information is passed to the long term store, whereas an easy task takes up a small amount of processing capacity and so more information can pass to the long term store. Hence, in this case, the phonological difficulties of the children with LI made it difficult for them to process low PP words, this increased difficulty used up more processing capacity than was used for the high PP words and so less was available for long term storage. In this way less information regarding the semantic features of the novel words passed to the long term store for the low PP words than for the high.

Unlike the majority of the other studies cited considering the influence of PP on processing, this study did consider the ND of the stimuli. The stimulus words were all bisyllabic, which necessarily reduces the number of neighbours, and so ND was zero for all stimuli except for two of the six high PP words (each having two neighbours). The authors therefore concluded that ND was "relatively low for all stimuli" (Alt & Plante, 2006, p. 945). It is indeed highly likely that this study has succeeded in removing the confound of ND from its results, and that the effects identified do arise from the influence of PP on processing. However, the influence of ND on processing in polysyllabic words is not fully understood. It is possible therefore that having two neighbours should be considered as a high ND because it is relatively high for bi-syllabic words (Storkel, 2004b). Hence we cannot be certain whether the results outlined identify differences in processing at the phonological level, at the lexical level or an interaction between the two. This study therefore seeks to address this issue through the use of stimuli which vary PP and ND orthogonally.

This study will therefore test whether the influence of PP on the performance of children with LI on a fast-mapping task supports claims for impaired phonological processing abilities in this group and in addition, through the consideration of ND will examine the ability of the children with LI to use their lexical knowledge to support fast mapping. As described in detail in Chapter 3 the ability of children to use their phonological and lexical knowledge to support processing will depend upon the structure, functioning and nature of the lexicon. Changes in the influence of PP and ND on fast mapping over development and with respect to vocabulary knowledge should therefore also provide insights into the trajectory of change in the structure and functioning of the lexicon in the two groups.

4.1.4 Research Questions

The nature of influence of PP and ND on the fast mapping abilities in TD children and those with LI have not been clearly identified and the developmental trajectory of influence of these variables remains in question. This study seeks to address the following questions for both TD children and those with LI:

1. Do phonological (PP) and lexical (ND) variables exert separable influences on the fast mapping abilities the children?
2. Do these influences change across development?
3. What do these changes tell us about the in the structure and functioning of the developing lexicon in typical development

With respect to children with LI the study seeks also to address the following:

1. Are the trajectories of influence of PP and ND different from those of TD children?
2. What do changes in the influence of PP and ND, and similarities and differences between the groups tell us about the structure and functioning of the developing lexicon in LI?

4.2 Method

This experiment utilises data from a number of tasks included in the test battery for the larger longitudinal case-series study described in Chapter 2. Comprehensive details regarding participants, data collection timelines and overall study protocol are given in Chapter 2. Detailed information regarding the specific measures used in this experiment are described below.

4.2.1 Measures

4.2.1.1 Vocabulary measures

The children were tested using the Expressive One Word Picture Vocabulary Test (EOWPVT) (Brownell, 2000a) and the Receptive One Word Picture Vocabulary Test (ROWPVT) (Brownell, 2000b). EOWPVT raw scores were chosen as the vocabulary measure for this experiment as expressive vocabulary has been shown to be a stronger predictor of developmental changes in linguistic abilities than receptive vocabulary (Marchman & Bates, 1994). Raw scores were used as they provide a more sensitive method for comparison between TD and LI groups than standard scores.

4.2.1.2 Phonology screen

The Phonology Assessment subtest of the DEAP (Diagnostic Evaluation of Articulation and Phonology) (Dodd et al., 2002) was completed in order to make allowances when scoring the non-word repetition task for phonological substitutions used in the child's spontaneous speech. In addition to the 50 items of the published test, 11 items were added by the author, specifically for use when scoring a sentence repetition task which was part of the wider test battery not reported here. These items were also included in the current analysis as they provided additional exemplars for the phonemes /g/, /h/, and /b/ in word initial position (see Appendix 3).

4.2.1.3 The word learning task

4.2.1.3.1 The non-words

A range of CVC non-words were created which contained only early developing consonants (m n p b t d k g s f w j and h) (2;06-3;06) (Grunwell, 1985). The Phonotactic Probability and Neighbourhood Density of the candidate non-words were calculated and stimuli chosen varying PP and ND orthogonally such that two of each category of non-word were created (Table 4.1).

	High PP	Low PP
High ND	High-High	High-Low
Low ND	Low-High	Low-Low

Table 4.1. Categories of non-word stimuli with PP and ND varied orthogonally

4.2.1.3.1.1 Phonotactic Probability

The PP of the non-words was calculated from data in the CELEX database (Baayen et al., 1995) using the following formula:

For a given syllable $C_1V_1\,C_2$

n = total number of different syllables in English

x = number of syllables beginning with C_1

y = number of the x group of syllables which then go on to have V_1

z = number of the y group of syllables which then go on to have C_2

The phonotactic probability was calculated as $\log \frac{x}{n} + \log \frac{y}{x} + \log \frac{z}{y}$

This calculation incorporates the probability that C_1 is the onset of the syllable, and the probability that C_2 is the offset. A normal distribution of the log transformed probabilities was created such that a value of 0 represented the mean of the distribution and +/- 1 represented one SD from the mean. These calculations allowed for 'high' and 'low' PP to be easily identified. The candidate stimuli were ranked according to these calculations. The CELEX calculations were triangulated using Vitevitch's online "Phonotactic Probability Calculator" (Vitevitch & Luce, 2004) which yielded positional segment frequencies and biphone frequencies for the candidate non-words; Positional segment frequency being the likelihood of occurrence of a given sound in a given word position and biphone frequency being the likelihood of co-occurrence of two adjacent sounds. These calculations are based on the Hoosier Mental Lexicon (Nusbaum *et al.*, 1984) which is based on the Merriam-Webster Pocket Dictionary with frequency counts derived from Kucera and Francis (1967).

4.2.1.3.1.2 Neighbourhood Density

Neighbourhood Density was defined as the number of neighbours differing from the target by 1 phoneme substitution, omission or deletion and was also calculated using the CELEX database (Baayen et al., 1995). Using the same database for both ND and PP calculations ruled out the possibility that the two measures may have been differentially influenced by the nature of the sampling procedures of the databases from which they were drawn.

An estimate of what might constitute high and low neighbourhood density for young children was determined by considering the characteristics of the 3 phoneme words in the Morrison Chappell and Ellis word list (Morrison et al., 1997) with an age of acquisition of less than 5 years, and the 3 phoneme nouns in the British English version of the CDI (Fenson et al., 1997). The ND of each of these words was calculated using the above method. The mean and standard deviation of the numbers of neighbours were then calculated. High ND was classified as anything above the mean ($\mu = 23.7$) and low, as anything falling at least one standard deviation below the mean (SD = 8 therefore low ND ≤ 16).

4.2.1.3.1.3 Stimuli selection

Candidate stimuli were ranked by ND and PP. For the high ND /high PP non-words the stimuli with the highest possible values for each measure were chosen. For the low ND/low PP words the stimuli with the lowest possible values were chosen. For the low ND/high PP and high ND/low PP stimuli those non-words which fulfilled the ND criteria for high and low status were identified and then those with the lowest or highest possible PP values were chosen as stimuli.

Care was taken to ensure the stimuli were sufficiently distinct from one another and contained only early developing phonemes.

	Word	ND*	Log normalised PP*	Positional segment frequency**	Biphone frequency**	Referent Category
High ND	teɪn	34	.6232	.1698	.0042	toy
High PP	bɑɪn	38	1.0597	.1816	.0071	pet
Low ND	hɔɪf	4	-1.6534	.0625	.0042	toy
Low PP	jɔʃ	7	-1.607	.0321	.0006	pet
High ND	heɪm	25	-.6206	.1180	.0026	food
Low PP	ʃeɪt	29	-.0386	.1049	.0037	vehicle
Low ND	hɑn	9	.7673	.1960	.0156	vehicle
High PP	gek	13	1.0869	.1524	.0076	food

*CELEX **Hoosier Mental lexicon

Table 4.2. ND and PP characteristics of the chosen stimuli

4.2.1.3.2 The referents

The above eight novel non-words were paired with eight novel referents in a story context. The story was set on an alien planet and the novel objects created so as to represent items which could be members of the categories 'alien' toys, food, pets and vehicles with two items in each semantic category. The semantic categories were chosen from those which appear in the CDI and so which exist in the lexicons of typically developing children aged 2; 06 years (Fenson et al., 1997). This was to increase the probability that the categories existed in the lexicons of the children with LI and so to minimise the possibility that comparisons with the

TD children were confounded by differences in semantic category knowledge. Novel words were assigned to the referents so that for each semantic category pair (toys, foods, pets, and vehicles) the novel word pair contrasted high and low PP and high and low ND (see Table 4.2). The referents and the distracter objects used in the measures of word learning are presented in Appendix 10.

4.2.1.3.3 The word learning context

The children were introduced to the word-referent pairings in a story context involving two aliens going shopping. At each new location the aliens each bought or used a new referent from one of the categories, hence buying a toy each at the toy shop, a pet each at the pet shop, eating some food at the café and catching a rocket home at the 'rocket stop'.
During the story each word-referent pairing was presented eight times. To increase the number of repetitions whilst maintaining the child's attention, a 'storyboard activity' was completed after the story. In this activity the child was supported to retell the story using toy figures and scenes. The child built the high street of shops where the aliens went shopping, retold the story and was asked to try to remember which alien bought which items at each shop. This game provided the opportunity for an additional two repetitions of the word-referent pairings and also provided a measure of semantic-feature mapping (see below).
The story structure and sentence structures were designed to be as simple as possible with the novel word always presented in sentence final position and the carrier sentences containing a maximum of three clause elements (e.g. 'Jim likes the tɛm' 'Here's the hɔɪf'). This was in order to minimise the possible confound of level of grammatical knowledge on the word learning process. The story and storyboard script are presented in Appendix 11.

4.2.1.3.4 The measures of learning

Three measures of the children's knowledge of the newly learned words were used; a comprehension probe, an expression probe and a semantic feature probe. The comprehension and expression probes were presented at three points in the experimental paradigm; for each new category pair after the story episode which introduced them (i.e. the toys were tested after the toy shop visit, the pets after the pet shop visit and so on); for all eight novel words at the end of the story; and again, for all eight words at the end of the story board game. The expression probe was presented first at each testing point in order that the additional repetitions of the words during the comprehension probe did not influence the children's responses. The semantic feature probe was a part of the storyboard game and was completed once. The children were not given feedback regarding the accuracy of their responses but rewarded and praised for their effort and concentration. The overall structure of the task is outlined in Figure 4.2.

Exposures	Measures of Word Learning
2 x Toys introduced 3 repetitions each	
	1. Toys expression and comprehension probe
3 additional repetitions of each toy	
2 x Pets introduced 3 repetitions each	
	2. Pets expression and comprehension probe
3 additional repetitions of each pet	
2 x Food introduced 3 repetitions each	
	3. Food expression and comprehension probe
3 additional repetitions of each food	
2 x Vehicles introduced 3 repetitions each	
	4. Vehicle expression and comprehension probe
3 additional repetitions of each vehicle	
2 repetitions of each novel word	
	5. All novel words expression and comprehension probe
Storyboard context	Semantic feature probe
2 repetitions of each novel word	
	6. All novel words expression and comprehension probe

Figure 4.2. Schedule of exposures and word learning measures in the fast mapping task

The expression probe: lexical retrieval and output

The expression probe considered the ability of the child to retrieve and produce the lexical representation they had created for the novel words. To succeed at this task the child must have created an accurate representation of the phonological string for the novel word, a representation of the referent for the novel word, and a link between the two and in addition must then access and produce that representation. Success on this probe therefore measured both the ability to fast-map a lexical-semantic representation and the ability to retrieve it. The probe was scored by counting the number of correct phonemes produced in order to give credit for partially correct representations or word retrieval.

The children were presented with a page of pictures including pictures of the object referents and a number of familiar, early developing nouns chosen randomly from the CDI, and were asked to name them. For expression probes 1 - 4 (see Figure 4.2) 5 pictures were presented, the 2 target referents and 3 additional familiar nouns. For expression probes 5 and 6 (see Figure 4.2) 12 pictures were presented, the 8 target referents and 4 additional familiar nouns. The familiar nouns were included to increase the children's experience of success as the author's previous experience of word learning tasks suggested that many children would perform at close to floor on this expression probe. Ensuring some success was intended to support the maintenance of the children's motivation and willingness to attempt to name the novel words. Where a child's first response was "I don't know" or I can't remember" they were encouraged to try again. The children's responses were transcribed in broad phonemic terms.

In order to score the expression probe with due consideration of the children's phonological systems, The DEAP Phonology Assessment for each child was analysed and tokens of the consonants used in the novel words identified. Those tokens which occurred in monosyllabic words and in a singleton context were considered. Tokens from polysyllabic words were excluded to reduce possible effects of articulatory assimilations (e.g. yellow → /lɛlo/) or unstressed syllable deletion (e.g. tomato → /moto/). All target vowel tokens were also identified. Any substitutions or omissions used by the child were noted and the expression probe scored in the light of the analysis, hence any errors in the expression probe which coincided with speech sound substitutions present in the DEAP Phonology Assessment were scored as correct. The dependent measure was therefore number of phonemes correct.

The comprehension probe: lexical semantic fast-mapping

The comprehension probe tested the abilities of the children to fast-map a representation of the phonological string for the novel word (a lexical representation), a representation of the referent for the novel word (a semantic representation), and a link between the two representations. The child was asked to "show me the X" and selected the corresponding picture from a choice of four. The four pictures included the target referent, the referent from the same semantic category in the story (the related distracter), another referent from the story from a different semantic group (the unrelated distracter), and a novel object which did not appear in the story (the foil).

Scoring of this task focussed on both overall fast-mapping success (i.e. the number of correct responses) and also on the pattern of errors, as it was anticipated that these error patterns would reflect the nature of the semantic networks being created by the children as they created novel semantic representations.

A response on the comprehension probe of choosing the target (T) at a level above chance would suggests the child had successfully created both a lexical and a semantic representation which was sufficient for them to recognise on a subsequent presentation, and the correct lexical-semantic link between the two.

A response of choosing the related distracter (RD) at a level above chance would suggest that the child had created a lexical representation which was sufficient for recognition but had either created a connection to the incorrect semantic representation, that of the object in the same semantic category as the target referent, or had integrated the novel referents into a semantic network with links created between the toy, pet, vehicle and food items. The child had therefore made a link between the lexical representation and the *semantic category* of the two novel referents but not to the specific semantic representation of the correct referent.

A response of choosing the unrelated distracter (UD) could suggest that the child was guessing and perhaps has not created a lexical representation sufficiently detailed for recognition. However if the child chose the UD at a level above chance then that would suggest that the child had created a lexical representation sufficient to recognise it again, but that this representation was not linked to a specific semantic representation. Rather it was linked to the semantic category 'appears in the story'. Hence the child had made semantic level representations of the referents, had made links between them, creating the global category 'appears in the story' but had not created the correct links between the lexical and semantic level representations or between the specific sub-categories of semantic representation (toy, pet, food, vehicle).

A response of pointing to the Foil (F) could, in the same way as for the UD, suggest that the child had not created a lexical representation which was sufficiently detailed for recognition and so the child was simply guessing. Pointing to the foil at a level above chance however may suggest that the child had not created a lexical representation of the word at all and so responded as though they have never heard the word before. That is, the child assumed that this 'novel word' must refer to a novel referent, and so chose the foil.

Responses can therefore be conceptualised as representing a decreasing level of detail in the fast-mapped representation across the four response types.

The semantic feature probe: semantic feature fast-mapping

The semantic feature probe considered the ability of the child to fast-map a detailed semantic representation of the referent. Specifically the children were scored on whether they had included in their semantic representation, associations between the referent and its location and the referent and its possessor. [3]

During the storyboard game the children were supported to retell the story with small alien figures, pictures of the locations in the story and the objects included in the story. As the child retold the story they took the aliens to the appropriate story locations. They were then prompted to find the objects which the aliens bought there. For example, when at the toy shop they were asked "can you find the toys Jim and Bob bought?". The child was presented with a choice of all of the referents in the story and an additional eight distracters, of which two could plausibly represent members of each of the semantic categories (e.g. having eyes so as to plausibly represent a pet). They were then asked to give the item to the correct alien (see Appendix 11).

The children were scored as to whether they remembered which items were bought at which location and which alien had bought which referent, hence scoring one point for mapping the semantic feature of 'location/semantic category' and so choosing the correct objects, and one point for the mapping the feature 'possessor' and so giving the object to the correct alien. the children therefore could score a maximum of two for each referent. Where the child chose the incorrect items they scored zero for the semantic feature 'location/semantic category', but were given the correct items to see if they could complete the second part of the task correctly (i.e. assigning the possessor).

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[3] The term "semantic feature" is used loosely to extend beyond traditional linguistic definitions of semantic features and to include the range of linguistic and non-linguistic conceptual information which children learn and associate with novel words in the first stages of fast-mapping. Hence, although 'possession' may not be a semantic feature in linguistic terms it may represent a conceptual feature which children map about a novel referent during the fast-mapping process. The term fast-mapping is not limited to mapping of linguistic information. There is evidence from visual to visual mapping studies that fast-mapping occurs for relations that are not traditionally considered linguistic (Wilkinson *et al.*, 1996). Also Kersten and Smith (Kersten & Smith, 2002) found that children learning lexical labels denoting actions learn detail about the action but also remember the appearance of the object involved in the movement.

4.3 Results and Discussion

A series of regression analyses and within and between subject ANOVAs and ANCOVAs were completed in order to consider the influence of development and phonological (PP) and lexical (ND) variables on the fast mapping abilities of TD children and those with LI. Results and discussion are presented in three sections, firstly those pertaining to the TD group, secondly those regarding the children with LI and finally statistical comparisons between the groups are presented.

4.3.1 Typically Developing Children: Results

The research questions addressed with respect to the trajectory of development of word learning skills in typically developing children were as follows:

1. Do phonological (PP) and lexical (ND) variables exert separable influences on the fast mapping abilities of the children?
2. Do these influences change across development?
3. What do these changes tell us about the in the structure and functioning of the developing lexicon in typical development?

These questions will be addressed firstly with reference to *overall fast-mapping ability*, as measured by the number of correct responses (T) in the comprehension probe, number of correct phonemes in the expression probe and the number of correct semantic features in the semantic feature probe. Secondly, results will be presented with reference to the *error patterns* exhibited in the comprehension probe to consider what these may tell us about the nature of the semantic networks being created by the children and how this process of creating a network may be affected by phonological and lexical variables.

4.3.1.1 Overall fast mapping ability

4.3.1.1.1 Comprehension probe: lexical semantic fast-mapping abilities

Linear regression analysis showed no significant relationship between age and choosing the Target in the comprehension probe [$R^2 = .01$, $F(1,37) = .31$ $p = .58$] (Figure 4.3). The TD children were therefore not improving in their overall ability to fast-map novel words over the age range studied (37-62 months)

Figure 4.3. TD trajectory of lexical-semantic fast mapping abilities: Target

The influence of PP on the abilities of the TD children to correctly identify the target in the comprehension probe across development was analysed using a one-way within subject ANCOVA with PP as the within subjects factor and age as the covariate. Phonotactic probability exerted a significant influence on the TD children's ability to fast map the novel words correctly such that low PP words had an overall advantage [$F(1, 36) = 4.29$, $p = .046$, partial $\eta^2 = .11$]. However there was a significant PP x Age interaction; the younger children demonstrating a high PP advantage and the older children demonstrating a low PP advantage [$F(1, 36) = 6.15$, $p = .02$, partial $\eta^2 = .15$] (Figure 4.4).

Figure 4.4. Influence of PP on TD children's lexical-semantic fast mapping ability: Target

Neighbourhood Density exerted a significant influence on the TD children's ability to fast map the novel words correctly such that low ND words had an overall advantage [$F(1, 36) = 7.53$, $p = .01$, partial $\eta^2 = .17$]. The ND x Age interaction approached significance [$F(1, 36) = 3.28$, $p = .08$, partial $\eta^2 = .08$]. Inspection of the trajectory suggests that the disadvantage to fast mapping exerted by high ND may be reducing across development (Figure 4.5).

Figure 4.5. Influence of ND on TD children's lexical-semantic fast mapping ability: Target

Taken together these results indicate that the TD children were not improving in their overall ability to fast-map novel words over the age range studied (37-62 months). However changes in the influence of PP and possibly also of ND across the age range are highly suggestive that significant changes in the *nature of the processing abilities and biases* brought to bear on the fast-mapping process were occurring across this age range. In addition separate and distinct effects of ND and PP on the process of fast-mapping in children have been demonstrated.

4.3.1.1.2 Expression probe: lexical retrieval and output

The developmental trajectory of scores on the expression probe is presented in Figure 4.6.

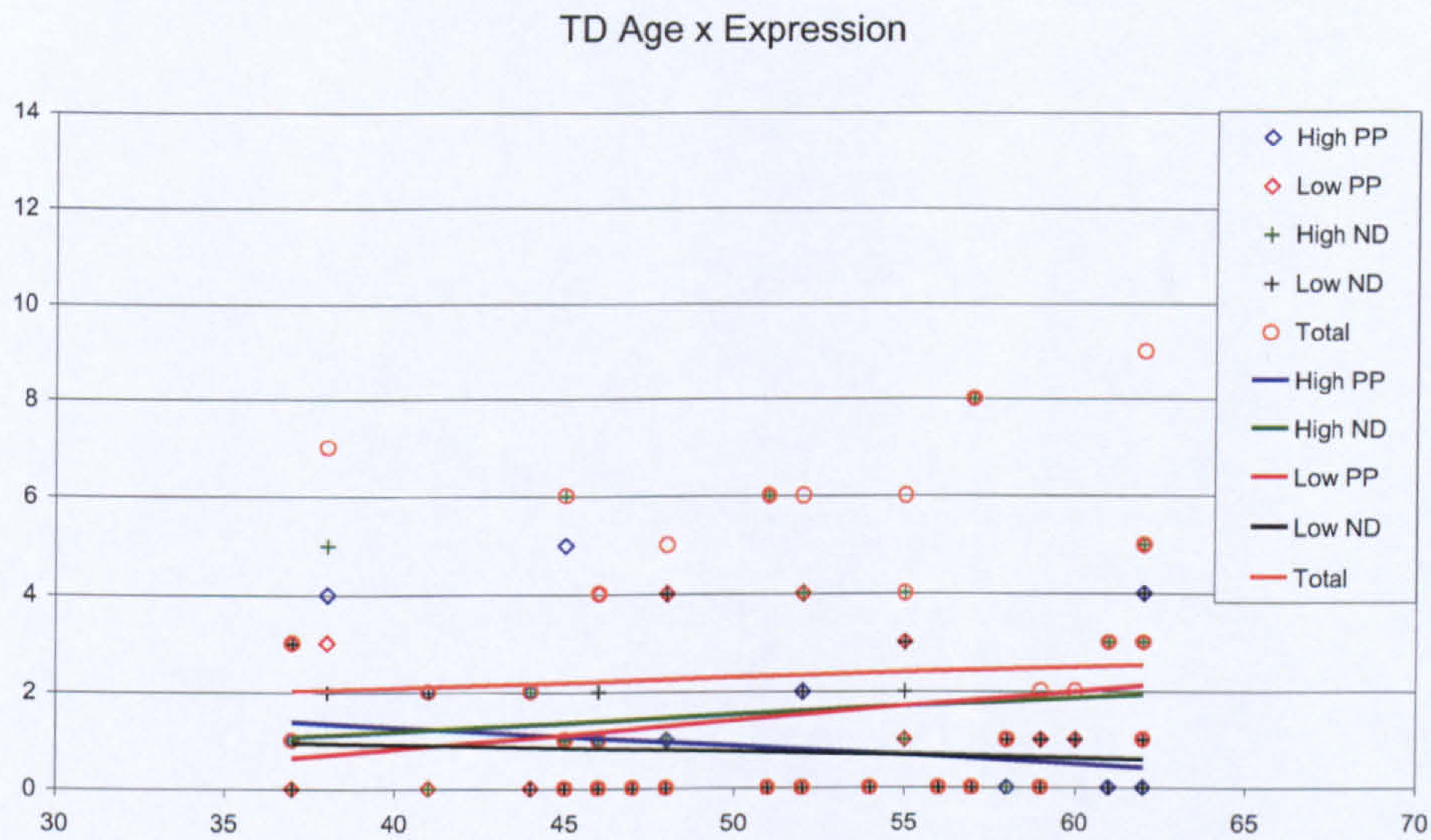

Figure 4.6. TD trajectory of lexical retrieval and output from fast mapped representations

As is evident from Figure 4.6 the TD children achieved very low scores on this probe. From a maximum possible score of 72, 13 children performed at floor, the average score was 2.3 and the highest score achieved was 9. In addition, linear regression demonstrated that the children's scores were not systematically related to age [Total score: $R^2 = .003$, $F(1,37) = .11$, $p = .74$].

A one way within subjects ANCOVA with PP as the within subjects factor and age as the covariate revealed that there was no significant difference in expression probe scores for high and low PP words [$F(1,36) = 2.16$, $p = .36$, $\eta^2 = .02$] however the PP x Age interaction approached significance such that high PP scores may be decreasing with age and low PP scores increasing [$F(1,36) = 3.89$, $p = .056$, $\eta^2 = .10$] (Figure 4.7).

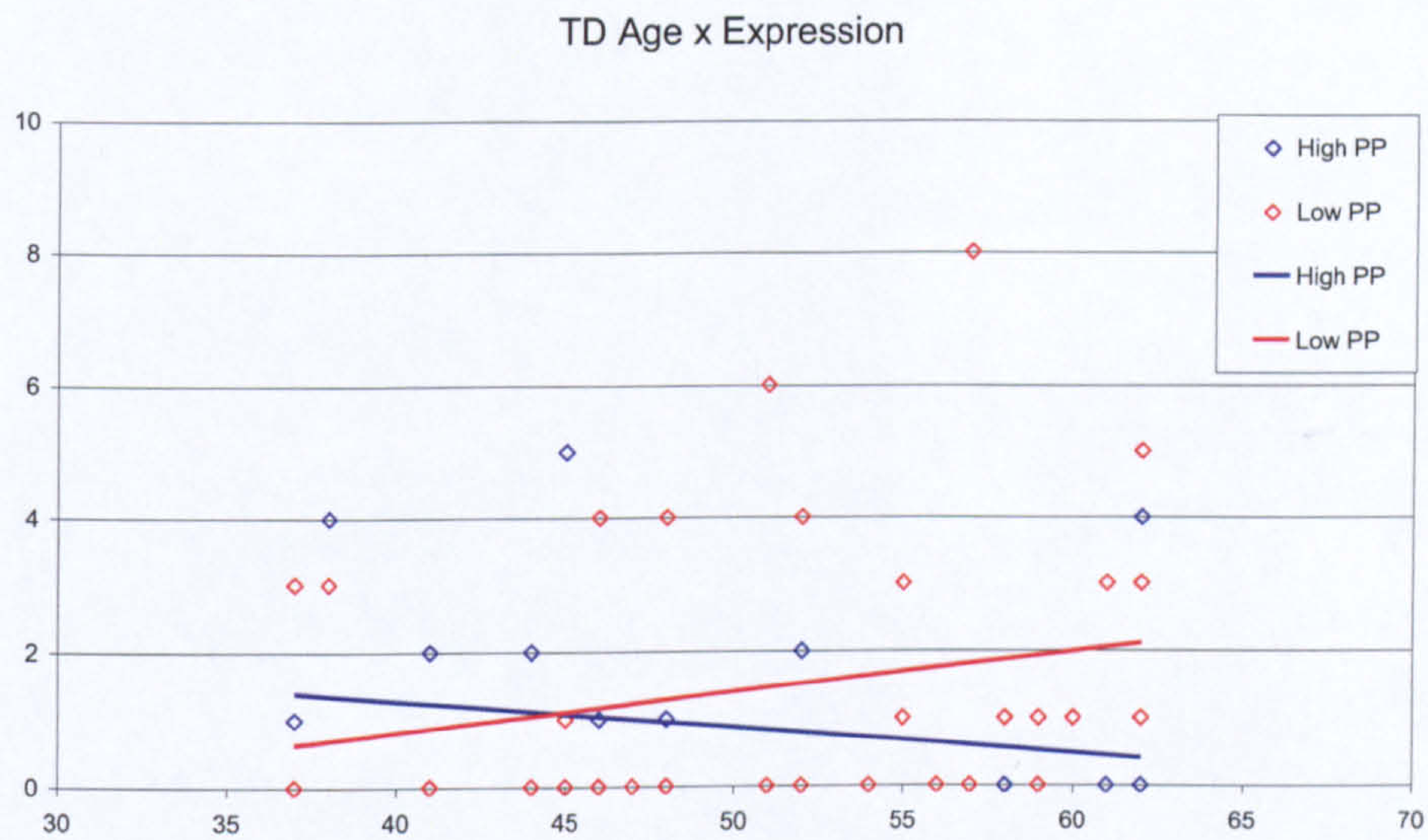

Figure 4.7. Influence of PP on TD children's expression probe scores

One way within subjects ANCOVA with ND as the within subjects factor and age as the covariate revealed that there was no significant difference in expression probe scores for high and low ND words and no significant interaction between ND and age [ND: $F(1,36) = .02$, $p = .88$, $\eta^2 = .001$; ND x Age: $F(1,36) = .834$, $p = .37$, $\eta^2 = .02$] (Figure 4.8). A one way within subjects ANOVA however did demonstrate a significant effect of ND such that high ND words scored more highly [$F(1,37) = 4.86$, $p = .03$, $\eta^2 = .12$]. This further analysis was completed as the patterns of interaction suggested by the graph in Figure 4.8 can mask significant main effects (Thomas et al., 2009).

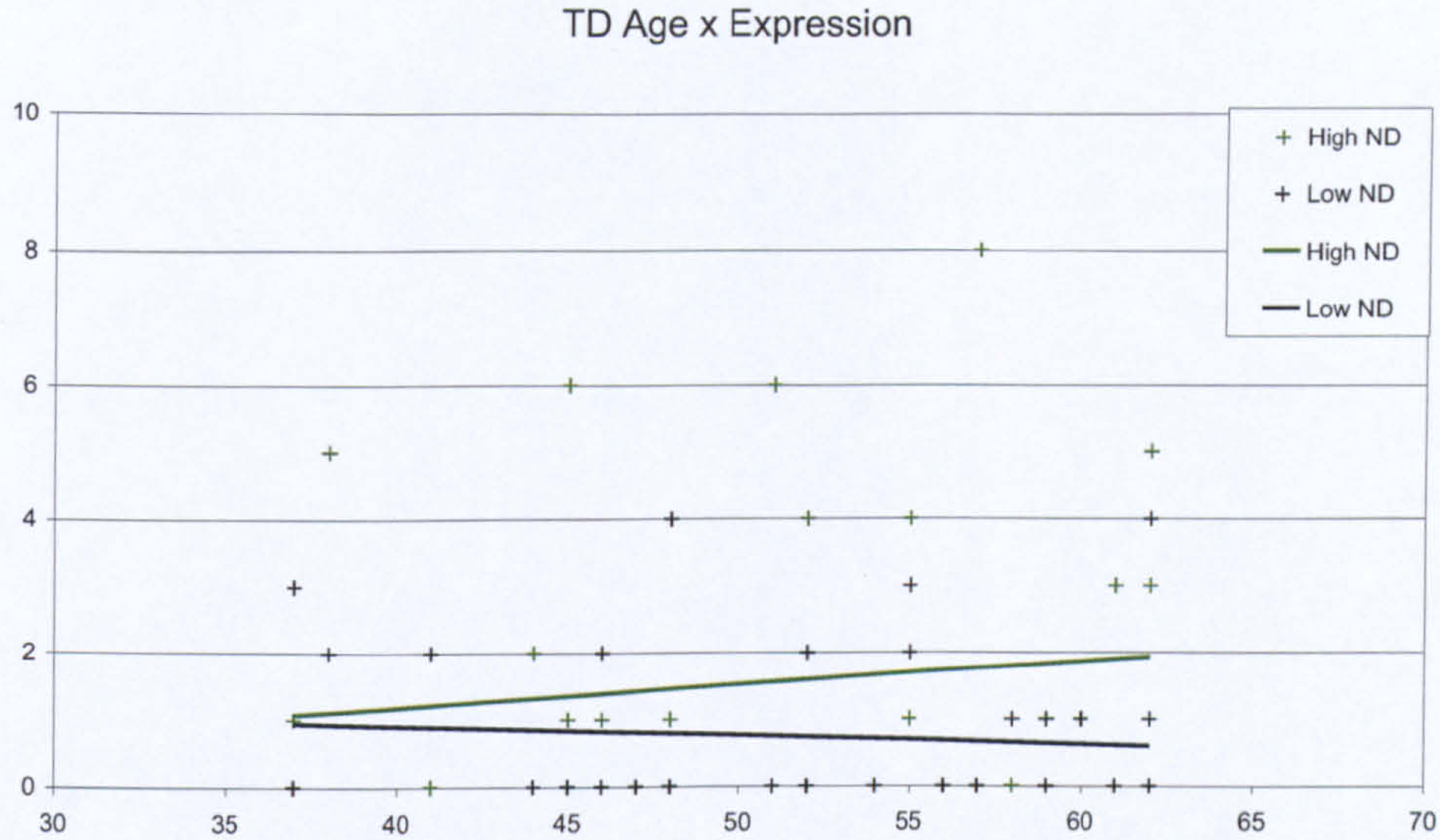

Figure 4.8. Influence of ND on TD children's expression probe scores

These results must be interpreted with caution due to the very low scores and the fact that the results only approach significance. It is possible that these results suggest that the effect of PP on expressive scores is similar to its effect on comprehension probe scores, hence the influence of PP measured here may reflect its influence on the process of fast-mapping a representation rather than on its retrieval. Alternatively it may indicate that PP has a similar effect on both mapping and retrieval processes. The influence of ND appears to differ from its influence on the comprehension probe scores. That is, a high ND advantage for the expression probe and a low ND advantage for the comprehension probe. Once again the children were not improving in overall ability with age. As previously stated, these results must be interpreted with caution however they are suggestive of distinct effects of ND on different aspects of the word learning process, a low ND advantage for fast-mapping and a high ND advantage for retrieval.

4.3.1.1.3 Semantic feature probe: semantic feature fast-mapping abilities

The developmental trajectories of responses to the semantic features probe are presented in Figures 4.9. Linear regressions were used to characterise the trajectories and a series of one-way within subject ANCOVAs with PP or ND as the within subjects factor and age as a covariate were used to explore the trajectory of influence of PP and ND across development.

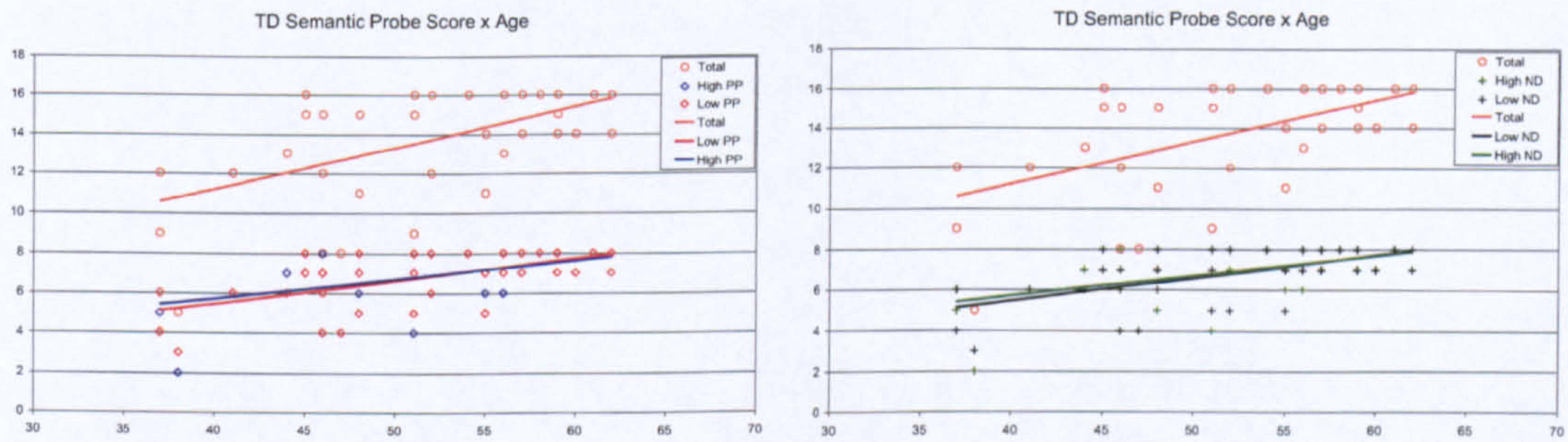

Figure 4.9. TD trajectory of semantic feature fast-mapping abilities

Linear regression analysis demonstrated a significant relationship between scores on the semantic features probe and age, that is the TD children's scores increased as they grew older [$R^2 = .30$, $F(1,37) = 15.34$, $p < .01$].

ANCOVA analyses showed their was no significant effect of PP [PP: $F(1,36) = 2.19$, $p = .15$, $\eta^2 = .06$; PP x Age: $F(1,36) = 1.92$, $p = .18$, $\eta^2 = .05$] and no significant effect of ND [ND: $F(1,36) = 1.13$, $p = .30$, $\eta^2 = .03$; ND x Age: $F(1,36) = .69$, $p = .41$, $\eta^2 = .02$].

In summary therefore the TD children appeared to learn more semantic features of the referents as they grew older but these scores were not affected by the PP or ND of the words. This result runs counter to the previous results as it is suggestive that the children's overall processing capacity may be improving with age, hence the older children were able to map more semantic features than the younger children. Increased processing capacity however was not demonstrated through increased accuracy in the other word learning measures as there was no systematic increase in scores with age. In addition, the fact that this measure, unlike the comprehension and expression probes, appeared to be independent of the influence of lexical and phonological variables is suggestive that semantic feature mapping may tap different processing mechanisms to those of the comprehension and expression probes. This issue will be returned to in the discussion.

4.3.1.2 Error patterns: comprehension probe

The TD children demonstrated the expected response pattern on the comprehension probe (Figure 4.10) such that the most common response was to correctly choose the Target, followed by choosing the Related Distracter, then the Unrelated Distracter, and finally Foils were the least frequent response.

A series of within subject ANOVAs demonstrated significant differences between the proportions of response types. [T versus RD: $F(1, 37) = 30.63$, $p <.01$, partial $\eta^2 = .48$; RD versus UD: $F(1, 37) = 33.84$, $p <.01$, partial $\eta^2 = .87$; UD versus Foil: $F(1, 37) = 4.42$, $p =.04$, partial $\eta^2 = .11$.]

Consideration of Figure 4.10 suggests that the error patterns may differ depending on the PP or ND of the words. To examine the effect of PP and ND on error patterns, two 3*2 within subject ANOVAs using the proportion of errors as the dependant variable were carried out. These ANOVAs each examined the factor Error with three levels, RD, UD and F, and either the factor PP or ND with two levels, high and low. There were no significant interactions between the proportion of errors and PP or ND [PP x Error: $F(2, 74) = .66$, $p = .57$, partial $\eta^2 = .02$; ND x Error: $F(2, 74) = 1.24$, $p = .30$, partial $\eta^2 = .03$].

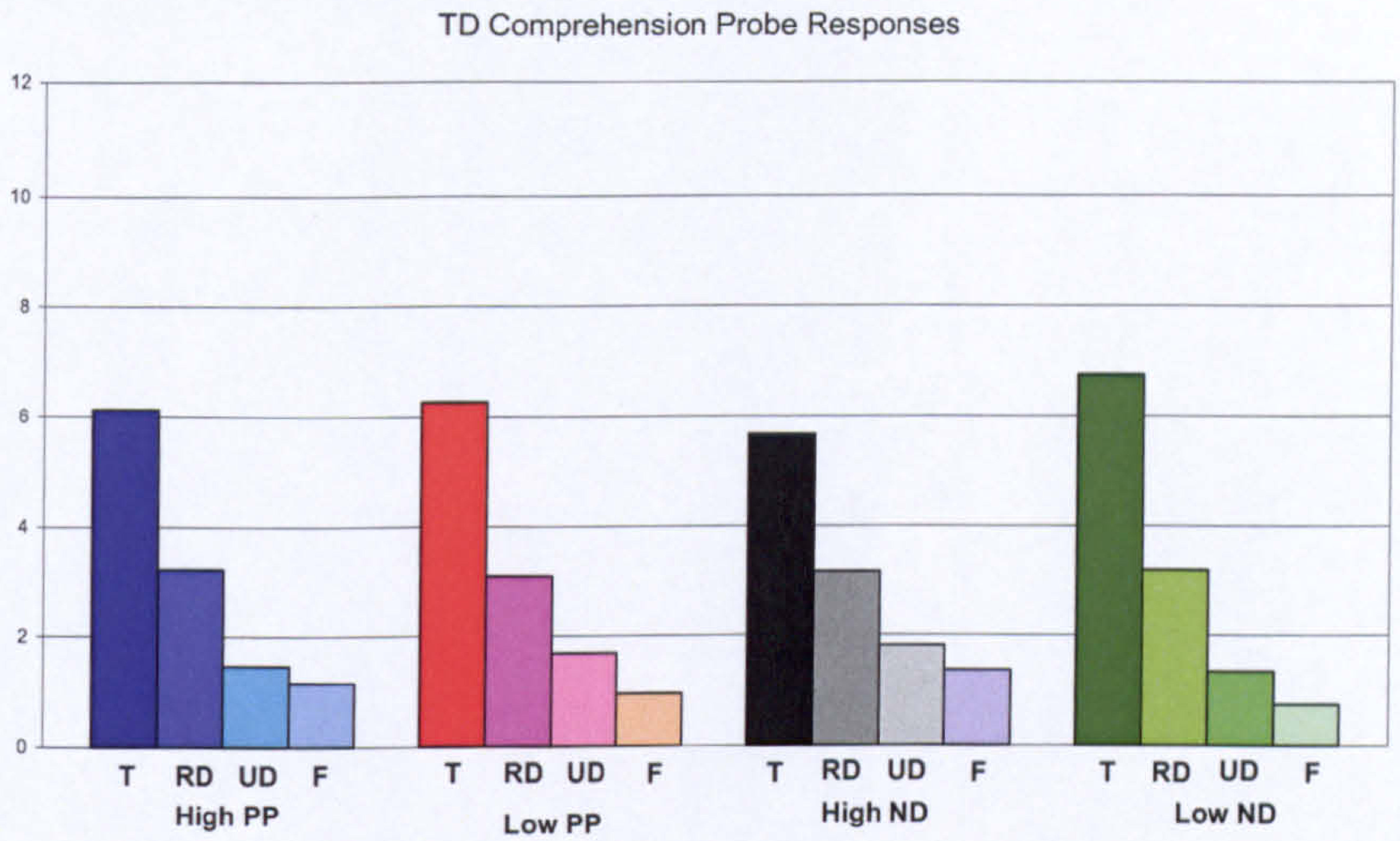

Figure 4.10. TD children comprehension probe pattern of responses

The developmental trajectory of the influence of PP and ND on error patterns was considered using a series of ANCOVAs with age as the covariate. The trajectory of influence of PP and ND on UD and F errors was simply a mirror of those for the choosing the Target. Hence for PP, as the children's tendency to learn high PP targets decreased with age the tendency to make high PP F and UD errors increased [PP x Age: UD: $F(1, 36) = 10.25$, $p < .01$, partial $\eta^2 = .22$; F: $F(1, 36) = 3.80$, $p = .059$, partial $\eta^2 = .10$], and for ND the overall low ND advantage evinced for choosing the Target was mirrored by increased UD and F errors for high ND words [UD: $F(1, 36) = 4.76$, $p = .04$, partial $\eta^2 = .12$; F: $F(1, 36) = 4.76$, $p = .04$, partial $\eta^2 = .12$]

The developmental trajectory of influence of PP and ND on the RD errors however differed from all other response types. For RD errors there was no significant effect of PP or ND and their influence did not change across the trajectory [PP: $F(1, 36) = .96$, $p =.34$, partial $\eta^2 = .03$;

PP x Age: $F(1, 36) = .79$, p =.38, partial $\eta^2 = .02$; ND: $F(1, 36) = .17$, p =.69, partial $\eta^2 = .01$; ND x Age: $F(1, 36) = .24$, p =.63, partial $\eta^2 = .01$].

Figure 4.11. Influence of PP on TD children's lexical-semantic fast mapping ability: RD errors

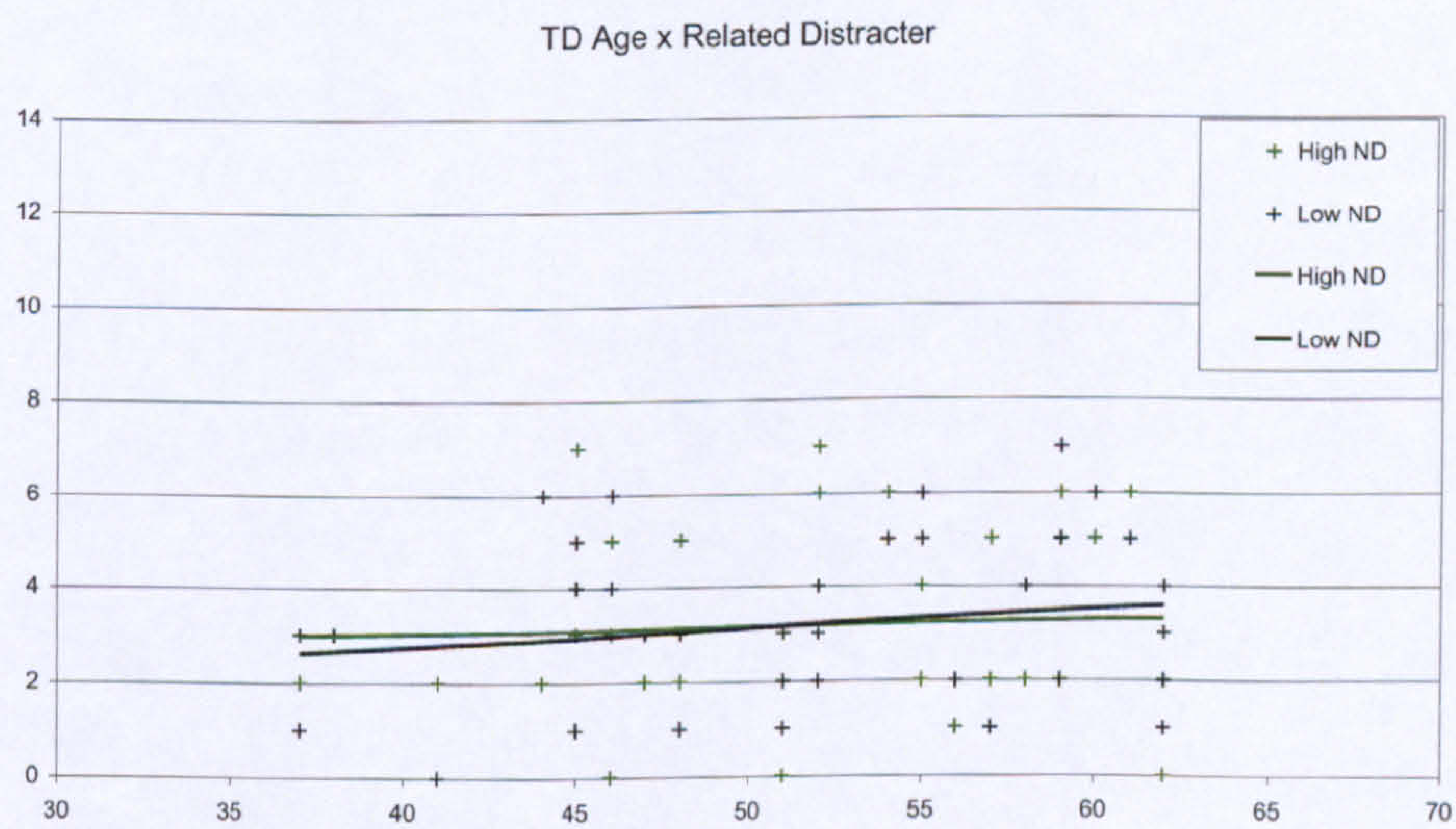

Figure 4.12. Influence of ND on TD children's lexical-semantic fast mapping ability: RD

Taken together the error data suggests that the TD children were most likely to either fast-map the word-referent pairing correctly or to at least map the word to the correct semantic category of the word (RD errors). Where this had not occurred the children then were more likely to make a UD than a F response, so indicating that they were usually able to recognise the fact that they had heard the word before and to then identify a referent from the story as a likely candidate for a correct response. This would indicate that the children had created a network of semantic representations for the novel referents 'appears in the story'. Phonological and lexical variables affected the children's ability to fast-map the words correctly and to make the correct link between the word form and the referent and, in a reciprocal way affected the frequency of UD and F errors. The number of RD errors however was not affected by the PP and ND of the words. It would seem therefore that creating semantic links between items within a category is a robust process for TD children, that the creation of the network begins at the very outset of word learning and is a process which is not readily affected by lexical and phonological variables.

4.3.2 Typically Developing Children: Discussion

The results described above demonstrate that lexical and phonological variables do exert separable influences on the fast-mapping abilities of children, that the influence of phonological variables (PP) changes across development and that the influence of lexical variables (ND) may also be changing across development. Surprisingly the children's overall fast-mapping abilities did not improve with age, rather, the changes in PP and ND described appeared to represent changes in the nature of the processing mechanism being used to learn new words and that these changes were more complex than merely an increase in overall processing capacity.

Error patterns suggested that the children were creating semantic networks from the very outset of word learning, usually at least creating a semantic category 'appears in the story' but most often were either creating a semantic link between the semantically related word pairs as indicated by a RD error (i.e. the toys, pets, food, vehicles) or creating a correct word-referent mapping as indicated by a correct response.

Lexical variables (ND) appeared to affect different aspects of word learning in different ways such that low ND supported fast-mapping but high ND supported lexical retrieval. Overall processing capacity also appeared to affect different aspects of the word learning process differentially. Hence, although increases in the numbers of semantic features mapped by the children with age would suggest increases in overall processing capacity, no overall increases in word learning ability with age were found in any of the other measures of word learning. The following discussion will therefore consider the effect of development, PP and ND on different aspects of the word learning process, will discuss how these results sit with past research results and will consider the final research question posed; what do the changes in the influence of PP and ND tell us about the structure and functioning of the developing lexicon?

4.3.2.1 Creating a lexical-semantic representation

4.3.2.1.2 The influence of phonological variables on fast-mapping ability

As identified above the phonotactic probability of the novel non-words exerted an influence on the children's abilities to choose the Target in the comprehension probe and hence to create a lexical and semantic representation of the novel words and to create a link between these two levels of representation. This effect changed across development moving from a high PP advantage in the youngest children to a low PP advantage for the older children. A reciprocal effect was found for the number of UD and F errors made.

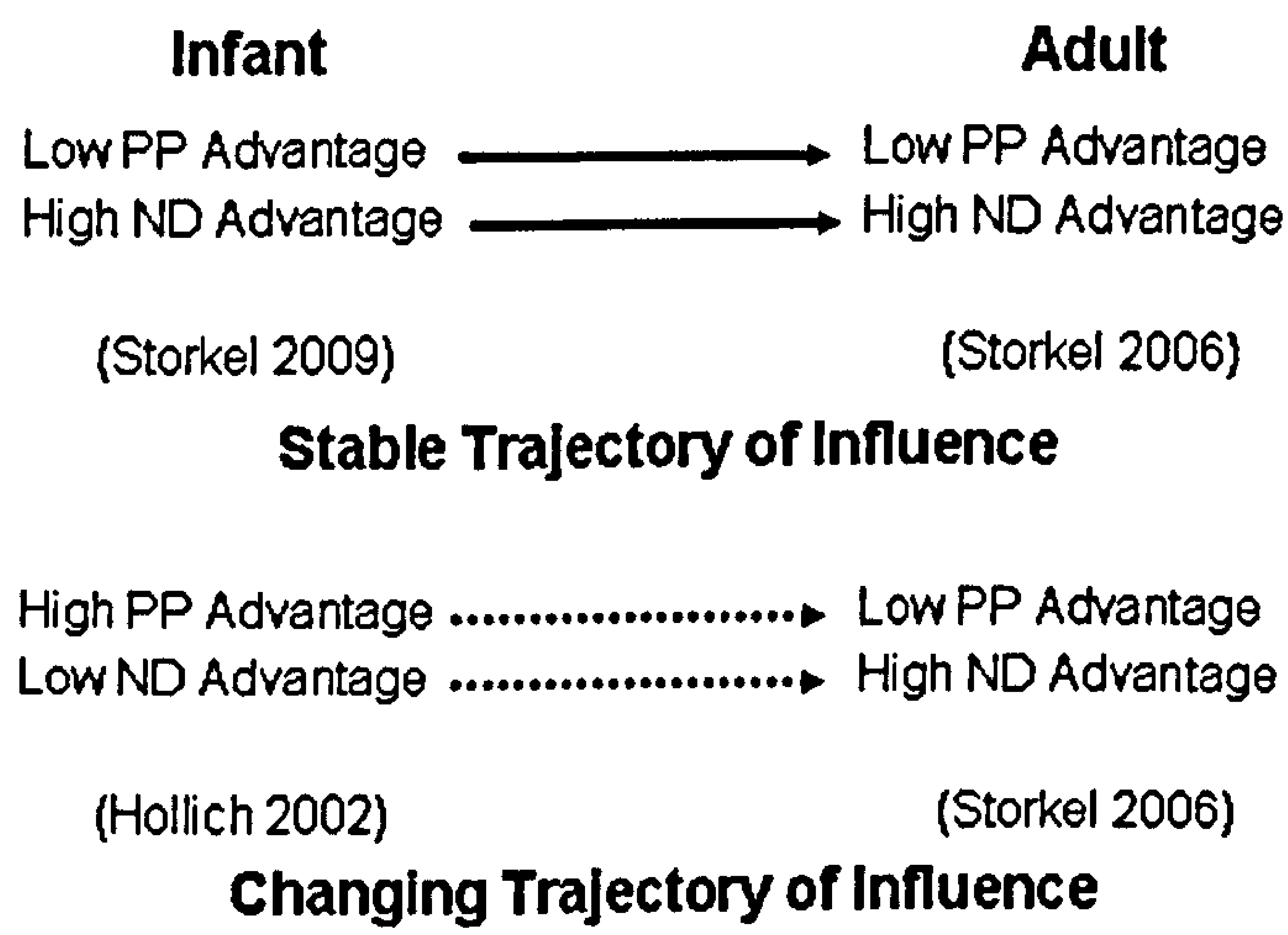

Figure 4.13. Possible trajectories of influence of PP and ND on word learning

These results therefore most closely correspond to those of Hollich and colleagues' results with respect to infants (Hollich et al 2002) and Storkel and colleagues' results with respect to adults (Storkel et al 2006). Hence for PP it would appear that for fast-mapping, the trajectory of influence of PP *changes across development* from a high PP advantage in infants and young children to a low PP advantage in older children and adults. The results presented here suggest that this 'switch' in processing bias occurs at around 4 years of age. What then might be the driver of such a 'switch'?

For infants and young children a bias towards mapping more frequent sound combinations may arise from continuities from the properties of the earliest, infant speech processing mechanisms. That is, sensitivities to the statistical regularities of the speech stream are thought to support the infant to abstract the phonetic regularities of the ambient language beginning with prosodic regularities by 6 months of age and moving to phonetic and phonotactic properties by 9 months of age (Jusczyk *et al.*, 1993). By 10 months of age these sensitivities result in a bias for listening to words with high PP (Jusczyk et al., 1994). Such a bias for high PP sequences could support the earliest stages of word learning as it is thought to be fundamental to the infants' ability to segment words from the speech stream. (Jusczyk, 1997b). That is, the infant is thought to meet the challenge of identifying individual words from the continuous speech stream through the integration of a number of cues; prosodic, distributional, phonotactic and phonetic. Prosodic cues are the first to develop, becoming available to the child at 7 ½ months of age (Jusczyk *et al.*, 1999b), however these are not sufficient to segment all words successfully and by 8 months of age distributional cues are also used and so the context within which a word is heard, is used to support segmentation (Jusczyk, 1997b). That is, the infant begins to 'remember' certain sound sequences, creating long term representations of them. Highly frequent word sequences (for example 'milk') create representations in the child's long term store and then subsequent presentations of the sound sequence activate this representation and therefore are perceived as single units. Subsequently the use of this word in a sentence supports the child to segment other sentence elements into individual words (e.g. 'chocolate milk carton' would be segmented into three units due to the presence of the familiar sequence 'milk'). It must be noted that this 'long term representation' is not equivalent to word learning at this stage as it does not necessarily implicate a link between the learned sound sequence and a semantic representation, rather it is thought that it constitutes a memory trace for the acoustic information of the word.

By 9 months of age phonotactic cues begin to be used (Mattys *et al.*, 1999). Phonotactic cues support the detection of highly probable and recurring sound sequences which would therefore most likely constitute a word, and also the identification of sound sequences with low probability (e.g /db/ or /kt/) which would therefore be most likely to constitute a word boundary. At 10 ½ months phonetic cues are integrated into the child's word segmentation 'tool-kit'. That is, infants have been shown to be sensitive to allophonic variation in speech sounds which are restricted to particular contexts (e.g. aspirated and unaspirated /t/ in word initial and final positions), to the distribution of these sounds within words, and to harness this knowledge to support them to detect word boundaries in continuous speech (Jusczyk *et al.*, 1999a).

A bias in favour of learning sound sequences with higher phonotactic probabilities in the infant would seem therefore to be a highly adaptive strategy for a number of reasons. Firstly, with respect to distributional cues, learning high frequency sequences easily, would create a set of long term representations for highly frequent sound combinations (e.g. in, is, mummy, daddy) which could then be used as distributional cues to further segment the speech stream and so identify more word units. A bias for doing this for high frequency sound sequences is obviously adaptive as learning a sequence which happens frequently will support further segmentation more frequently than if low frequency sequences were learned first. Secondly, with respect to phonotactic cues, identifying familiar sound sequences has been shown to support children's semantic mapping such that the presence of a familiar sound sequence is thought to instigate the 'search' for a probable referent. That is, the presence of sound sequences which the children recognise as 'word forms' has been shown to support both the individuation (Xu, 2002) and the categorisation of objects (Waxman & Lidz, 2006) in 9-12 month old infants and hence their semantic learning . Identifying and learning frequently occurring sound sequences therefore is an adaptive strategy for learning both word forms and word referents and so supports fast and efficient word learning.

Why then might children at the age of 4 'switch' their word learning preference to a bias for words with low PP? It is possible that a strategy of learning word with high PP becomes inefficient at a certain critical mass of vocabulary. That is, at a certain point in vocabulary learning, learning words which mostly have a high PP would become maladaptive for a number of reasons. Firstly, not all words have a high PP and, as the lexicon grows, the need to learn words with a wider range of phonotactic patterns becomes more necessary. Secondly, if word learning were triggered by a high PP sound sequence then this would entail the child's word learning mechanism be 'on' for most of their interactions with others. As described above this would be highly adaptive for very young children and would sit well with our knowledge of the impressive speed of lexical acquisition which has been described in the first years of language acquisition. However once the child has a large lexicon, to have a word learning mechanism which is switched 'on' for most of the time would be very wasteful of processing resources. That is, as the child would be encountering fewer novel words each day and would also be able to segment the speech stream into words using their lexical knowledge rather than their phonetic and phonotactic knowledge, the high PP bias would become less useful.

Storkel and colleagues (2006) suggested that the low PP advantage they found in adult processing could be explained by assuming that PP was being used as a pre-lexical processing trigger for word learning such that novelty of the phonotactic pattern instigated new word learning. The results presented here corroborate their finding and in addition identify the time point at which this change in bias occurs in the developmental trajectory. We could therefore perhaps characterise infants and young children as 'statistical learners' who are primed to learn many new words at a very fast rate, and older children and adults as 'novelty learners' who learn words only when novelty has been identified.

4.3.2.1.3 The influence of lexical variables

The neighbourhood density of the novel non-words exerted a separate and distinct influence on the children's fast-mapping abilities as indicated by their abilities in the comprehension probe. That is, overall low ND was advantageous to word learning with the interaction between age and ND approaching significance suggesting that the largest low ND advantage was present in the youngest children and that this advantage was decreasing with development. This trajectory therefore is distinct from that of the PP of the words and once again most closely corresponds to the findings of Hollich and colleagues' with respect to infants (Hollich et al 2002) and Storkel and colleagues' results with respect to adults (Storkel et al 2006). Hence for ND it would appear that for fast-mapping, the trajectory of influence of ND *changes across development* from a low ND advantage in infants and young children to a high ND advantage in older children and adults. It should be noted however that Storkel's adult data, demonstrating a high ND advantage, came from an expression probe and that the children in this study also demonstrated a high ND advantage for lexical retrieval. It is therefore also possible that the influence of ND is actually constant across development but differs according to task demands. The trajectory of influence of ND illustrated in Figure 4.5 is however suggestive of either a 'switch' in processing bias with respect to ND or a reduction in the ND effect over development, but further work with a wider age range of subjects would be necessary to be certain regarding this trajectory.

The pattern of influence of ND would suggest that the youngest children were able to identify words with few neighbours as being novel and hence attempted to learn those words. However, they found this more difficult for words with many neighbours, and so, as they were less able to discriminate those words from words which already existed in their lexicons, did not 'switch on' the word learning mechanism. For the older children this effect appears to diminish implying that the children become more able to make fine grained distinctions between the words they hear and those in their lexicons and so trigger word learning even for words with many neighbours. This result could be interpreted as indicating changes in the specificity of the child's lexical representations as described in the Lexical Restructuring Model (LRM) (Walley et al., 2003). However, in keeping with the model of speech processing presented in Chapter 3 and the findings of Werker (Werker & Curtin, 2005; Werker & Yeung, 2005) and Swingley and Aslin (2006), this result could also represent changes in the structure and functioning of the overall speech processing mechanism which would be most accurately characterised as the emergence of a sub-lexical/phonemic level of representation and changes in the number and nature of the connections between lexical nodes within the speech processing system. These changes then would allow for increased lexical processing specificity through the support of phonological categories with which to distinguish between word forms.

It should be noted that the older children in this study were beginning formal literacy instruction and were beginning to be exposed to phoneme-grapheme links and word segmentation strategies. It is possible that this instruction may also be playing a part in the children's development of phonological categories and to the timing of this switch in processing.

4.3.2.1.4 The interactive effects of lexical and phonological variables

The separable effects of ND and PP across the developmental trajectory described here obviously, 'in the moment' of word learning are operating simultaneously and so produce an overall effect which emerges from the interaction of the two variables and the two levels of processing mechanism.

In younger children (3 - 4 years) and older children (4 – 5; 06 years) the combined effects differ. In the younger children the high PP and the low ND biases are at their strongest, with the high PP bias supporting the system to learn many new words and the low ND bias tempering this PP influence so that the word learning mechanism isn't 'on' for every new word form heard but is only on for words which are significantly different from those which already exist in the child's lexicon. Hence in the younger children the lexical level may be operating as the word learning trigger through the influence of ND and the sub-lexical/phonemic level may be operating as a statistical learning device, identifying and learning frequent sound combinations.

In the older children the low PP bias is now at its strongest and the effect of ND appears to be reducing. Hence for these children, PP now has taken over as the word learning trigger with low PP suggesting 'newness' and being identified at a pre-lexical level. The children are now able to segment the speech stream into word units using their existing lexical knowledge and also do not need to learn as many high PP combinations as they have learned a great many of these already. Hence identifying and learning high PP sequences is no longer adaptive and so the pre-lexical speech processing mechanism can be put to a different use. In addition the emergence of sub-lexical/phonemic representations and the use of these distinctions in lexical processing, now allows the children to use phonemic contrasts in order to identify new words. This therefore reduces the negative impact of high ND on word learning as the children find it easier to identify which fine grained distinctions may carry meaning and therefore may represent the presentation of a new word.

This 'averaging out' of biases across the age span and changes in the structure and functioning of the speech processing and word learning mechanisms appear to produce no overall increase in fast-mapping efficiency across the age-range studied here. Rather they suggest adaptive re-organisation which results in the maintenance of the overall level of fast-mapping ability, despite the changes which increased lexical knowledge bring to the challenges of word learning across development.

4.3.2.2 Creating a semantic representation and a semantic network

Insights into the semantic level of representation of the newly learned words were gained both from the semantic features probe and from the error data from the comprehension probe. That is, the semantic feature probe was designed to tap the amount of semantic feature detail the children learned about the referents and the comprehension probe error data spoke to the nature of the semantic networks which were created by the children.

4.3.2.2.1 Semantic-feature mapping

Performance on the semantic feature probe was independent of lexical and phonological variables but did improve with age. This improvement with age may relate to increases in memory, processing capacity and/or attention control supporting the children to learn more information about the referents during the word learning task. It is important to note however that this is the only probe where age related change in scores and hence perhaps improvement in overall processing capacity was evident. That is, it would seem logical that if children were improving in their overall processing capacity that this would affect their *overall* word learning ability, not this one isolated aspect of the task. There are two possible explanations for this finding. One is that this task is not tapping overall processing capacity but rather increases in language abilities which support the children to learn more semantic feature information from the story context within which the words are presented and to understand the questions asked in the semantic feature probe more readily. The second possibility is that changes in overall processing capacity have influenced semantic feature mapping but not the other aspects of word learning measured due to their much greater reliance on lexical and phonological processing. That is the other measures of word learning are inextricably linked to the formation of a lexical representation for the novel word and so are influenced by phonological and lexical variables.

The changes in the organisational structure of the speech processing and word learning mechanisms described above therefore would explain why *overall processing capacity* has not improved on these tasks. Rather changes in *processing systems* have emerged which change the nature but not the overall level of efficiency of the word learning process. The mapping of a detailed representation of the semantic features of a referent could proceed without a lexical representation being formed and so could index that aspect of processing capacity which is independent of lexical and phonological processing. The fact that the semantic feature probe scores were unaffected by the influence of ND and PP would support this interpretation. Alt and colleagues have also found that TD children are able to map semantic features equally under a range of processing conditions and also suggest that the skills involved in mapping lexical labels and semantic features may be independent in typical development (Alt & Plante, 2006; Alt et al., 2004).

4.3.2.2.2 Creating a semantic network

Error data from the comprehension probe speaks to the nature of the semantic networks being created by the children. The children were most likely to either fast-map the word-referent pairing correctly (T) or to at least map the word to the correct semantic category of the word (RD errors). Where this had not occurred the children then were more likely to make a UD than a F response, so indicating that they were usually able to recognise the fact that they had heard the word before and to then identify a referent from the story as a likely candidate for a correct response. This would indicate that the children had at least created a network of semantic representations for the novel referents 'appears in the story' and often had also created the network for the semantic categories of toy, pet, food, and vehicle. It therefore seems that from the very outset of word learning typically developing children do not create isolated semantic representations of novel words but rather, immediately integrate them with other novel words they are learning into semantic categories. It is also possible that these semantic networks involve integration into existing semantic networks in the child's lexicon, however the error data is not informative on that point.

Phonological and lexical variables affected the children's ability to fast-map the words correctly and to make the correct link between the word form and the referent (T) and, in a reciprocal way affected the frequency of UD and F errors. The number of RD errors however was not affected by the PP and ND of the words. It would seem therefore that creating semantic links between items within a category is a robust process for TD children and so was not readily affected by lexical and phonological variables. Hence PP influenced the creation of lexical and semantic representations and the link between them (T) but not the formation of links between novel semantic representations.

It should be noted that Storkel (2001) found that PP did exert an effect on the proportion of RD errors made. The possible source of these differences will be considered in due course, however, whatever their cause it seems clear that typically developing children create semantic networks between representations from the very outset of word learning.

4.3.2.3 Lexical retrieval and output of newly learned words

The expression probe taps both what is learned during fast mapping and also subsequently what supports access and retrieval of the new representation. It must be noted that the TD children achieved very low scores on this task and so the following interpretation of the results must be viewed cautiously.

It appears that PP may have influenced expression in the same way as it did for comprehension, suggesting that perhaps the PP effects measured on this probe relate to its influence on the creation of the representation rather than on its retrieval. It is of course possible that PP may affect retrieval but that its effects exactly parallel those it exerts on the mapping process. ND however exerted opposing influences on comprehension and expression with low ND supporting creation of the lexical representation, through mechanisms already discussed, and high ND supporting retrieval. The mechanism for support of retrieval could be through facilitative activation of lexical neighbours linked to the new representation which then boost activation at lexical and sub-lexical levels and so support retrieval. Having more neighbours would therefore be supportive to greater access. These results imply that the TD children are creating links between *lexical representations* immediately that they fast map them in a similar way to the links established between semantic representations.

This process of facilitation for access could also support longer term retention of newly learned words through the process of stabilisation described by Storkel and colleagues (Storkel et al., 2006). Therefore, even if the children don't hear the new word again, a lexical representation with high ND could be reinforced through spreading activation from its neighbours when they are activated. This increased frequency of secondary activation for a high ND word could strengthen links between the lexical representation and the sub-lexical/phonemic level with fewer exposures to the new word than for a word with fewer neighbours. Hence the same process could be supportive of both long term 'word learning' and lexical access. Creating a lexical network at the very outset of word learning would therefore appear to be highly adaptive and supportive of the long term retention of words.

Finally, the fact that ND exerted opposing influences on comprehension and expression with, low ND supporting the creation of the lexical representation and high ND supporting retrieval, could perhaps partly explain the children's very low scores on this probe. That is, if the children were more able to create a lexical representation for low ND words but then high ND supported their retrieval, the children would only have learned very few high ND words to then retrieve for expression. This conflicting bias would therefore make retrieval very difficult directly after fast-mapping but may support access after a delay or after longer term word learning had occurred.

4.3.2.4 Placing the results in context

Three issues emerge from the results of the present study which require further exploration if they are to be fully integrated with previous research findings; firstly the nature of influence of PP on overall fast-mapping, secondly the influence of PP on the creation of semantic networks and representations, and thirdly the developmental trajectory of influence of PP and ND on word learning.

4.3.2.4.1 The influence of PP on fast mapping

Previous fast mapping studies in children carried out by Storkel and colleagues have consistently demonstrated a high PP advantage (Storkel, 2001, 2003; Storkel & Rogers, 2000). The present study demonstrated a low PP advantage overall and a changing trajectory of influence beginning with a high PP advantage which changed to a low PP advantage across development.

The most obvious source of difference between the studies is the fact that Storkel did not manipulate or control for the ND of the stimuli. As PP and ND are highly correlated Storkel's studies are best characterised as representing a comparison between high ND/PP words and low ND/PP words. However, the present study demonstrated an overall low ND and low PP advantage and so the influence of ND on Storkel's stimuli does not explain the high PP advantage in her results.

The crucial difference between Storkel's research and the present study is our focus on the *developmental trajectory of influence* of the variables. The present study examines the fast-mapping abilities of children aged 3;01 – 5; 02 and Storkel considers children aged 3;02 – 6;04. Our results demonstrate a high PP advantage in the children aged between approximately 3;02 and 4;00 and are suggestive that a high ND advantage may be emerging in the children aged 5;02 and above. Storkel's participants therefore may include a group evincing a high PP advantage (3;02 – 4;00) a group evincing a low PP advantage (4;00 – 5; 02) and a group evincing a high ND advantage (5;02 – 6; 04). *On average* therefore this group of children would demonstrate an overall high PP advantage, however by considering the influence both of ND and of development on processing, this study has demonstrated a more complex picture of the influence of PP on fast-mapping ability.

4.3.2.4.2 The influence of PP on creating a semantic representation and network

The present study found that the number of RD errors in the comprehension probe was not influenced by either the PP or ND of the novel words. However, Storkel (2001) did find an effect of PP such that a greater proportion of RD errors occurred for words with high PP than low PP.

Once again, a number of methodological differences between the studies may account for this disparity in results and again the most obvious candidate being the fact that in the present study, PP and ND are orthogonally varied. This could mean that the differences in phonotactic probabilities between the high and low PP conditions in the current study were less extreme than in Storkel's study and were not sufficiently different to exert an effect on processing. However PP did exert an effect on all other response types in the TD group and so this seems unlikely. Comparisons of the stimuli using a series of Two Sample T-tests found no significant differences between the stimuli in the two studies except for the biphone probabilities of the low PP items ($t(6) = 2.07$ $p = .042$ one tailed). In this case the stimuli used in the present study had higher biphone PP than those of Storkel (2001) (see Appendix 12). This may explain the differences in results between the two studies.

There were, however a number of additional methodological differences which should be considered. In order to make the task appropriate for children with SLI and to minimise the possible confound of the influence of language knowledge on the word learning process, the story and sentence frames were simpler than those used by Storkel (2001), the target words always appeared in sentence final position, early developing semantic categories were used and the number of exposures was 10 rather than 7.

Any of the above changes could therefore be the source of the difference between the studies. In fact *all* of the above changes *together* could have resulted in a lower processing load for the current task than the task presented in Storkel (2001) and so the overall success of the TD children could have made it less sensitive to the effects of PP. However as the T, UD and F responses were affected by PP then it may be that this interpretation is an oversimplification. An alternative source of the difference may be the choice of early developing semantic categories for the novel referents (toys, pets, food and vehicles in the current study as opposed to toys, musical instruments, candy machines and pets in Storkel (2001)). Perhaps being able to integrate all of the novel words into an *existing* semantic category facilitated the creation of a semantic network for the novel words and this facilitative effect overrode that of PP. This explanation would be in keeping with Storkel's most recent study of CDI data (2009) where, for children over 1;10 words with many semantic neighbours were easier to learn than those with few.

4.3.2.4.3 Developmental trajectory of influence of PP and ND

Results of the present study suggest a changing trajectory of influence of both PP and ND with development, from high PP to low PP advantage and from low ND to high ND advantage. They therefore fit most comfortably with the two experimental studies which claimed to manipulate ND and PP separately, namely Hollich et al (2002) and Storkel et al (2006).

Results which are harder to integrate with the current study however are those from Storkel's analysis of CDI data (Storkel, 2009). Storkel found a low PP and high ND advantage in children aged between 1;04 and 2;06 for word learning when the dependant veariable for analysis was the percentage of children using the words. Storkel herself acknowledges that these results are difficult to interpret as they represent the product of the word learning process rather than the process itself.

Results from the present study, suggesting that low ND may facilitate fast-mapping of a representation but high ND may facilitate retrieval for expression may however, provide a clue as to why words with high ND were advantaged in the CDI data. One possibility is that, as this data represents a record of those words used by the child, the high ND bias may be a measure of its facilitative effects on retrieval. That is despite the fact that, in reality, the lexicons of the children sampled may have been comprised of more low ND representations, the children found it easier to use those with high ND. This explanation seems unlikely as ND is only one of many factors which will dictate whether or not a word which exists in a child's lexicon is used or not. For example it would seem logical that pragmatic and functional constraints would override lexical biases in word use where a lexical representation does exist. Hence to find a high ND bias in CDI data it would seem most likely that it must represent the composition of the lexicon not simply its use.

The more likely explanation is that, as described previously, the stabilisation process described by Storkel and colleagues (Storkel et al., 2006) would support the longer term retention of a high ND words through spreading activation from its neighbours when they are activated.

The low PP advantage described by Storkel (2009) is more difficult to reconcile with the findings of the current study which do not suggest a low PP advantage until the children are at least 4 years of age. It is possible that the influence of PP changes more than once during the course of development, from low PP in the infant to high PP in the pre-schooler and low PP again in the school-age child. The bias for high PP sound sequences in infants, however is well established and so this explanation seems unlikely. It would seem more likely that the source of the difference lies in the distinction between the process and product of word learning, or between fast-mapping and longer term retention.

The distinction between fast-mapping and 'word learning' would therefore appear to be an important one, however it is challenging to determine where fast-mapping ends and 'word learning' begins. The operational definition described here, that 'word learning' occurs where a lexical network of neighbours has been created, is problematic as it would appear that lexical and semantic networks are created from the very outset of word learning. Studies of both types of word learning are warranted and methodologies perhaps comparing massed and distributed presentations of novel words may prove fruitful (Riches *et al.*, 2005).

4.3.2.5 The structure and functioning of the developing lexicon

The results of the current study are consistent with the model described in Chapter 3 based on the PRIMIR model (Processing Rich Information from Multi-dimensional Interactive Representations) (Werker & Curtin, 2005), and Perrehumbert's "probabilistic phonology"(Pierrehumbert, 2003)

4.3.2.5.1 Lexical level representations

The nature of influence of ND on fast-mapping suggests that young children are able to identify words with few neighbours as being novel, however they find this more difficult for words with many neighbours. Older children gradually become more able to make fine grained distinctions between the words they hear and those in their lexicons and so begin to trigger word learning even for words with many neighbours. I propose that these changes are best characterised as being the result of changes in the structure and functioning of the overall speech processing mechanism through the emergence of a sub-lexical/phonemic level of representation and changes in the number and nature of the connections between lexical nodes within the speech processing system. These changes allow for increased lexical processing specificity through the support of phonological categories with which to distinguish between word forms (Swingley & Aslin, 2006).

This explanation is favoured over the lexical restructuring account, which suggests that *lexical representations* become more fine-grained and less holistic as the ND of the words increase, for both empirical and theoretical reasons. Empirically, a number of researchers have demonstrated infants' abilities to detect fine grained distinctions for word recognition, hence suggesting that lexical representations are well specified even in very young children, although it must be acknowledged that these abilities are fragile and are sensitive to task demands and the saliency of the distinctions (Ballem & Plunkett, 2005; Swingley & Aslin, 2000). In addition, we suggest that theoretically, it is not sound to posit that a lexical node, having no representational content of its own, can restructure. Rather the restructuring must be occurring at the level of sub-lexical/phonemic level of representations which emerge as a consequence of increased neighbourhood density in the connections between the lexical nodes.

4.3.2.5.2 Sub-lexical/phonemic and phonetic/indexical level representations

The influence of PP on fast-mapping provides evidence for the influence of a phonetic/indexical level of processing and also of changes in the nature of that level of processing across development. That is, the phonetic/indexical level functions as a statistical learning device in the infant, supporting segmentation of the speech stream and early word-form learning. In the older child however, once the sub-lexical/phonemic level of representation emerges, the phonetic/indexical level does not become redundant but rather is used mostly to encode socio-linguistic and pragmatic information (Werker & Curtin, 2005). In addition to these functions it would appear that, in the older child, this pre-lexical level also takes on the role of word-learning trigger, allowing the word learning mechanism to be switched on at the very first exposure to a new word form, as indexed by low PP, and without reference to lexical knowledge.

The PRIMIR model emphasises the fact that all levels of representation remain available at all times and that different tasks and acoustic demands (e.g. unfamiliar speaker or accent or degraded input) can call on different aspects of the speech processing mechanism to varying degrees and in different ways.

4.3.2.6. Conclusion

The developmental trajectory of word learning is a complex one involving separate, changing and interactive influence of PP and ND, and demonstrating changes in the nature of the speech processing mechanism in children across development and in the nature of word learning from fast mapping to long term retention. These differences suggest adaptive re-organisation of the lexicon where changes in *processing systems* have emerged which change the nature but not the overall level of efficiency of the word learning process but which may represent increased efficiency in the speech processing mechanism.

4.3.3. Children with LI: Results

The children with LI conducted the fast mapping procedure on four separate occasions over a 15 month period. In order to consider the data from the children with LI as cross-sectional trajectories it was necessary to remove the issue of autocorrelation of the four measures taken from the same individual. To this end, four separate cross-sectional data-sets were created from the LI data from each of Data Points 1 - 4.

There are a number of issues relating to these response patterns which differ significantly from the TD children's performance which will be discussed further in due course. However one important difference had significant implications for the choices made regarding data analysis. That is the children with LI appeared to be improving with age across the four data sets. This change between Data Points could not be statistically validated due to the issue of autocorrelation of the data. However inspection of the graphs (Appendix 13) demonstrates probable improvements from one Data Point to the next. This could be due to changes in the children's fast mapping abilities over time however, as the choice was made not to vary the non-word to referent pairings between presentations, it is possible that these changes could also be the result of practice effects and that the children were building their lexical representations across Data Points. This was thought to be extremely unlikely when the task was designed as children with LI have been shown to be very poor at learning new words, requiring many more presentations than used in this task to learn and retain a representation (Gray, 2003, 2004), and because of the lengths of time between presentations. However, as the TD children did not evince improvement in their abilities with age and facilitative effects of distributed presentations for word learning in LI have recently been demonstrated (Riches et al., 2005) this raises the possibility that the changes seen in the LI group may be confounded by practice effects. The trajectory at Data Point 1 however can be seen as a true test of the LI children's fast mapping abilities as this was the first presentation of the task, whereas those at Data Points 2, 3 and 4 may be best characterised as the process of word learning across time. The chosen data analysis strategy reflects this revised conceptualisation of the results. Hence the planned analysis of the *fast mapping trajectory* of the children with LI and the *comparisons to the TD group* were confined to Data Point 1. The results presented below therefore pertain only to Data Point 1.

The research questions addressed with respect to the trajectory of development of word learning skills in children with LI were as follows:

1. Do phonological (PP) and lexical (ND) variables exert separable influences on the fast mapping abilities of the children?
2. Do these influences change across development?
3. What do these changes tell us about the in the structure and functioning of the developing lexicon in typical development?

These questions will be addressed firstly with reference to *overall fast-mapping ability*, as measured by the number of correct responses (T) in the comprehension probe, number of correct phonemes in the expression probe and the number of correct semantic features in the semantic feature probe. Secondly, results will be presented with reference to the *error patterns* exhibited in the comprehension probe to consider what these may tell us about the nature of the semantic networks being created by the children and how this process of creating a network may be affected by phonological and lexical variables. The remaining questions, with regard to comparisons to the TD group will be presented in section 4.3.5 Group Comparisons.

4.3.3.1 Overall fast mapping ability

4.3.3.1.1 Comprehension probe: lexical semantic fast-mapping abilities

Linear regression analysis demonstrated a significant relationship between age and choosing the Target in the comprehension probe [$R^2 = .40$, $F(1,12) = 7.42$, $p = .02$] hence the children improved in their fast mapping abilities over development.

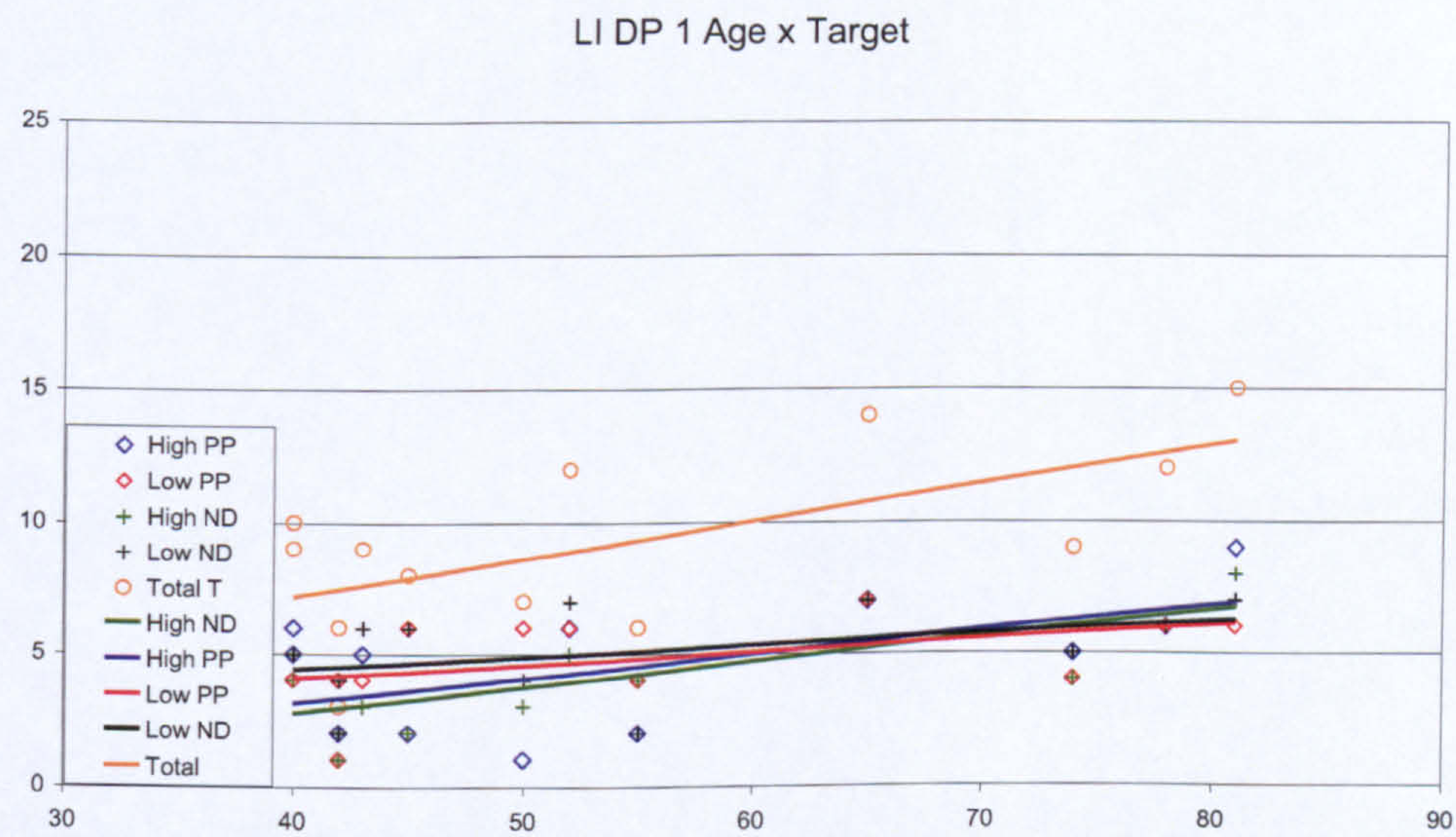

Figure 4.14. LI trajectory of lexical-semantic fast mapping abilities: Target

The influence of PP on the abilities of the children with LI to correctly identify the target in the comprehension probe across development was analysed using a one-way within subject ANCOVA with PP as the within subjects factor and age as the covariate. Phonotactic probability did not exert a significant influence on the ability of the children with LI to fast map the novel words correctly [$F(1, 11) = 1.01$, $p = .34$, partial $\eta^2 = .08$] and the PP x Age interaction was also not significant [$F(1, 11) = .90$, $p = .36$, partial $\eta^2 = .08$] (Figure 4.15).

Figure 4.15. Influence of PP on lexical-semantic fast mapping ability in children with LI: Target

The influence of ND on the abilities of the children with LI to correctly identify the target in the comprehension probe across development was analysed using a one-way within subject ANCOVA with ND as the within subjects factor and age as the covariate. Neighbourhood Density exerted a significant influence on the ability of children with LI to fast map the novel words correctly such that low ND words had an overall advantage [$F(1, 11) = 8.43$, $p = .01$, partial $\eta^2 = .43$]. The ND x Age interaction approached significance [$F(1, 36) = 3.37$, $p = .09$, partial $\eta^2 = .23$]. Inspection of the trajectory suggests that the disadvantage to fast mapping exerted by high ND may be reducing across development (Figure 4.16).

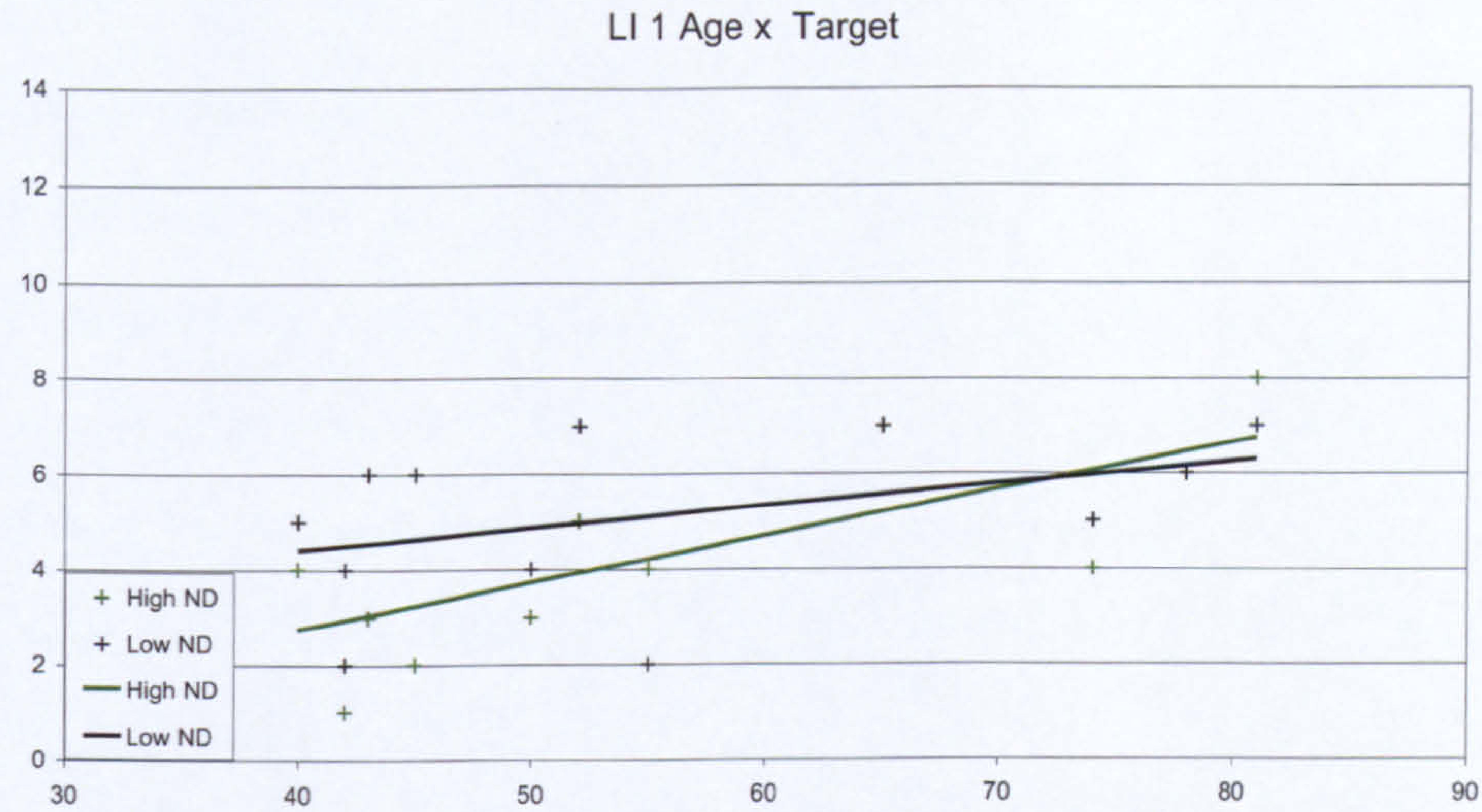

Figure 4.16 Influence of ND on lexical-semantic fast mapping ability in children with LI: Target

Taken together these results suggest that children with LI were improving in their overall ability to fast-map novel words over the age range studied (3;04 – 6;07). The PP of the words did not exert a significant influence and this did not change across development. The influence of ND however, appeared to be changing such that an initial low ND bias may have been reducing with age. The influences of ND and PP on fast-mapping were therefore separable and distinct.

The children with LI differ from the TD children in their lexical semantic fast-mapping abilities in three ways; their overall scores did increase with age, the PP of the novel words did not affect their ability to choose the target, and PP did not have a changing trajectory of influence. The influence of ND however, appeared to be similar between the two groups.

4.3.3.1.2 Expression probe: lexical retrieval and output

The developmental trajectory of scores on the expression probe is presented in Figure 4.17. The children with LI achieved very low scores on this probe but fewer children were at floor than the TD children (3 of the 13 children with LI as opposed to 13 of the 38 TD children). From a maximum possible score of 72, the average score was 4.77 and the highest score was 9. In addition, linear regression demonstrated that the children's scores were not systematically related to age although the regression approached significance [Total score: $R^2 = .24$, $F(1,11) = 3.52$, $p = .09$].

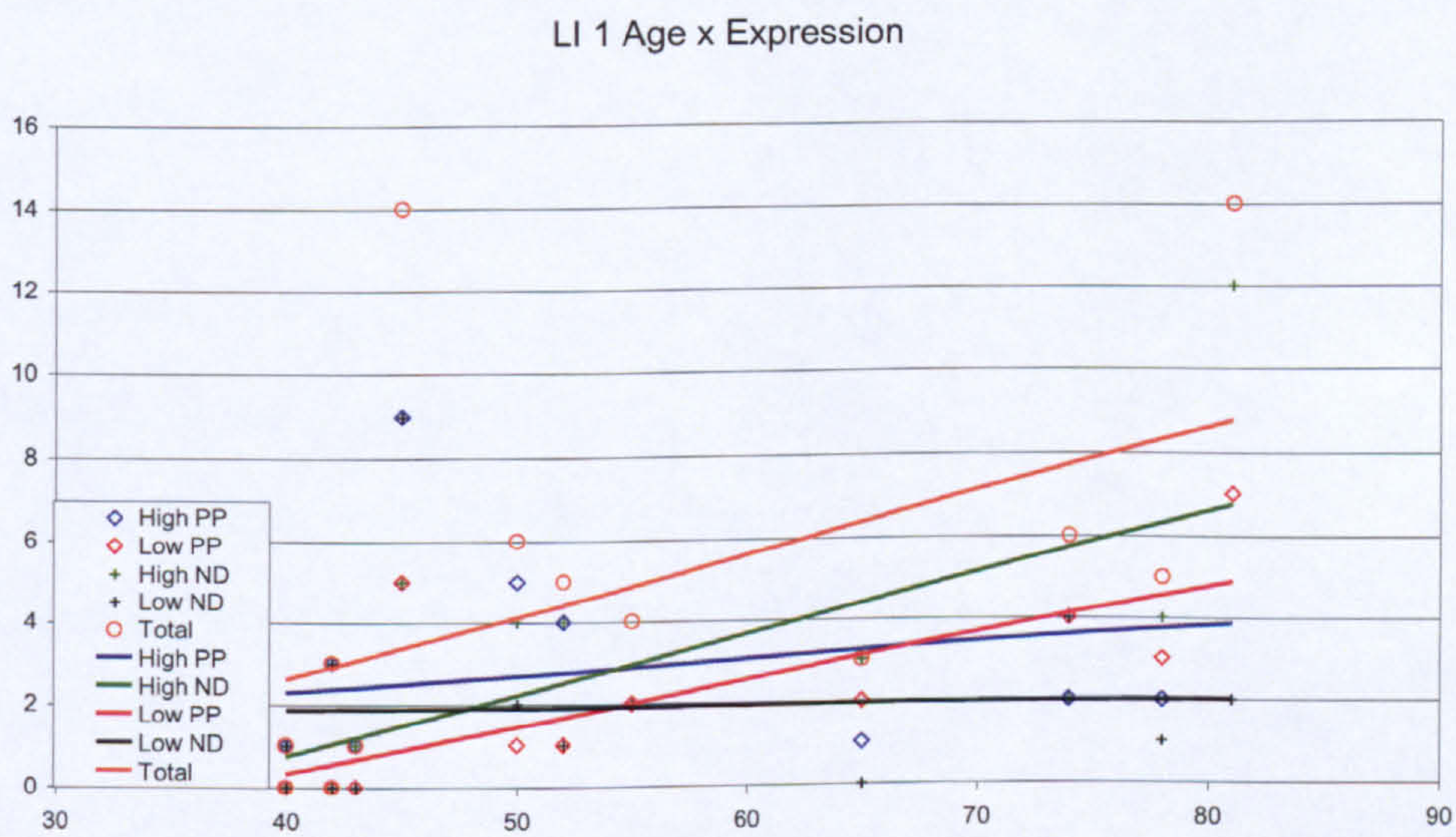

Figure 4.17. Trajectory of children with LI: lexical retrieval and output from fast mapped representations

A one-way within subjects ANCOVA with PP as the within subjects factor and age as the covariate revealed that high PP words were more accurately produced than low PP words [$F(1,11) = 8.61$, $p = .01$, $\eta^2 = .44$] and there was a significant PP x Age interaction such that low PP scores but not high PP scores significantly improved with age [$F(1,11) = 4.90$, $p = .049$, $\eta^2 = .31$].

A one-way within subjects ANCOVA with ND as the within subjects factor and age as the covariate revealed no main effect of ND [$F(1,11) = .99$, $p = .34$, $\eta^2 = .08$]. However there was a significant ND x Age interaction such that high ND scores improved significantly with age but low ND scores remained stable across the trajectory [$F(1,11) = 4.90$, $p = .049$, $\eta^2 = .31$].

These results suggest that both PP and ND exert differential effects on lexical semantic fast-mapping and lexical retrieval and output. That is, for PP the children with LI did not demonstrate a significant effect of PP on lexical semantic fast-mapping or a significantly changing trajectory of influence with age, however for retrieval of the newly learned words, a high PP advantage was evident and low PP scores appeared to be improving with age. For ND a low ND advantage was evident in the comprehension probe, a high ND advantage was developing in the expression probe and changing trajectories were in evidence across development for both probes; the comprehension probe suggesting a decreasing degree of influence of ND across development and the expression probe demonstrating an increasing effect.

The influence of ND once again seems similar between the two groups but the influence of PP differs. For the TD children PP exerted similar effects on fast-mapping and retrieval, for the children with LI, PP appeared only to exert an effect on retrieval. This result could represent a facilitative effect on output of high PP sound sequences or could perhaps represent an effect of PP on the fast-mapping process which was not identified by the comprehension probe score.

4.3.3.1.3 Semantic feature probe: semantic feature fast-mapping abilities

The developmental trajectories of responses to the semantic features probe are presented in Figure 4.18. Linear regressions were used to characterise the trajectories and a series of one-way within subject ANCOVAs with PP or ND as the within subjects factor and age as a covariate were used to explore the trajectory of influence of PP and ND across development.

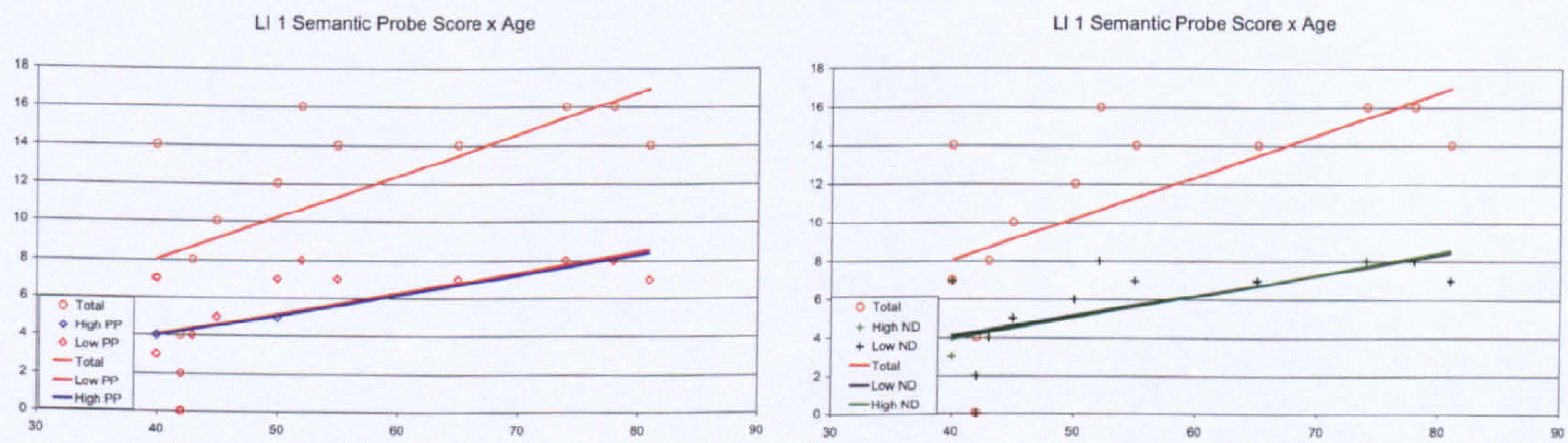

Figure 4.18. Children with LI: Trajectory of semantic feature fast-mapping abilities

Linear regression analysis demonstrated a significant relationship between scores on the semantic concept probe and age, that is the children with LI achieved higher semantic concept probe scores as they grew older [$R^2 = .45$, $F(1,12) = 8.06$, $p = .02$].

ANCOVA analyses showed scores were not affected by PP [PP: $F(1,11) = .03$, $p = .86$, $\eta^2 = .003$; PP x Age: $F(1,11) = .03$, $p = .88$, $\eta^2 = .002$] or ND [ND: $F(1,11) = 1.98$, $p = .19$, $\eta^2 = .15$; ND x Age: $F(1,11) = .99$, $p = .34$, $\eta^2 = .08$].

In summary therefore the children with LI appear to learn more semantic feature information about the referents as they grow older. These scores were not affected by the PP or ND of the words and so this pattern of results is very similar to that of the TD group.

4.3.3.2 Error patterns

4.3.3.2.1 Proportions of errors

The children with LI demonstrated an unexpected pattern of responses. That is, the expected pattern would be that of steadily decreasing scores across the responses of Target, Related Distracter, Unrelated Distracter and Foil. This pattern was evident in the TD children's responses (Figure 4.10) however inspection of Figure 4.19 suggests that the LI children chose the Target significantly more often than any other response but that there was then no systematic decrement in scores across the other response types.

A series of repeated measures ANOVAs were used to consider the differences between the proportions of response types and demonstrated a significant difference between the proportion of Target and RD responses [T versus RD: $F(1, 12) = 6.51$, $p = .03$, $\eta^2 = .352$] but no significant differences between the proportion of RD and UD errors [$F(1, 12) = 2.29$, $p = .16$, $\eta^2 = .16$], UD and Foil errors [$F(1, 12) = .04$, $p = .86$, $\eta^2 = .003$] or RD and Foil errors [$F(1, 12) = .59$, $p = .46$, $\eta^2 = .05$].

The children with LI performed at above chance levels for choosing the Target and so demonstrated their ability to create a lexical representation which is sufficiently detailed and accurate as to be recognised at a subsequent presentation, a semantic representation which is sufficiently detailed and accurate for recognition of the referent, and a correct link between the two. However, when the children with LI did not create this correct representation their error responses were random such that, they were equally likely to choose the RD the UD or the Foil. Hence their fast mapping of a word would appear to either be at floor or at ceiling.

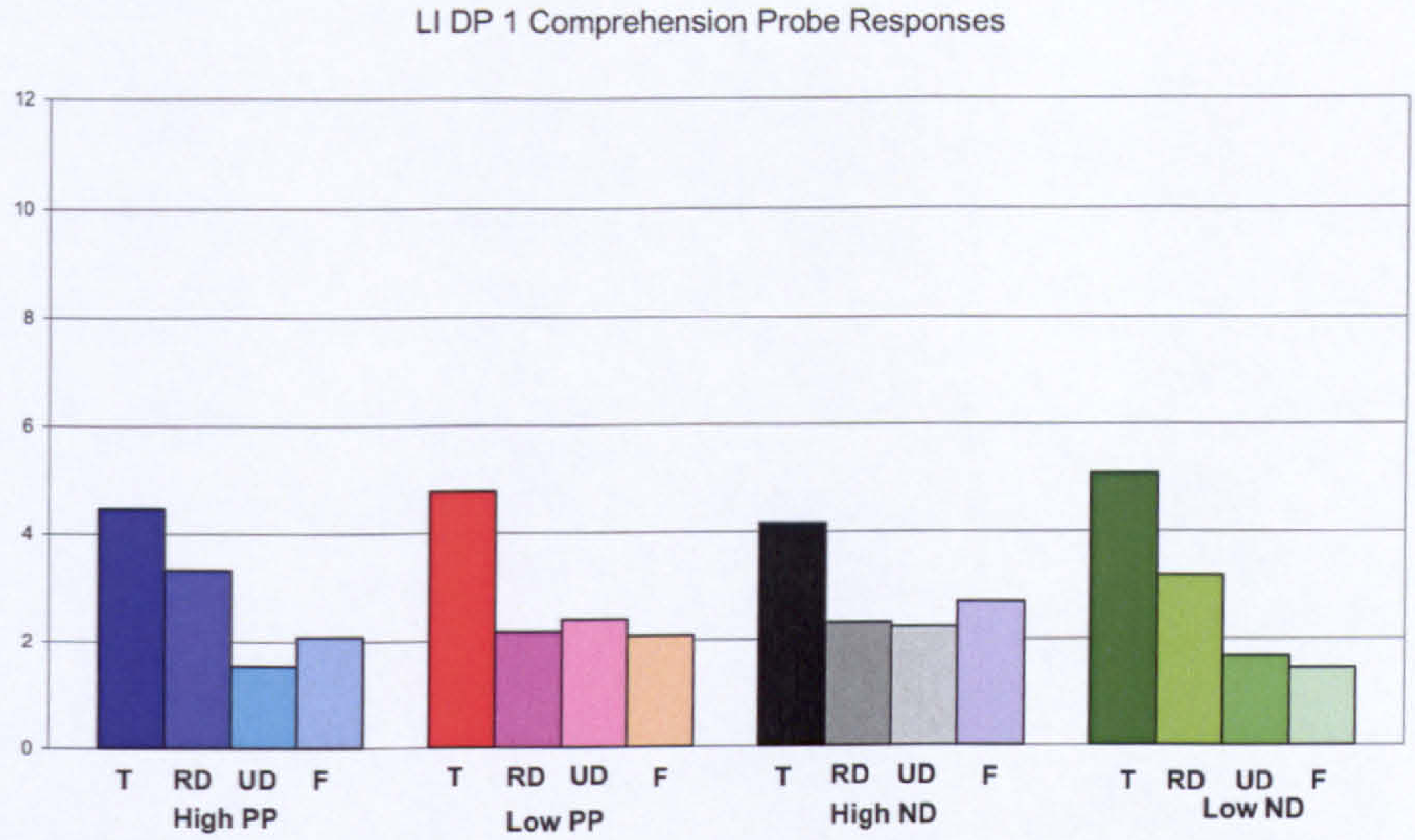

Figure 4.19. Children with LI comprehension probe pattern of responses

Consideration of Figure 4.19 is suggestive that the error patterns may differ depending on the PP or ND of the novel words. That is, for high PP and low ND words it appears that RD errors may be more frequent than UD and Foil errors. To test this, two 2*3 within subjects ANOVAs were completed to consider the influence of PP and ND on the proportion of errors. Results of the two-way within subjects ANOVA with PP as the first factor, (high and low) and proportion errors as the second factor (RD, UD, Foil) found a significant PP x Error interaction [$F(2, 24) = 3.50$, $p = .046$, partial $\eta^2 = .23$]. A series of one-way within subjects ANOVAs demonstrated that the source of this interaction lay in a significant difference between the proportion of RD and UD errors for high PP words [$F(1, 12) = 8.10$, $p =.02$, partial $\eta^2 = .40$] which was not evident for the low PP words [$F(1, 12) = .11$, $p =.74$, partial $\eta^2 = .01$].

Results of the two-way within subjects ANOVA with ND as the first factor, (high and low) and proportion errors as the second factor (RD, UD, Foil) found that the ND x Error interaction approached significance [$F(2, 24) = 3.26$, $p = .06$, partial $\eta^2 = .21$]. A series of one-way within subjects ANOVAs demonstrated that the difference between the proportion of RD and UD errors for low ND words approached significance [$F(1, 12) = 3073$, p =.08, partial $\eta^2 = .24$] but that this was not the case for high ND words [$F(1, 12) = .02$ p =.89, partial $\eta^2 = .002$]. Hence the proportion of errors was influenced by PP such that high PP words had a higher proportion of RD errors than low PP words, and the influence of ND approached significance such that low ND words had a higher proportion of RD errors than those with high ND.

There was no significant difference between the proportion of UD and Foil errors for any of the experimental conditions [High PP: $F(1, 12) = .46$ p =.51, partial $\eta^2 = .04$; Low PP: $F(1, 12) = .23$ p =.64, partial $\eta^2 = .02$; High ND: $F(1, 12) = .27$ p =.62, partial $\eta^2 = .02$; Low ND: $F(1, 12) = .15$ p =.70, partial $\eta^2 = .01$].

Taken together these results indicate that for all of the experimental conditions, the LI group were most likely to create a correct lexical-semantic representation (T). For high PP and low ND words the next most likely error was RD suggesting that the children were beginning to create semantic category networks for these words. For low PP and high ND words however the proportion of RD and UD errors were not significantly different from one another. Hence for these words, the children either were completely right (T) or were at chance in their response, suggesting little or no information had been learned during fast mapping.

This pattern of errors differed from the TD children in a number of ways. Firstly, the expected pattern of steadily decreasing scores across the responses of Target, Related Distracter, Unrelated Distracter and Foil was evident in the TD children's responses but not those of the children with LI. It is possible to conceptualise the differences between the T, RD, UD and Foil errors as representing successively smaller amounts of mapped information. These differing patterns between the groups could therefore represent differing total amounts of mapped information over the course of the task with the TD group mapping more information overall from the story than the LI group. Alternatively, these differences could represent the fact that the children with LI were not creating semantic networks between the items in the story and between the items in the same semantic category.

Secondly, the pattern of errors was affected by PP and ND in the children with LI but not the TD children. This is suggestive that for TD children the integration of novel representations into a semantic network is a robust one which is not easily affected by lexical and phonological factors whereas for children with LI integration into a semantic network only occurred under certain processing conditions, namely for high PP and low ND words.

These results therefore suggest that for children with LI the process of creating a semantic network is vulnerable and is affected by an *interaction* between overall processing capacity limitations and lexical and phonological processing variables.

4.3.3.2.2 Trajectories of errors

The developmental trajectory of the influence of PP and ND on error patterns was considered using a series of ANCOVAs with age as the covariate. The main effect of PP and PP x Age interactions were not significant for RD, UD or for F errors [RD: PP: $F(1, 11) = 2.08$, $p = .18$, partial $\eta^2 = .16$; PP x Age: $F(1, 11) = .03$, $p = .87$, partial $\eta^2 = .002$; UD: PP: $F(1, 11) = .48$, $p = .50$, partial $\eta^2 = .04$; PP x Age: $F(1, 11) = .51$, $p = .49$, partial $\eta^2 = .05$; F: PP: $F(1, 11) = .25$, $p = .63$, partial $\eta^2 = .02$; PP x Age: $F(1, 11) = .51$, $p = .49$, partial $\eta^2 = .04$].

The error data analyses demonstrated that the proportion of RD errors were influenced by PP and so a one way within subject ANOVA was completed to test whether including age as a covariate had masked the main effect of PP in the analysis. This analysis did demonstrate a significant effect of PP such that more RD errors were made for high PP words than for low [$F(1, 12) = 5.23$, $p = .04$, partial $\eta^2 = .30$] (Figure 4.20).

Figure 4.20. Influence of PP on lexical-semantic fast mapping ability in children with LI: RD

The main effect of ND and the ND x Age interactions were not significant for RD or UD errors [RD: ND: $F(1,11) = .57$, $p = .57$, partial $\eta^2 = .05$; ND x Age: $F(1, 11) = .62$, $p = .45$, partial $\eta^2 = .05$; UD: ND $F(1,11) = .08$, $p = .78$, partial $\eta^2 = .01$; ND x Age: $F(1, 11) = .31$, $p = .59$, partial $\eta^2 = .03$]. For F errors however, Neighbourhood Density did exert an influence. High ND words were more likely to elicit Foil errors than low ND words [ND: $F(1,11) = 8.39$, $p = .02$, partial $\eta^2 = .43$; ND x Age: $F(1, 11) = 2.21$, $p = .17$, partial $\eta^2 = .17$] (Figure 4.21).

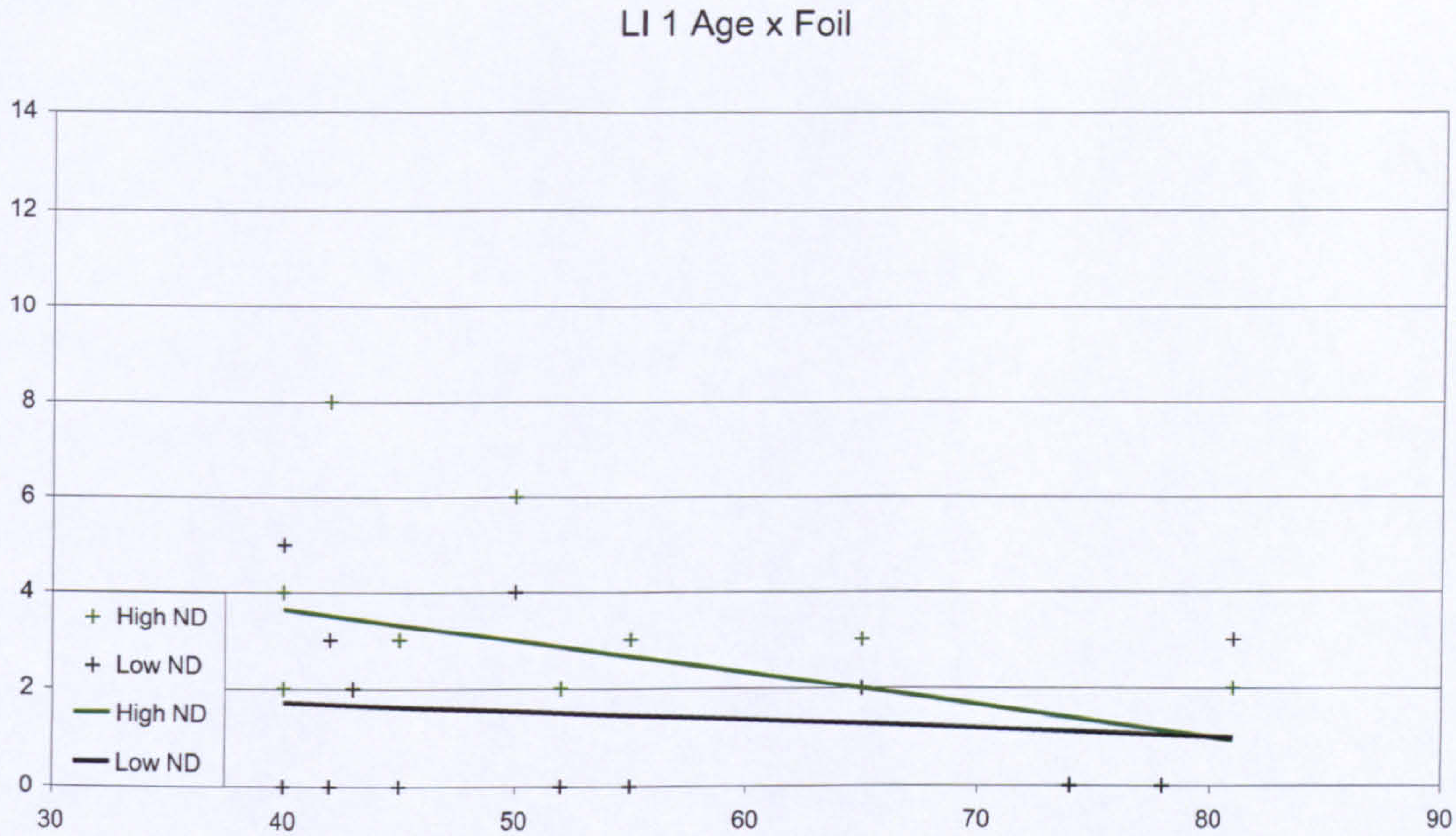

Figure 4.21. Influence of ND on lexical-semantic fast mapping ability in children with LI: Foil

These trajectories therefore are suggestive that PP does influence fast-mapping in children with LI but that this influence differs from TD children both in terms of the type of responses influenced (i.e. RD but not T responses), and that fact that the trajectory in children with LI did not change across development.

For the children with LI, ND affected both T and F responses whereas in the TD children ND affected T, F and UD responses. It would appear therefore that for the children with LI word learning was totally off (as indicated by F) or totally on (as indicated by T) and that low ND words switched on the word learning mechanism and high ND did not. For the TD children the same mechanism was in place but, as UD errors were also affected by ND, it is possible that the TD children were mapping *some* information about the high ND words. If this is the case then there may be subtle differences between the groups in their ability to detect new words.

4.3.4. Children with LI: Discussion

The goal of the above analysis was to consider whether phonological and lexical variables exert separable influences on the fast mapping abilities of children with LI, whether these influences change across development, and, to consider what these findings tell us about the structure and functioning of the developing lexicon in LI.

The results demonstrate that lexical and phonological variables do indeed exert separable influences on the fast-mapping abilities of children with LI, being best characterised as a high PP and low ND advantage. However, the high PP advantage was not evident for all aspects of the mapping process.

The influence of phonological variables (PP) did not change across development, with high PP being advantageous across the age range studied here (40 – 81 months). The influence of lexical variables (ND) however may have been changing across development for fast-mapping and was changing for retrieval. As for the TD children, ND appeared to affect different aspects of word learning in different ways such that low ND supported fast-mapping but high ND was becoming supportive of lexical retrieval in the older children.

Unlike the TD children, the overall fast-mapping abilities of the children with LI did improve with age as did their ability to map semantic features. These results may suggest increases in overall processing capacity and/or attention resources with age in the LI group. It should be noted that changes in processing capacity in the TD group were not paralleled by increases in word learning ability due to changes in the nature of the speech processing mechanism. The same changes appear not to be present in the development of the children with LI.

Error patterns demonstrated a striking pattern of 'all or nothing' mapping where the children were above chance in their ability to correctly identify the target but then, when they were in error, were equally likely to choose the RD, UD or F responses. Further consideration of the effect of PP and ND showed that under certain processing conditions (high PP and low ND), RD errors were more likely than UD errors. This result is suggestive that high PP and low ND created processing conditions which facilitated the creation of a semantic network whereas in less favourable processing conditions, the children were not able to construct these networks. Overall therefore, the results suggest that the children with LI made fewer and less extensive semantic networks than the TD children.

The following discussion will therefore consider the trajectory of influence of effect PP and ND on the creation of a lexical-semantic representation, a semantic representation and network and on lexical retrieval and output and will consider the final research question posed; what do the changes in the influence of PP and ND tell us about the structure and functioning of the developing lexicon in LI?

4.3.4.1 Creating a lexical-semantic representation

4.3.4.1.2 The influence of phonological variables on fast-mapping ability

The PP of the novel words did not affect the ability of the children with LI to choose the Target in the comprehension probe but did affect the rate of RD errors and expression scores. PP therefore did affect the fast-mapping abilities of the children with LI but not their ability to make a correct form and referent representations and form-referent links.

It is only when the children's error patterns are considered that the reasons for this immunity to the influence of PP for choosing the Target is elucidated. That is, the 'all or nothing' pattern of mapping described previously suggests that, the children with LI learn words using a 'paired association' learning strategy and only use a 'semantically integrated' learning strategy, making links between novel semantic representations, under optimal processing conditions (Figure 4.19).

The 'paired association' learning style appears to allow the children to succeed in creating a lexical representation, a semantic representation and a link between the two equally well under a range of processing conditions. This learning style may be a compensatory strategy for an impaired word learning mechanism which proves adaptive, in that it allows for success whatever the phonological properties of the word, but which also has maladaptive consequences, in that it reduces the amount of semantic information which is coded about the word through links between the representations.

These results are suggestive that the PP of the novel words did influence the fast-mapping abilities of children with LI but did so in the context of a system which was attempting to learn words using a qualitatively different learning strategy to the TD children. PP therefore affected different aspects of the fast-mapping process in the two groups. Where PP did exert an influence in the children with LI (expression probe scores and RD errors), high PP words were advantaged in processing and this advantage remained constant across the age range studied here. This absence of a switch in processing bias between high and low PP words across development differs therefore from the TD group and is suggestive of the persistence of an immature speech processing bias or processing architecture in the children with LI. If vocabulary knowledge is the driver of changes in the nature of the speech processing mechanism then such immaturity could simply reflect the smaller vocabularies of the children with LI. Group comparisons presented in section 4.4 will explore this possibility further.

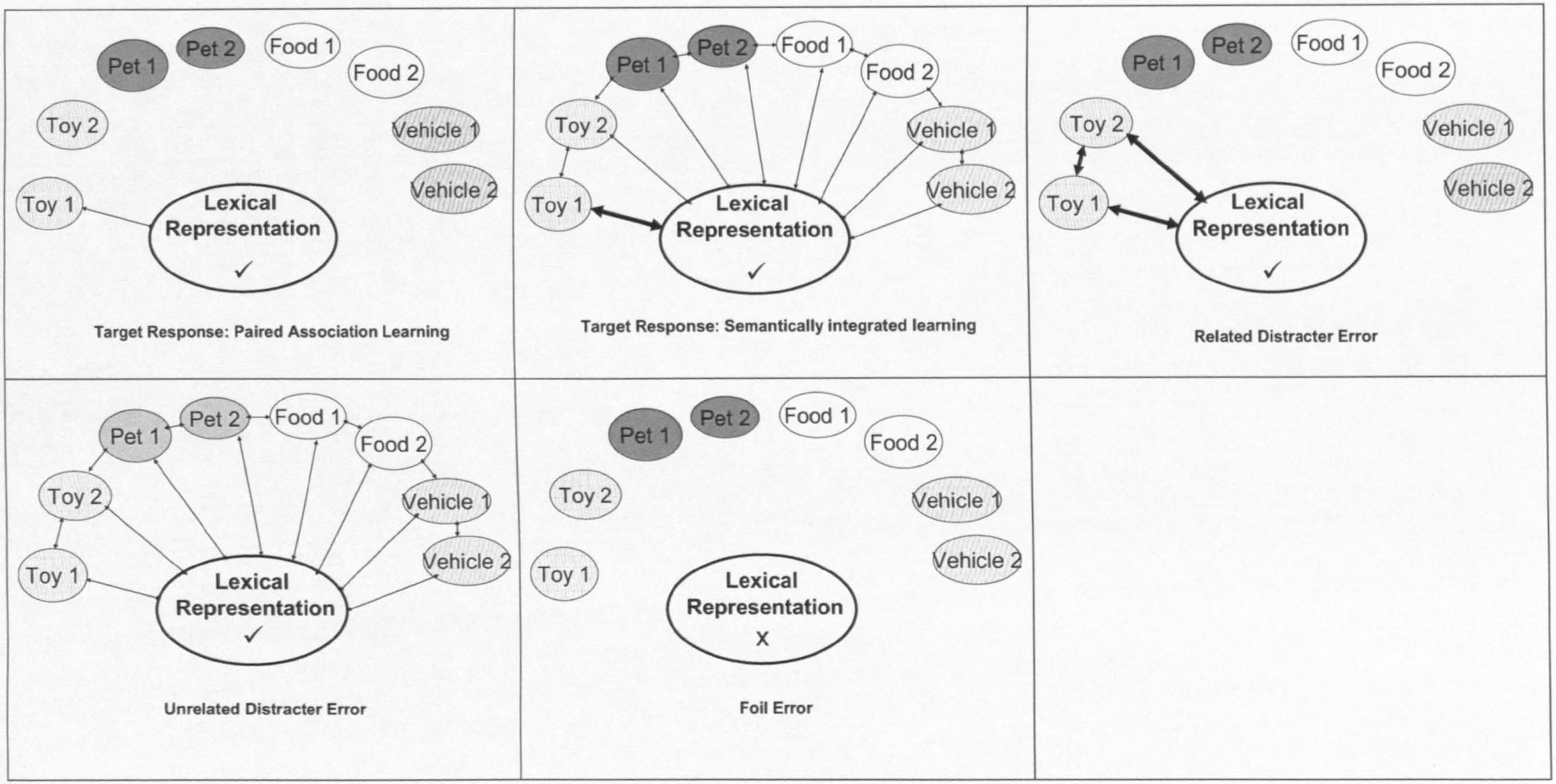

Figure 4.22. Possible semantic networks as indicated by responses on the comprehension probe

4.3.4.1.3 The influence of lexical variables

The ND of the target novel words did affect the ability of the children with LI to fast-map the novel words such that words with low ND were more accurately identified in the comprehension probe than high ND words. In addition the low ND advantage appeared to be reducing across development. These results are very similar to the TD group and so suggest that the children with LI, like the TD children, are increasingly able to detect fine grained distinctions between words they hear and those in their lexicons as they get older. In interpreting the results of the TD group it was hypothesised that this increasing ability represents the emergence of a sub-lexical/phonemic level of representation which allows for more accurate distinctions between word forms through the use of phonemic categories. That is younger children may view neighbours of familiar words as 'near misses' of known words as they do not have phonological categories to help them to decide if , for example 'tog' is an allophonic/accentual variation of 'dog' or a new word and so they do not 'switch-on' their word learning mechanisms. As phonemic categories emerge the children become able to distinguish more readily between known and unknown words and so the low ND bias for triggering word learning reduces.

This result is surprising for two reasons. Firstly the fact that the 'paired association' style of learning, which made the children with LI immune to the effect of PP in their form-referent mapping ability does not override the effect of ND and secondly the fact that this pattern of results is highly suggestive that the children with LI may be developing lexical networks and sub-lexical representations in a similar way to the TD children. This result runs counter to previous research detailing impairments in the nature of lexical and sub-lexical representation in children with LI (Bishop, 1997b; Bishop, 2000; Chiat, 2001; Constable et al., 1997; Conti-Ramsden, 2003a; Maillart et al., 2004; Mainela-Arnold et al., 2008; Seiger-Gardner & Brooks, 2008).

The first of these points, that the 'paired association' learning style did not override the effect of ND in the same way as it did PP, may be explained if PP and ND affect different stages of the fast-mapping process. If low ND acts as a trigger to word learning and switches the word learning mechanism on, but PP exerts a continuous probabilistic effect on mapping once learning is triggered, then the results can be accommodated within the same explanatory framework. That is, the 'paired association' learning strategy could only have an effect once learning was taking place. If detecting 'newness' is the word learning trigger then the effect of low ND as a cue to detect newness would occur prior to the beginning of the word learning process and so would be immune to the effects of the 'paired association' learning strategy. The second issue, whether the nature of the lexical networks and emerging sub-lexical level representations are in fact similar between the two groups, will be further elucidated by the group comparisons presented in section 4.4, however, error patterns may also hold additional clues.

In the TD group, the ND of the novel words affected the rate of T, F and UD responses. In addition, the proportion of UD errors was significantly greater than the proportion of F errors. If ND was acting as a trigger to word learning and UD responses are seen as indicating partial, incomplete mapping then the TD children must have been able to trigger word learning for high ND words *at least some of the time.* That is they must have at least mapped sufficient lexical information to recognise the word again and sufficient semantic information to recognise that it occurred in the story.

For the children with LI however, the ND of the novel words affected T and F responses only and overall the LI group demonstrated no significant difference between their proportion of UD and Foil errors. In the context of this pattern of errors, if the ND effect found in the frequency of F errors was simply a reciprocal result brought about by the effect of ND on the rate of choosing the Target then an equivalent effect would also be in evidence for the UD errors. As this is not the case. this result therefore suggests that there is something about choosing a Foil rather than a UD which is affected by ND in this group of children. Choosing the Foil would suggest that the children have not mapped *any* information about the word and so, during the comprehension probe, behave as though they have never heard the word before, hence choosing a novel item as the most likely candidate to go with the apparently completely novel word (Mervis & Bertrand, 1994). Such a pattern would be consistent with a word learning-mechanism staying completely 'off' during exposure however it would require that the children notice that the word is novel in the testing context despite not doing so in the word learning context. This is an odd result but such differences in speech processing performance depending on the context of the task are not without precedent and have been demonstrated in TD infants (Werker & Yeung, 2005). The level of processing load of the two tasks (identifying a novel word within a story versus identifying a novel word in a 'show me the x' paradigm) could therefore interact with the children's speech processing abilities making novel-word identification easier in the testing context than in the story context. Hence the apparent group differences could be explained such that the TD children were able *intermittently and inconsistently* to detect newness for high ND words whereas the children with LI *never* switched on the word learning mechanism for those words which elicited a F response, and so did not *partially* learn words. This difference may therefore indicate that children with LI did in fact have sparser lexical networks and immature sub-lexical representations and so were less able to detect newness in high ND words than the TD children. Whether this difference is due to overall processing capacity limitations, immature sub-lexical level representations, or an interaction between the two is, however, moot and will be further explored through group comparisons presented below.

A second possibility is that novel semantic representations may be created appropriately but that the children with LI find it more difficult to create a lexical network and so links between each of the novel semantic representations were not created during the fast-mapping process. This would suggest that it is the nature of the *creation of the network* which is fragile in children with LI. This is an idea which will be returned to in due course.

4.3.4.1.4 The interactive effects of lexical and phonological variables

The separable effects of ND and PP operate simultaneously 'in the moment' of word learning so producing an overall effect which emerges from the interaction between the two variables and the two levels of processing mechanism. These influences change across development and so their interactive influence for the younger children (aged approximately 40 – 70 months) and the older children (aged approximately 70 – 81 months) will be described separately

In the younger children with LI, like the younger TD children, high PP and low ND are the most facilitative to fast mapping. In the LI group having high PP supports the system to learn more about a word (as indicated by increased RD errors and expressive probe scores) and the low ND bias acts as a trigger to word learning through the detection of 'newness' for words which are significantly different from those which already exist in the child's lexicon. Hence it appears that in the younger children the lexical level may be operating as the word learning trigger through the influence of ND and the sub-lexical/phonemic level may be operating as a statistical learning device, which facilitates the identification and learning of frequent sound combinations. However, once the word learning mechanism has been switched on, the children with LI apply a strategy of paired association learning which masks the effect of PP on form-referent mapping. The influence of PP therefore is only evident with respect to the creation of a semantic network and for lexical retrieval and output.

In older children with LI the PP effects remain the same as for the younger children, however the children's sensitivity to ND appears to be reducing. This is suggestive that the children with LI are creating sub-lexical/phonemic representations and using these distinctions in lexical processing. In the TD group the switch in PP bias across the developmental trajectory from high PP to low PP was thought to be driven by the emergence of sub-lexical/phonemic level representations. The fact that this does not occur in the children with LI, despite the apparent emergence of sub-lexical/phonemic level representations is therefore unexpected and may indicate crucial differences in the nature of the speech processing mechanism between the two groups. This issue will be returned to when considering group differences and in relation to the nature of the structure and functioning to the developing lexicon in LI below.

4.3.4.2 Creating a semantic representation and a semantic network

4.3.4.2.1 Semantic-feature mapping

Performance on the semantic feature probe was independent of lexical and phonological variables but did improve with age. This improvement with age may relate to increases in processing capacity and/or attention control supporting the children to learn more about the referents during the word learning task.

This pattern of semantic feature mapping results is very similar to that of the TD children however for the TD group the semantic feature probe was the only score increasing systematically with age. For the children with LI however comprehension and expression probe scores also increased with age. This result could be suggestive of separate mechanisms in TD for semantic-feature mapping and lexical-semantic mapping and of related mechanisms in children with LI.

Alt, Plante and Creusere (2004) investigated the abilities of TD children and those with LI to learn semantic features during a fast-mapping paradigm. They found that in TD children there was no correlation between the children's existing vocabulary knowledge and the number of semantic features learned during the task. However these scores were correlated in the children with LI. Alt and colleagues suggest that "the skills involved in fast-mapping semantic features and lexical labels are independent skills in children with NL [Normal Language]" (Alt et al., 2004, p.418). For the children with LI they suggest that the correlation "speaks more to their overall impairment in multiple aspects of language learning than to an inherent connection between the skills involved in word learning." (Alt et al., 2004, p.418).

In 2006 Alt and Plante, went on to investigate the semantic feature fast mapping abilities of TD children and those with LI under a range of processing conditions (Alt & Plante, 2006). They found that the TD children were able to map semantic features equally well under any of the processing conditions considered, but that the children with LI were affected by the phonological properties of the words. This result could therefore support the suggestion of separate mechanisms in TD for semantic-feature mapping and lexical-semantic mapping and of related mechanisms in children with LI.

Alt and Plante's finding that the semantic feature mapping abilities of the children with LI were affected by the PP of the novel words (Alt & Plante, 2006) runs counter to the results presented here such that in this study this particular aspect of word learning was not affected by the ND or PP of the words in either group. It must be noted however that Alt and Plante's study placed much greater processing demands on the children, with four semantic features being mapped for each novel object and a total of 24 novel objects being presented. The effect of atypical processing mechanisms or of subtle differences in stimuli characteristics therefore may only become apparent when the processing system is stressed by working at its maximum capacity. The semantic feature task presented here may simply not have challenged the processing systems of the participants sufficiently for any differences between groups or conditions to emerge. In addition, the absence of an effect on TD children's semantic feature mapping may be indicative, not of separate mechanism, but rather that TD children's abilities in this skill are extremely robust and efficient and are not easily challenged by changes in processing demands.

4.3.4.2.2 Creating a semantic network

Error data from the comprehension probe speaks to the nature of the semantic networks being created by the children. This data suggests that the children with LI were able to make connections between their newly created semantic representations only under optimal processing conditions, and so, did not build semantic networks as easily or as quickly as the TD children.

In addition the children with LI did not create the lexical network 'appears in the story' at all (as indicated by there being no significant difference between F and UD error rates). Overall therefore it appears that the children with LI made fewer and less extensive semantic networks than the TD children and their abilities to do so appear to be less robust and so were affected by the lexical and phonological properties of the stimuli.

There are a number of possible explanations for this difficulty in creating semantic networks during fast-mapping. Possible candidate explanations are: firstly that the children may have specific difficulties in creating connections within a network; secondly that the difficulty may arise as the result of an overall processing capacity limitation; thirdly, that impaired sub-lexical and/or phonetic/indexical processing abilities could interact with the child's overall processing capacity resulting in less information being mapped when processing conditions are challenging; and finally it could be the result of the application of the maladaptive 'paired association' learning style which has arisen as a compensatory strategy for some other level of impairment. These candidate explanations will be considered with reference to the nature of the structure and functioning of the developing lexicon below.

Whatever the cause of this error pattern it provides an important window into how a semantic deficit may arise from processing limitations and/or atypical speech processing mechanisms within a developing and interactive system. Hence conceptual information, which is coded through connections within a semantic network (e.g. semantic category membership, associations between items presented in the same 'event') is likely not to be encoded during fast-mapping by children with LI. Such a limitation could be crucial in the ontogenesis of the grammatical deficits typically found in LI such as, for example, the use of predicate argument structures. If such limitations were at play during the learning of a new verb then perhaps difficulties with learning verb argument structure may arise through impaired mapping of conceptual information about the novel verb. That is, in TD children this conceptual information may be encoded through connections with representations for the other items which occur within the verb learning context (i.e. the arguments). If the children with LI are less able to make these connections during verb learning, such lexical learning deficits may contribute to impaired learning regarding argument structures and so play a crucial role in the emergence of grammatical impairments in LI.

Further work examining whether this impaired semantic learning during fast-mapping persists over the course of slow mapping a word and whether continuities exist between semantic and grammatical impairments over the developmental trajectory would appear to be warranted.

4.3.4.3 Lexical retrieval and output of newly learned words

The expression probe taps both what is learned during fast mapping and also subsequently what supports access and retrieval of the new representation. Phonotactic probability exerted a significant influence on the expression probe scores such that high PP words were retrieved and produced more readily than those with low PP. As the children's ability to map the Target was not affected by PP, this result is most likely to reflect a facilitative effect for *retrieval* of the novel words arising from the higher resting thresholds of the sub-lexical/phonological level representations, and the stronger facilitative connections between the sound combinations for these high PP words. It is also possible however that PP did exert an effect on the initial mapping of the representations but that this effect was not evident in the comprehension probe. That is, high PP may have supported greater phonetic/phonological detail to be encoded about the novel words and so increased the accuracy in the expression probe. This effect may not have been evident in the comprehension probe because the paired association mapping strategy ensured that the children with LI mapped sufficient information to recognise the lexical representation again whatever the phonological characteristics of the word. More detailed phonological information may have been mapped about the high PP words in the same way that it appears that more semantic detail was mapped about these words. This pattern once again differs from the pattern of the TD children in that the children with LI persist with a high PP advantage to processing whereas the TD children's bias switched from high PP to low PP.

The neighbourhood density of the novel words did not exert a significant effect on expression probe scores however the interaction between age and ND was significant as high ND words were becoming advantaged over the age range studied. This effect can be seen to be primarily one which acts on *retrieval* as low ND supported the creation of the representation. This pattern of influence is very similar to that found in the TD children and so appears to indicate that the children with LI, like the TD children, create links between lexical representations which then facilitate lexical access, from the very outset of the word learning process.

4.3.4.4 The structure and functioning of the developing lexicon

There are a number of qualitative similarities and differences between the fast-mapping abilities of the TD children and those with LI which need to be accommodated in an explanatory framework of the structure and functioning of the developing lexicon in children with LI. In terms of differences, they are the nature of the semantic networks created, the use of a paired association fast-mapping strategy and the nature of the developmental trajectory of influence of PP. In terms of similarities they are that lexical networks and the emergence of sub-lexical representations appear to be developing similarly between the groups. Within a dynamic system the characteristics of one level of processing have implications for other aspects. In order to fully understand the system those aspects thought to be causally linked are therefore presented together hence the following first presents the nature of the semantic networks and the use of paired association learning, and secondly the nature of the developmental trajectory of influence of both PP and ND.

4.3.4.4.1 Semantic networks and the use of paired association learning

As previously identified the children with LI appeared to make fewer and less extensive semantic networks than the TD children and their abilities to do so were less robust and so were affected by the lexical and phonological properties of the stimuli.

Possible candidate explanations for this finding are: firstly that the children with LI may have specific difficulties in creating connections within a network; secondly that the difficulty may arise as the result of an overall processing capacity limitation; thirdly, that impaired phonological/sub-lexical processing abilities could interact with the child's overall processing capacity resulting in less information being mapped when processing conditions are challenging; and finally it could be the result of the application of the maladaptive 'paired association' learning style which has arisen as a compensatory strategy for some other level of impairment.

Taking each point in turn, the first explanation, that the children with LI may have difficulties creating connections within a network is one which may be worthy of further study. Recent research suggests that phonological and lexical processing in children with LI is vulnerable to interference from lexical neighbours and that the nature of the lexical processing system in this group of children may be less able to suppress activation of interfering lexical representations or that these interfering words may not decay as rapidly as in typically developing lexical processing systems (Mainela-Arnold et al., 2008; Seiger-Gardner & Brooks, 2008). These properties could emerge from a network wherein the creation of connections between representations and changes in the weighting and pruning of those connections, have progressed in an atypical manner. It is also possible that greater interference could occur as a result, not of the nature of the connections between representations within the network, but of the nature of the sub-lexical level representations within the lexicon. Indeed the influence of ND on expression probe scores suggested that the children with LI were building networks at the lexical level in a very similar way to the TD children, hence suggesting that the creation of connections per se was not an area of difficulty for these children. Further studies considering the nature of the changing organisational structure of connections within the developing lexicon are needed to consider this possibility further.

The second possible explanation is that overall processing capacity limitations may restrict the total amount of semantic information learned by the children with LI over the course of the word learning context. This in turn limits the ability of the children to create connections between semantic representations as, either they do not create all of the semantic representations for the novel referents to connect together, or the process of making a connection (i.e. remembering two referents from a semantic category rather than one) utilises more processing capacity than simply making an unconnected form-referent mapping.. This process therefore only occurs under optimal processing conditions.

The third possibility is that impaired phonological/sub-lexical processing abilities could interact with the child's overall processing capacity and so limit the amount of information mapped about words whose phonological characteristics challenge the child's phonological/sub-lexical processing abilities. That is, processing phonological/sub-lexical information with an impaired system uses more processing capacity than in a typically developing system and so less capacity is available for the semantic mapping aspect of the fast-mapping process.

Distinguishing between these latter two explanations is extremely difficult. Maniela-Arnold and Evans (2005) demonstrated that a capacity limitation explanation for the poor performance of children with LI on a competing language processing task was overly simplistic as the children with LI were not poorer that their TD age matched peers where the task comprised high frequency words, but were poorer for low frequency words. They concluded that working memory capacity is not distinct from language knowledge and that "degraded linguistic representations may have an effect on performance on verbal working memory span tasks in children with LI" (Mainela-Arnold & Evans, 2005, p. 897). Verbal working memory and verbal processing capacity are related concepts but are certainly not interchangeable and so, whether an equivalent effect of degraded linguistic representations is in evidence in a fast-mapping paradigm requires further testing. The group comparisons presented below will attempt to untangle the relative influence of phonological/sub-lexical processing abilities and capacity limitations on the fast-mapping abilities of the children with LI using a similar approach to that of Mainela-Arnold and Evans (2005). That is, the group comparisons will consider whether or not the PP of the novel words exerts a greater effect on the fast-mapping abilities of the children with LI than those with TD. If the groups are indeed differentially affected by the PP of the novel words this would be highly suggestive that a processing capacity limitation explanation is overly simplistic and that the nature of the speech processing system is implicated.

Finally the paired association, 'all or nothing' learning style plays a role in the limited semantic networks created by the children with LI. This strategy may be a compensatory one which has emerged as an atypical processing mechanism attempts to cope with the demands of word-learning and which has both adaptive and maladaptive consequences. That is in order to learn the high and low PP words equally well the children with LI direct all of their processing capacity to form and referent learning and to the creation of a link between the lexical and the semantic representations. They therefore do not map any additional information (i.e. do not make links with the other semantic representations) except under optimal processing conditions. As this strategy results in removing the effect of PP on 'successful' word learning it seems probable that it has emerged in the processing mechanisms of children with LI in order to compensate for atypical phonological/sub-lexical processing rather than in response to an overall capacity limitation. In order to test this, the fast-mapping style of younger TD children would need to be investigated to consider whether TD children with equivalent processing capacity to the children with LI also override the influence of PP in form-referent formation. That is to determine whether this is an atypical or an immature pattern. The group comparisons presented below will attempt to consider this issue through comparing the influence of PP on fast-mapping success between the groups with respect to their vocabulary knowledge.

4.3.4.4.2 The nature of the developmental trajectory of influence of PP and ND in LI

The TD children demonstrated a switch in PP bias across the developmental trajectory from high PP to low PP and it was hypothesised that this was driven by the emergence of sub-lexical/phonemic level representations. The fact that this does not occur in the children with

LI, despite the fact that this group's response to the ND of the novel words suggests that sub-lexical/phonemic level representations were emerging, is therefore unexpected and may indicate crucial differences in the nature of the speech processing mechanism between the two groups.

There are four possible explanations for this result: firstly that the differences between the group simply reflect differences in the level of vocabulary knowledge hence the children with LI are simply demonstrating an immature pattern which will 'catch-up' as their vocabulary knowledge increases; secondly that the sub-lexical/phonemic level representations have not emerged sufficiently robustly yet in the children with LI for this processing 'switch' to take place; thirdly that the switch in the TD children is not in fact driven by the emergence of sub-lexical/phonemic level representations but by some other trigger and it is this trigger which is absent in the children with LI; finally that the children with LI are impaired, not at the sub-lexical/phonemic level but at the phonetic/indexical level and this impairment results in an inability to switch processing bias.

The first explanation, that the group differences simply reflect differences in the vocabulary knowledge between the groups, will be tested through group comparisons of the effect of PP with respect both to age and to vocabulary knowledge and are presented below. Group comparisons of the effect of ND on processing with respect to age and vocabulary knowledge will also shed light on the second possible explanation, that the sub-lexical/phonemic level representations have not emerged sufficiently robustly yet in the children with LI for this processing 'switch' to take place.

If group differences still exist in the influence of PP on fast mapping once the vocabulary knowledge of the two groups has been taken into account and in the context of no group differences in the influence of ND, then the final two explanations will need to be considered.

4.3.4.5. Conclusion

The TD children and children with LI studied here present with qualitatively different fast-mapping profiles with key differences in their form-referent mapping, their response to the PP of the novel words and the nature of the formation of semantic networks despite apparently similar responses to the ND of novel words.

Possible explanations for the fast-mapping profile in the children with LI include an overall processing capacity limitation, a phonological/sub-lexical processing impairment, or some other impairment in the nature of the development of the speech processing mechanism, perhaps relating to the nature of the connections within the network or to the nature of phonetic/indexical level of processing.

The following group comparisons will attempt to distinguish between these candidate explanations through comparing the relative influence of ND and PP on group scores with respect to age and to vocabulary knowledge.

4.3.5 Group Comparisons: Results

The aims of the study were to answer the following questions

1. Are the trajectories of influence of PP and ND different from those of TD children?
2. What do changes in the influence of PP and ND, and similarities and differences between the groups tell us about the structure and functioning of the developing lexicon in LI?

The second question can now be further specified with respect to the candidate explanatory frameworks described above;

3. Are the group differences suggestive of an overall processing capacity limitation, a phonological/sub-lexical processing impairment or some other, as yet unidentified impairment in the nature of the development of the speech processing mechanism?

In order to answer these questions group differences were considered with respect to age and vocabulary knowledge, with respect to age to consider whether children with LI were poorer at fast-mapping than their peers and with respect to vocabulary knowledge to consider whether any group differences can be explained by the smaller vocabularies of the children with LI.

In order to differentiate between the candidate explanatory frameworks described above the crucial comparisons are the pattern of results with respect to nature of influence of ND and PP on processing and whether these influences differ between the groups. In addition, as the nature of influence of PP and ND change over time the comparisons must be made with respect to age or to vocabulary knowledge.

The pattern of results compatible with each explanatory framework is therefore as follows:

- An overall processing capacity limitation: The children with LI perform more poorly than the TD children with respect to age but when compared with respect to vocabulary knowledge, no significant differences between the groups exist. In addition, the trajectories of influence of PP and ND with respect to vocabulary knowledge do not differ between the groups.

- A phonological/sub-lexical processing impairment: the group trajectories of fast-mapping ability are differentially affected by ND when compared with respect to vocabulary knowledge.
- An impairment in the nature of the development of the speech processing mechanism which is not related to phonological/sub-lexical processing: the group trajectories of fast-mapping ability are differentially affected by PP but not by ND when compared with respect to vocabulary knowledge.

The pattern of results will be described firstly with reference to *overall fast-mapping ability*, as measured by the number of correct responses (T) in the comprehension probe, number of correct phonemes in the expression probe and the number of correct semantic features in the semantic feature probe. Secondly, results will be presented with reference to the *error patterns* exhibited in the comprehension probe.

4.3.5.1 Overall fast-mapping ability

4.3.5.1.1 Comprehension probe: lexical-semantic fast-mapping abilities

ANCOVA analyses with age as the covariate revealed that the children with LI were poorer in their abilities to choose the Target than the TD children [$F(1, 47) = 5.38$, $p = .03$, partial $\eta^2 = .10$]. ANCOVA analyses with vocabulary as the covariate found no significant group differences in the number of Target responses [$F(1, 47) = 1.16$, $p = .29$, partial $\eta^2 = .02$]. With respect to the influence of PP, mixed 2*2 ANCOVAs (PP: high, low; Group: TD, LI; Covariate: Age or Vocabulary) were completed to examine group differences in the influence of PP with respect to age and vocabulary knowledge.

When age was co-varied there was a significant PP x Group x Age interaction [$F(1, 47) = 6.26$, $p = .02$, partial $\eta^2 = .12$]. Within subject ANCOVAs demonstrated that the influence of PP significantly changed across development in the TD group but did not do so in the LI group [TD: $F(1, 36) = 6.15$, $p = .02$, partial $\eta^2 = .15$; LI: $F(1, 11) = .90$, $p = .36$, partial $\eta^2 = .08$].

When vocabulary was co-varied there were no significant group interactions [PP x Group x Vocabulary: $F(1, 47) = .10$, $p = .75$, partial $\eta^2 = .002$; PP x Group: $F(1, 47) = .16$, $p = .69$, partial $\eta^2 = .003$]. Therefore the influence of PP changed across development in the TD children but not those with LI and these differences may be explained by the level of vocabulary knowledge of the two groups.

With respect to the influence of ND mixed 2*2 ANCOVAs (ND: high, low; Group: TD, LI; Covariate: Age or Vocabulary) were completed to examine group differences in the influence of ND with respect to age and vocabulary knowledge.

When age was co-varied neither the ND x Group nor the ND x Group x Age interactions were significant [ND x Group: $F(1, 47) = .30$, $p = .58$, partial $\eta^2 = .01$; ND x Group x Age: $F(1, 47) = .60$, $p = .44$, $\eta^2 = .01$].

When vocabulary was co-varied there were no significant group interactions [ND x Group: $F(1, 47) = .16$, $p = .69$, partial $\eta^2 = .003$; ND x Group x Vocabulary: $F(1, 47) = .80$, $p = .38$, partial $\eta^2 = .02$].

Taken together these results confirm that the trajectory of influence of PP with respect to age differs between the groups and the trajectory of influence of ND is very similar. When compared with respect to vocabulary however no significant group differences remain suggesting that the differences in processing bias can be explained by the vocabulary levels of the two groups and that the skills of the children with LI therefore represent immature rather than impaired processing and that this immaturity is closely linked to the level of their vocabulary knowledge. These conclusions may be premature however as the TD children were applying a 'paired association' strategy for their mapping of the Target which overrode the effect of PP on their performance. Group differences in those scores which did evince a PP effect in the children with LI need to be investigated before such conclusions can be confidently drawn.

4.3.5.1.2 Expression probe: lexical retrieval and output

ANCOVA analyses revealed that the children with LI scored more highly in the expression probe than the TD children when both age and vocabulary knowledge were co-varied [Age: $F(1, 48) = 4.64$, $p = .04$, partial $\eta^2 = .09$; Vocabulary: $F(1, 48) = 8.39$, $p = .01$, partial $\eta^2 = .15$].

Mixed 2*2 ANCOVAs (PP: high, low; Group: TD, LI; Covariate: Age or Vocabulary) were used to examine group differences in the influence of PP and group differences with respect to age and vocabulary knowledge.

The Group x PP x Age interaction was significant [$F(1, 47) = 4.24$, $p = .045$, partial $\eta^2 = .08$] but the Group x PP interaction was not significant [$F(1, 47) = 2.02$, $p = .16$, partial $\eta^2 = .04$]. Previously reported within subject ANCOVA's demonstrated that the PP x Age interaction and the main effect of PP only approached significance in the TD group but were significant in the scores of the children with LI. For both groups the pattern appeared to represent an initial high PP advantage with low PP scores increasing with age. The difference between the groups therefore may simply represent the difference in overall scores. That is, the higher scores of the children with LI were sufficient to produce statistically significant trends whereas the very low scores of the TD children were not, despite similar processing effects. ANCOVA analyses with vocabulary as a covariate demonstrate no significant interactions [PP x Group x Vocabulary: $F(1, 47) = .002$, $p = .96$, partial $\eta^2 = .00$; PP x Group: $F(1, 47) =$

.64, $p = .43$, partial $\eta^2 = .01$]. Hence the differences in the effect of PP on retrieval and output between the groups appear to be attributable to the differences between the groups in vocabulary knowledge.

Mixed 2*2 ANCOVAs (ND: high, low; Group: TD, LI; Covariate: Age or Vocabulary) were used to examine group differences in the influence of ND and group differences with respect to age and vocabulary knowledge. There were no significant ND x Group interactions [Age: $F(1, 47) = 1.30$, $p = .26$, partial $\eta^2 = .03$; Vocabulary: $F(1, 47) = 1.82$, $p = .18$, partial $\eta^2 = .04$], the ND x Group x Age interaction was not significant [$F(1, 47) = 1.66$, $p = .20$, partial $\eta^2 = .03$] but the ND x Group x Vocabulary interaction was significant [$F(1, 47) = 5.29$, $p = .03$, partial $\eta^2 = .10$].

Further one-way ANCOVA analyses found the ND x Vocabulary interaction was significant for the children with LI [$F(1, 11) = 8.77$, $p = .01$, partial $\eta^2 = .44$] but not for the TD children [$F(1, 36) = .84$, $p = .37$, partial $\eta^2 = .02$].

These results therefore demonstrate a differing relationship between ND and vocabulary between the two groups. Figure 4.23 represents the trajectories of influence of high and low ND with respect to vocabulary knowledge on lexical retrieval and output. On inspection of this graph it would appear that the group differences lie mainly in terms of magnitude of effect and so, once again, may simply be an artefact of the higher scores obtained by the children with LI (which in itself is an interesting result). Alternatively they may represent a larger increase in the facilitative effect of high ND on the processing of the children with LI than would be predicted by their growth in vocabulary knowledge. This result will be considered further in the discussion below.

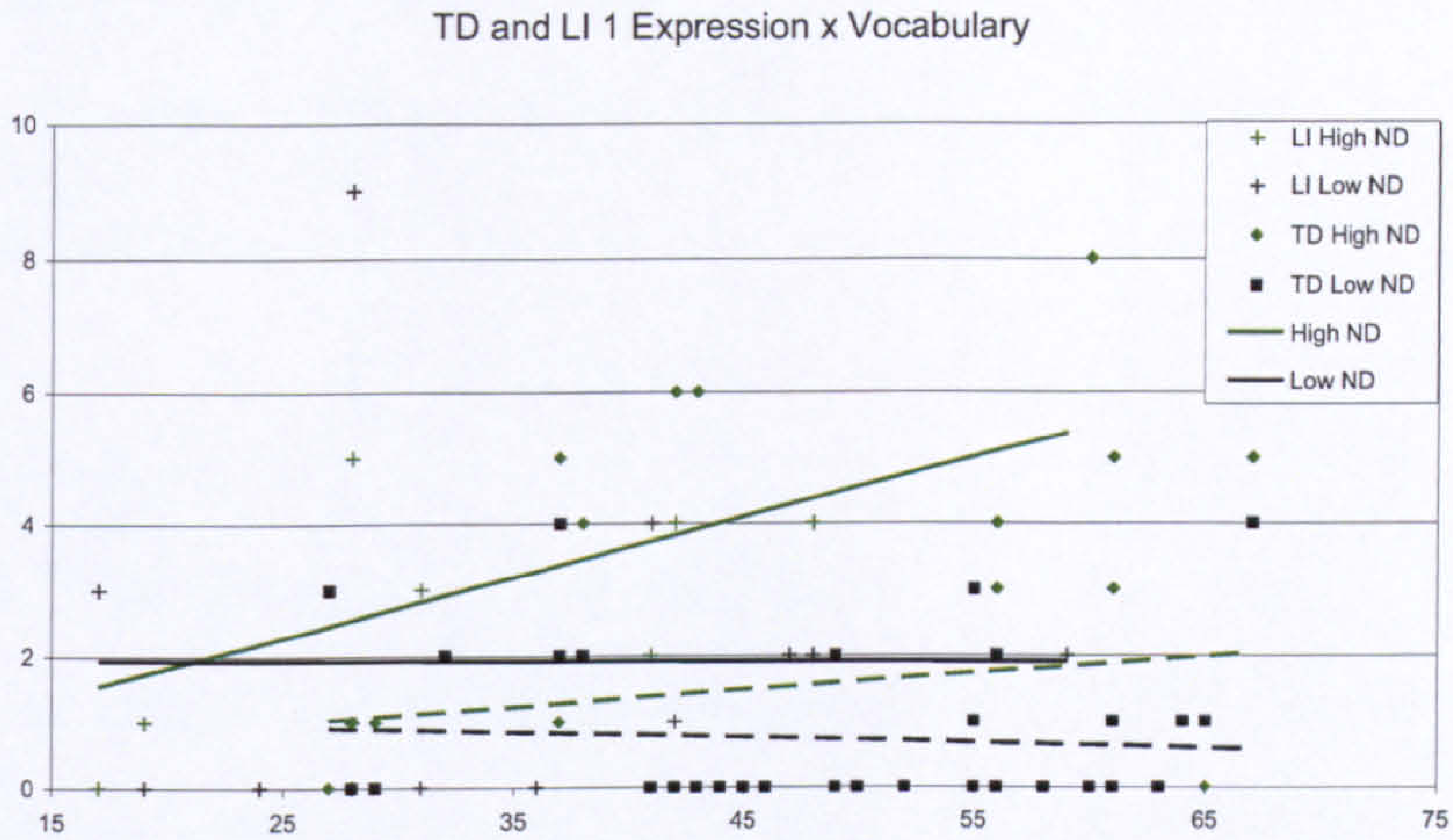

Figure 4.23. LI and TD trajectories of influence of high and low ND with respect to vocabulary knowledge for lexical retrieval and output.

4.3.5.1.3 Semantic feature probe: semantic feature fast-mapping abilities

Group differences were explored using a series of mixed 2*2 ANCOVAs (PP: high, low; Group: TD, LI; Covariate: Age or Vocabulary) (ND: high, low; Group: TD, LI; Covariate: Age or Vocabulary).

The children with LI scored more poorly than the TD group on the semantic features probe when age was co-varied [$F(1, 47) = 4.97$, p = .03, partial $\eta^2 = .10$] but there were no difference between the groups once vocabulary knowledge was considered [$F(1, 47) = 2.46$, p = .12, partial $\eta^2 = .05$]. Therefore the children with LI learned fewer semantic features than the TD group however these group differences appear to be closely linked to the children's level of vocabulary knowledge.

Neither group was affected by ND or PP and there were no significant interactions Group x PP or Group x ND interactions [Group x PP: $F(1, 47) = 1.07$, p = .31, partial $\eta^2 = .02$] ; Group x PP x Age: $F(1, 47) = .84$, p = .37, partial $\eta^2 = .02$; Group x PP x Vocabulary: $F(1, 47) = .05$, p = .83, partial η^2 = ..001; Group x ND: $F(1, 47)$ = .18, p = .68, partial η^2 = .004; Group x ND x Age: $F(1, 47)$ = .30, p = .59, partial η^2 = .01; Group x ND x Vocabulary: [$F(1, 47)$ = .69, p = .41, partial η^2 = .04].

4.3.5.2 Error Patterns

4.3.5.2.1The influence of PP on error patterns

A 2*2*3 mixed ANCOVA compared the within subjects factors PP, with two levels, high and low, Proportion Errors with 3 levels, RD, UD and Foil and the between subjects factor, Group with two levels, TD and LI and with age as a covariate found no overall group differences [$F(1, 49)$ = 1.24, p = .27 partial η^2 = .03] and no significant group interactions, although the 4-way interaction PP x Error x Group x Age approached significance [$F(2, 94)$ = 3.05, p = .05 partial η^2 = .06]. Two 2*3 within subjects ANCOVAs (PP, Error, Age as a covariate) found a significant Error x PP x Age interaction for the TD group [$F(2, 72)$ = 3.81, p = .03 partial η^2 = .10] but not the LI group [$F(2, 22)$ = .206, p = .82 partial η^2 = .02], reflecting the changing nature of influence of PP across development in the TD group which was not present in the LI group.

A 2*2*3 mixed ANCOVA with vocabulary as a covariate found similar results with no overall group differences [$F(1, 47)$ = .000, p = .99 partial η^2 = .00] and no significant group interactions, although the 4-way interaction PP x Error x Group x Vocabulary approached significance [$F(2, 94)$ = 2.77, p = .07 partial η^2 = .06]. Two 2*3 within subjects ANCOVA (PP, Error, vocabulary as a covariate) found a significant Error x PP x vocabulary interaction for the TD group [$F(2, 72)$ = 4.93, p = .01 partial η^2 = .12] but not the LI group [$F(2, 22)$ = .01, p = .52 partial η^2 = .60], suggesting that the differences in the changing nature of influence of PP across development between the groups may not be entirely explained by differences in their vocabulary knowledge.

4.3.5.2.2 The influence of ND on error patterns

Two mixed 2*2*3 mixed ANCOVAs were completed to consider group differences in the influence of ND on error patterns in the comprehension probe with respect to age and vocabulary knowledge respectively. Each compared the within subjects factors ND, with two levels, high and low, Proportion Errors with 3 levels, RD, UD and Foil and the between subjects factor, Group with two levels, TD and LI.

These analyses found no overall group differences [Age: $F(1, 47) = 1.24$, p = .27, partial η^2 = .03; Vocabulary: $F(1, 47) = .00$, p = .99, partial η^2 = .00] or interactions [Age: Group x ND $F(1, 47) = .30$, p = .58, partial η^2 = .01; Group x ND x Age $F(1, 47) = .60$, p = .44, partial η^2 = .01; Group x Error x ND x Age: $F(2, 94) = .73$, p = .48, partial η^2 = .02][Vocabulary: Group x ND $F(1, 47) = .16$, p = .69, partial η^2 = .003; Group x ND x Vocabulary $F(1, 47)$ = .80, p = .38, partial η^2 = .02; Group x Error x ND x Vocabulary: $F(2, 94) = .39$, p = .68, partial η^2 = .01].The influence of ND on error patterns was therefore not significantly different between the two groups.

4.3.6 Group Comparisons: Discussion

When compared with respect to age the children with LI were poorer than the TD children in their ability to create a form-referent representation during fast mapping and so in their ability to choose the Target in the comprehension probe, and also in the number of semantic features they had learned about the referents. However the children with LI were better than the TD children in terms of the number of phonemes they produced correctly in the expression probe. This is an unexpected result and one which will be returned to later. There were no significant group differences in the pattern of errors produced.

When compared with respect to vocabulary knowledge there were no significant group differences for choosing the Target, learning semantic features or in the pattern of errors produced. These results suggest that it is not fast mapping per se which impairs the word learning abilities of children with LI. Rather, once their existing vocabulary knowledge, and so their processing capacity and efficiency is considered, they are as able to fast-map a new word as TD children.

The expression probe scores remained significantly different between the groups such that the children with LI produced more correct phonemes on the expression probe than would be predicted by their level of vocabulary knowledge.

The effect of PP differed between the groups when compared with respect to age for the comprehension probe score and error patterns and also on the expression probe. The group differences in comprehension probe responses reflected the changing pattern of influence of PP in the TD group as the children grew older (from high PP advantage to low PP advantage) and the absence of this switch in bias in the children with LI. These group differences could simply reflect an immature pattern of processing such that the children with LI were simply exhibiting the processing bias which was appropriate for their level of vocabulary knowledge. Comparisons with respect to vocabulary knowledge found no significant differences between the groups and therefore suggest that the differences in the trajectory of influence of PP on processing between the groups can be explained by the level of vocabulary knowledge of the two groups.

Results of the group comparisons of the nature of the trajectory of influence of PP on error patterns however provide tentative support for the suggestion that the differing trajectories cannot be entirely explained by the vocabulary levels of the two groups. That is, as the children with LI may have been using a 'paired association' strategy which compensated for the effect of PP on their ability to create a form-referent representation, group comparisons using the number of Target responses as the dependent variable may not be sensitive to the effects of PP on the processing of the children with LI. As PP did exert a measurable effect on other aspects of the fast mapping abilities of the children with LI (e.g. the proportion of RD errors) then comparisons between the groups considering error patterns may be more sensitive to the effect of PP on processing in the LI group. Group differences in this analysis approached significance when vocabulary knowledge was co-varied and Error x PP x Vocabulary interactions were significant for the TD children but not those with LI. This result will be explored further when considering the candidate explanatory frameworks for the nature of the group differences below.

The effect of ND did not differ between the groups for comprehension probe scores, error patterns or semantic feature mapping when compared with respect to age or vocabulary knowledge. Hence the influence of ND on processing appears to be very similar between the groups. The groups did differ however regarding the influence of ND on their expression probe scores. That is, the relationship between ND and vocabulary differed between the groups but the relationship between ND and age did not. It appears that the group differences lie mainly in terms of magnitude of effect of ND and so may simply be an artefact of the higher scores obtained by the children with LI. Alternatively they may represent a larger increase in the facilitative effect of high ND on the processing of the children with LI than would be predicted by their growth in vocabulary knowledge.

The following discussion will address the research questions identified at the outset of the study, namely whether or not the trajectories of influence of PP and ND differ between the groups and what this tell us about the structure and functioning of the developing lexicon in LI. However first, two surprising findings will be considered, namely the superior performance of the children with LI on the expression probe and the finding that it appears that fast mapping per se is not an area of difficulty for this group of children.

4.3.6.1 Superior lexical retrieval and output and equivalent fast-mapping ability in LI

The unexpected result that children with LI obtained higher expression probe scores than the TD children warrants further consideration, particularly as it occurs in the context of poorer scores on the comprehension probe. It must be underlined that for both groups of children the scores were extremely low (from a maximum score of 72 the TD children $\mu = 2.3$, LI $\mu = 4.77$) and the majority of responses for both groups were "I don't know" or "I can't remember". When this occurred children were encouraged to "have a guess" but were extremely reluctant to do so. The main difference between the groups therefore was that the children with LI were much more willing to attempt the novel words that the TD children. This willingness to try despite the fragility of the lexical representations and/or retrieval process on the part of the children with LI may be a product of a number of differences between the groups. For example the children with LI may have poorer meta-linguistic awareness so that they are less aware of the fragility of their lexical representations and/or retrieval processes than the TD children. Alternatively it may be that the children with LI have more experience of using poorly retrieved words than the TD children as the imperative to communicate in the context of a poorly specified lexical system, has, in the past, created the necessity to override any uncertainty about the words they may be using. A final possibility is that having speech and language therapy may have made 'having a try', even when unsure, a more familiar experience for this group of children.

There is however another possible explanation which may relate to differences in the fast-mapping process between the groups. In order to access a word, a semantic representation must first be activated by the recognition of the referent in semantic memory, activation from the semantic representation must then spread to the lexical node, to the sub-lexical/phonological representations linked to that node and must then be turned into a motor plan for production. Activation therefore derives from the strength of the connections between these levels of representation and the strength of the initial activation (Gershkoff-Stowe & Hahn, 2007). The nature of the semantic representation therefore, as the locus of the beginning of activation, is crucial to word retrieval and increased 'depth' of semantic representation, as measured by detail in the drawing of referents (McGregor *et al.*, 2002) and exposure to gestural cues regarding the nature of the referents (Capone & McGregor, 2005), has been shown to facilitate retrieval. It is possible therefore that the paired association learning style of the children with LI as opposed to the semantically integrated learning style of the TD children may contribute to their increased ability to access the novel words. This would seem counter-intuitive if depth of semantic representation is thought to facilitate retrieval. However, recall that activation derives from the strength of connections between the levels of representations and the strength of the initial activation. Having a representation which is not connected to other competing semantic representations could therefore concentrate all of the activation to one lexical node rather than to competing lexical nodes via links to related semantic representations and so could increase the activation strength for retrieval of the lexical node and connected phonological/sub-lexical level representations. This paired association learning may therefore result in an additional, apparently adaptive consequence for the fast-mapping abilities of children with LI, enabling the children both to override the effects of PP on processing and to retrieve newly learned words more readily than TD children. However, the strategy also has the maladaptive consequences that the children with LI make fewer and less extensive semantic networks than the TD and so conceptual information, which is coded through connections within a semantic network (e.g. semantic category membership, associations between items presented in the same 'event') is likely not to be encoded during fast-mapping by children with LI.

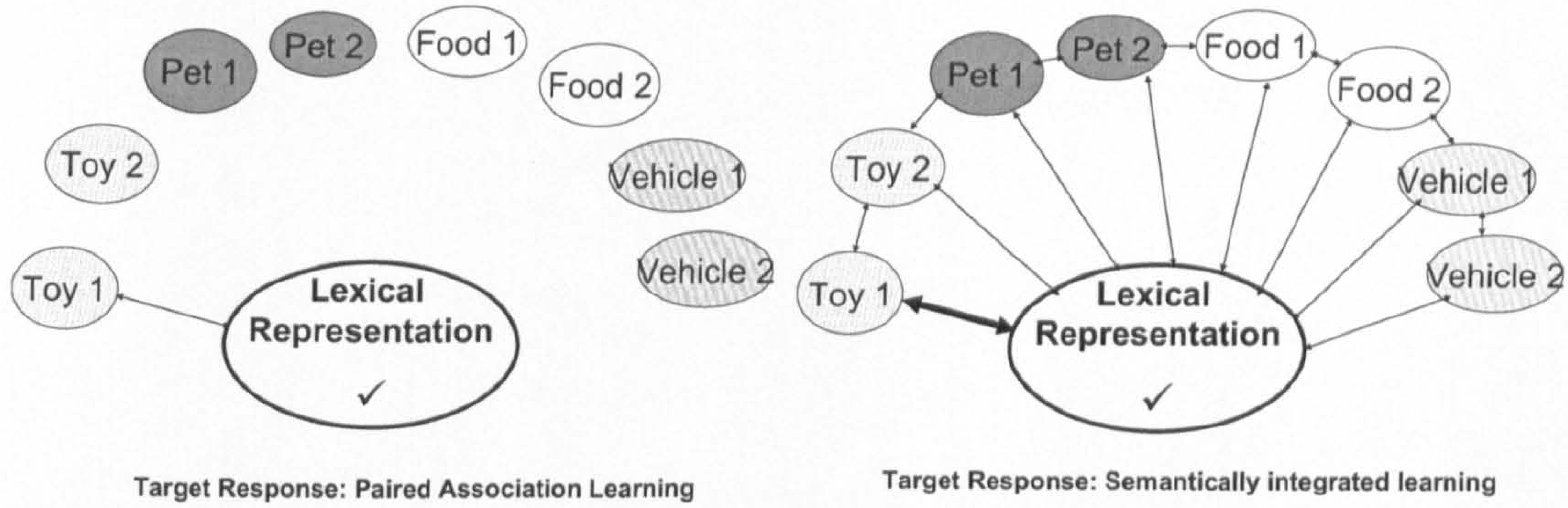

Figure 4.24. Possible networks created by paired association and semantically integrated learning

This impairment in the creation of semantic networks, as discussed previously, may have significant implications for the ontogenesis of LI across development through the development of grammatical impairments. However in addition it may also have long term consequences for vocabulary learning over time through effects on the overall efficiency of the word learning mechanism and may begin to shed light on the second unexpected finding of this study, that, in controlled experimental conditions children with LI are not poorer at fast mapping novel words than would be predicted by their existing level of vocabulary knowledge. Children with LI have long term vocabulary learning difficulties and they fall further and further behind their peers in this important area of development (Stothard et al., 1998). If fast mapping itself isn't the problem for children with LI then what is?

One contributory factor to this compounding difficulty with learning new words may be the sparseness of the semantic network described above. Gershkoff-Stowe and Hahn (2007), taught 16 – 18 month olds 12 unrelated novel nouns over 12 weekly sessions and found that they were then able to fast-map a new set of unrelated nouns more readily than a control group who had been exposed to familiar rather than novel nouns in the preceding 12 weeks.

Hence the act of learning new words facilitated further fast-mapping. The authors suggest that this facilitative effect arose from the formation of a semantic "neighbourhood of collective activity" (Gershkoff-Stowe & Hahn, 2007, p. 692). That is, the children created a semantic neighbourhood based on the learning context (i.e. 'words that I learn in the university lab') and this pre-existing neighbourhood facilitated fast-mapping of new words. The authors suggest that "broadening the base of conceptually related links within a single neighbourhood produces patterns of activation that support the accessibility of individual words"(Gershkoff-Stowe & Hahn, 2007, p.692). If this strategy of creating ad-hoc, context based networks does facilitate future word learning then the fact that the children with LI in this study appeared not to use such a strategy could, perhaps, play a part in the compounding nature of the word learning impairments found in children with LI (Stothard et al., 1998).That is, the children with LI in this study, unlike those with TD did not choose the UD at a level above chance and so, unlike the TD children were not creating the ad-hoc semantic network 'appears in the story'. Hence it may be that creating fewer and sparser semantic networks during fast-mapping will hinder not only the development of a representation for that particular word but also future learning of novel words which may have been associated semantically with that word.

This impairment in semantic network formation is likely to be only one of many factors which combine to produce the long term word learning difficulties documented in children with LI. However, as vocabulary learning is so closely related to existing vocabulary knowledge the widening gap between TD children and children with LI across development may simply reflect the properties of exponential growth. That is, if the rate of vocabulary growth is proportionate to the current amount of vocabulary knowledge then the widening gap may simply be a property of this exponential learning process. This would suggest that children with LI may be limited in their word learning ability due to capacity limitations brought about by their limited existing word knowledge. This certainly appears to be the case from the results presented here. However, in the messy reality of word learning in the course of daily interaction, additional challenges may affect both fast and slow mapping than exist in carfully controlled word learning experiments. For example syntactic and semantic cues may be less readily available to support their learning than for TD children and, it is possible that in very challenging contexts, perhaps when processing at speed or with a very high processing load, then children with LI may fall even further behind their peers (Alt et al., 2004; Oetting *et al.*, 1995). In addition, over time the inability to create ad-hoc categories identified in this study, may also handicap the learning of new words and so handicap the growth of vocabulary knowledge still further than might be predicted by their current level of knowledge.

Further research is recommended to investigate the relatively under-researched process of slow mapping of words both in TD and in children with LI. It appears likely that what is learned during fast-mapping and the nature of the child's speech processing mechanism interact to affect the development of a lexical representation over time. Future research investigating this process could further elucidate the ontogeny of LI and of the typically developing lexicon.

4.3.6.2 The structure and functioning of the speech processing mechanism in LI

The key question with regard to the nature of the speech processing mechanism in LI is whether any group differences found are suggestive of an overall processing capacity limitation, a phonological/sub-lexical processing impairment or some other, as yet unidentified impairment in the nature of the development of the speech processing mechanism?

The pattern of results compatible with each explanatory framework is as follows:

- An overall processing capacity limitation: The children with LI perform more poorly than the TD children with respect to age but when compared with respect to vocabulary knowledge, no significant differences between the groups exist. In addition, the trajectories of influence of PP and ND with respect to vocabulary knowledge do not differ between the groups.
- A phonological/sub-lexical processing impairment: the group trajectories of fast-mapping ability are differentially affected by ND when compared with respect to vocabulary knowledge.
- An impairment in the nature of the development of the speech processing mechanism which is not related to phonological/sub-lexical processing: the group trajectories of fast-mapping ability are differentially affected by PP but not by ND when compared with respect to vocabulary knowledge.

It therefore appears that the most likely explanation is that an overall capacity limitation, closely linked to the children's existing level of vocabulary knowledge limits the amount of information that the children with LI learn from the fast mapping context and that no other additional impairments in the nature of the speech processing mechanism exist. There is certainly no evidence for a phonological/sub-lexical processing impairment as the two groups demonstrated very similar responses to the ND of the novel words and similar developmental trajectories with respect to the influence of ND. This result therefore suggests that the children with LI have difficulties learning new words because they have smaller lexicons which imply smaller capacity and processing efficiency and so poorer word learning. The children's difficulties therefore compound across development leaving them further and further behind their peers. This does not explain why and how they have smaller lexicons in the first instance and so further work considering why and how the late and slow start into word learning occurs is necessary.

There is, however, tentative support for the third explanation listed above. That is, an impairment in the nature of the development of the speech processing mechanism which is not related to phonological/sub-lexical processing. Such an explanation is suggested because the differences in the trajectory of influence of PP between the groups may not be entirely explained by the children's level of vocabulary knowledge.

The TD children demonstrated a switch in PP bias across the developmental trajectory from high PP to low PP and it was hypothesised that this was driven by the emergence of sub-lexical/phonemic level representations. The fact that this does not occur in the children with LI, despite the fact that this group's response to the ND of the novel words suggested that sub-lexical/phonemic level representations were emerging, is therefore unexpected and may indicate crucial differences in the nature of the speech processing mechanism between the two groups.

What might explain this result? It could be that the switch in PP bias found in the TD children is not in fact driven by the emergence of sub-lexical/phonemic level representations but by some other trigger and it is this trigger which is absent in the children with LI . One such trigger might be the development of phoneme-grapheme knowledge, which perhaps is less successful in the children with LI and so delays the switching process. However, increased phoneme-grapheme knowledge would affect phonological/sub-lexical processing and therefore should be measurable through the influence of ND on processing. The absence of a group difference in the influence of ND would appear to rule this explanation out. The interpretation of a null result is of course problematic and it is possible that differences may exist but that the measure used here was not sufficiently sensitive to identify them.

Considering the influence of ND on processing however does appear to be a promising avenue to pursue in future research in order to investigate the emergence of sub-lexical/phonological knowledge in young children.

A second explanation is that the children with LI are impaired, not at the sub-lexical/phonemic level but at the phonetic/indexical level and this impairment results in an inability or a delay in their ability to switch processing bias. That is, despite the fact that the drivers for change are in place (i.e. well developed sub-lexical/phonemic representations), the children are unable to change the way that they process pre-lexical phonetic regularities and so become fixed in a more immature pattern of processing.

Such an impairment could perhaps reflect continuity of an early impairment in the statistical learning mechanism which, in TD, is crucial for segmentation of the speech stream at the earliest stages of lexical development and which, if impaired in children with LI, may explain their late and slow start into word learning. Chiat (2001), suggests that children with LI may be impaired in their ability to use prosody to support early word mapping and Evans and colleagues (2009) have demonstrated that children with LI have difficulties in abstracting statistical regularities both from speech and non-speech auditory stimuli. It must be noted that Evan's study included children between the ages of 6;05 and 14;04 and so does not provide empirical support to the claim that this is a causal deficit in LI, however it does provide support for the data in the current study which suggests a deficit in phonetic/indexical processing in older children with LI. Indeed Evan's study extends the conceptualisation of the deficit beyond speech processing to a more general problem with implicit learning for auditory stimuli.

Alternatively, the fixing of the system in a more immature pattern of processing could reflect the nature of connectionist networks, which, when learning patterns which are highly inconsistent (such as are found in phonological and grammatical learning) are liable to become entrenched in a particular pattern of processing and hence plasticity reduces after a certain period of learning (Plunkett et al., 1997; Seidenberg & Zevin, 2006; Thomas & Johnson, 2008; Westermann *et al.*, 2006). Such a pattern has been thought to explain the phenomenon of 'critical periods' in development. It is possible therefore that children with LI may have been so slow in their lexical learning that by the time their lexicons reach the critical mass to produce a highly detailed phonological/sub-lexical level of processing and thence to induce change in the phonetic/indexical level of processing, the phonetic/indexical level of processing has become entrenched in the more immature pattern of processing and is not able to switch in the same way as the TD children.

These ideas are of course speculative and rest upon statistical comparisons which only approached significance. However the trajectories of development of non-word repetition abilities in this group of children reported in Chapter 3 are also highly suggestive of an entrenchment in an immature processing style and demonstrated that this pattern of immature processing persisted in the LI group into the 4^{th} block of data collection when the children were aged between 4; 07 and 8 years.

Further longitudinal research including both younger and older children than those included in the current study is indicated to consider both whether an early deficit in statistical learning is implicated in the onset of LI and whether older children with LI are indeed entrenched in this immature pattern of processing or whether the 'switching' in bias found in the TD children is simply delayed in this group of children.

4.3.6.3 Clinical implications

Children with LI are worse at fast mapping than their same age peers and this appears to result from poorer processing capacity and efficiency which is both a cause and a consequence of having limited lexical knowledge. This processing limitation appears to affect the creation of a semantic network to a greater degree than other aspects of word learning and this difficulty in creating semantic networks may have implications for word learning which go beyond its effect on individual words, to affect future word learning. In addition, the ability of children to use novel words expressively should not be seen to constitute 'knowing' a word as apparently 'good' expressive abilities in this study, occurred in the context of poor comprehension skills and limited semantic network formation.

The children with LI were functioning at a level commensurate with their level of vocabulary knowledge. As vocabulary learning ability is predicted by the current level of vocabulary knowledge it is easy to see how a late and slow start into word learning can result in an ever increasing gap between the child with LI and their peers. Breaking that cycle is a non-trivial task, which will require age-appropriate interventions focussing on the child but also, perhaps more importantly, on the child's language learning environment. That is, the capacity limitations of the child with LI must be considered in all contexts where vocabulary learning may take place and strategies put in place which will reduce the overall processing load of the task and hence free up processing capacity for learning (Gathercole & Alloway, 2006). In addition strategies and therapy activities which will support deeper and more interconnected semantic learning are recommended, such as the use of gesture by adults interacting with pre-schoolers (Capone & McGregor, 2005) and training analogical reasoning in primary aged children (Masterson & Perrey, 1999).

Robust vocabulary instruction has a long tradition in the mainstream curriculum of the United States school system and a large evidence base for efficacy of teaching approaches exists (Beck *et al.*, 2002). Therapists and teachers working with children with LI in the U.K. may be able to draw on such resources for specific intervention approaches and also the possible benefits of the integration of such vocabulary instruction approaches into mainstream school curricula should perhaps be explored.

4.3.6.4 Future directions.

The current study suggests that knowing few words makes learning more words more difficult. Future work is recommended in a number of areas; to establish the best models of intervention to break the cycle of poor word learning; to consider whether an early impairment in phonetic/indexical processing, perhaps linked to a global deficit in implicit statistical learning, could be a causal mechanism in the late and slow start into word learning of children with LI; to consider whether the speech processing mechanism in LI fixes with an immature processing architecture; to develop a fully specified model of the developing lexicon which conceptualises immature and impaired lexicons as 'inefficient networks' rather than as being comprised of 'holistic representations' and so explores all levels of representation in the speech processing mechanism (phonetic/indexical, sub-lexical/phonological, semantic) and also the nature of the interactivity between them, across the developmental process.

CHAPTER 5

DISCUSSION

A developmental approach to LI: Insights and future directions

5.1 The Aims and Outcomes of the Thesis

This thesis set out to apply a 'developmental emergent' perspective to our understanding of LI. To date very little empirical data exists which has been collected from an explicitly developmental emergent perspective and so some crucial factors are missing from our understanding of the disorder, namely the nature of the developmental trajectory of LI, the nature of individual difference in that trajectory and the nature of interactivity between domains and subsystems in the moment and across development in this disorder. This study seeks to contribute to that necessary empirical data and to test whether the expectation that a developmental perspective and methodology adds to our understanding, is justified.

This thesis focussed on the developing lexicon with the expectation that understanding the nature of the trajectory of the developing lexicon in TD and LI could provide important insights into the early ontogeny of LI and that through careful description of the process of neuroconstruction of the early LI profile it may prove possible to uncover important insights into causal mechanisms, to describe atypical trajectories and to identify potential drivers of change which could be harnessed for early interventions.

This study therefore had the following aims with respect the developing lexicon in LI

1. To provide a first detailed description of the "perturbed" process of emergent modularisation in young children with LI based on empirical longitudinal data
2. To pilot the methodology of longitudinal case studies of language impaired children and hence consider whether the expectation that a developmental perspective and methodology adds to our understanding is justified.
3. To consider what this empirical longitudinal data tell us about current theories as to
    i. the causal mechanisms
    ii. the course of the perturbed emergent pathway

iii. the nature of the relationships between 'early' and 'late' patterns of impairment and of interactions between domains

The pursuit of these aims has resulted in a number of insights regarding the nature of the typically developing lexicon and that of children with LI and of the probable implications of the identified lexical and phonological processing impairment for the broader trajectory of language development in LI. These insights will be described below and the implications for clinical interventions and future research identified. Caveats and cautions regarding possible methodological considerations will then be identified and, finally a case will be presented for the benefits of the application of a developmental emergent model of LI for research and practice and the possible implications of this approach for our understanding of LI explored.

5.2 Implications for a Developmental Emergent Model of the Typically Developing Lexicon

The key findings from the current study imply that the developing speech processing mechanism is one in which multiple levels of representation are available at all times during processing, that these levels interact in the moment of processing and across development and that different task demands call on different aspects of the speech processing mechanism to varying degrees and in different ways. Hence in order to understand speech processing the function of the mechanism *as a whole* must be considered.

In addition the study's results suggest that the process of "lexical restructuring" does not refer to an abstract representation of a lexeme being depicted in greater and greater detail, but rather to the effects on processing which are exerted by the number of neighbours with which a lexical node has to compete for recognition and access, the nature of the similarities between the node and its neighbours and the nature of the sub-lexical representations to which it is connected.

Hence the behaviours which have been conceptualised as "lexical restructuring" are a function of changes in the structure of the whole lexicon as a result of additional lexical representations being added to the network and the effect which these changes in the number and nature of neighbours connected to the given lexical node exert on processing at the phonetic and sub-lexical levels of processing. That is, these additional lexical representations have effects at a number of levels; on processing of pre-lexical acoustic-phonetic input through feedback from the lexical nodes such that if two nodes are now competing for recognition then greater acoustic phonetic detail needs to be processed; on processing at the sub-lexical level both 'in the moment', in a similar way to that described above for acoustic-phonetic processing, and also over development through the creation of sub-lexical representations (phonemes, syllables, rimes) in order to distinguish between competing word forms and so create a more efficient processing mechanism than a phonetic-acoustic level operating in isolation; on processing at the lexical level through excitatory and inhibitory links between the nodes which also feed activation to the sub-lexical level.

In addition this study has provided empirical evidence of a change in the nature of the 'mechanics' of speech processing across development such that changes in lexical and sub-lexical levels of representation resulted in changes in the nature of phonetic/indexical processing during fast mapping. Hence the speech processing system of TD children did not simply evince an ever increasing capacity for fast mapping rather it demonstrated reorganisation as a function of changes in the nature of emerging representations and changing qualities of the lexical and sub-lexical network.

5.3 Implications for a Developmental Emergent Model of the Lexicon in LI

5.3.1 Implications for the phonological processing impairments in LI

The above model of speech processing and the findings of the non-word repetition and word learning tasks reported suggest that in order to explain the phonological processing and storage deficits found in LI, once again the nature of the speech processing mechanism *as a whole* must be considered. In this way the deficits found in LI are best conceptualised as resulting from an inefficient speech processing architecture which can only be understood when it is acknowledged that the nature and functionality of this architecture changes across development in response to changes in the child's existing lexical knowledge and the sub-lexical/phonological level representations which they have been able to abstract from that knowledge. The 'inefficient speech processing architecture' explanation suggests that children with LI are impaired in encoding, storage and access and that such a system is prone to high levels of both interference and decay. The result of this 'inefficient speech processing architecture' is that children with LI have a mutually dependent triad of impairments in lexical knowledge, sub-lexical/phonological processing, and verbal processing capacity. This account challenges the PWM and phonological sensitivity theories of LI suggesting instead that all of the aspects of impairment invoked by these competing explanations (storage, encoding and access) occur simultaneously and interdependently in the speech processing mechanisms of children with LI.

The 'inefficient speech processing architecture' hypothesis therefore suggests that the deficits found in LI emerge from a complex set of interactions between numerous sub-systems within the speech processing system both in the moment and across development and hence requires researchers to move away from the search for an impaired *level of processing* to the search for an understanding of the workings of a whole atypical mechanism.

Furthermore it appears that in addition to differences 'in the moment' of processing between the speech processing mechanisms of children with LI, differences in the developmental trajectory and developmental processes may exist. That is if, as the developmental emergent model of language development predicts, language is constructed over development through iterative cycles of uptake-abstraction-reorganisation, then the results of this study suggest that lexical development in children with LI may be impaired in all three of these developmental processes. That is, this study has identified an impairment in the first of these steps, *uptake*, through the effects on learning of a limited speech processing capacity which is both a cause and a consequence of poor lexical learning. It also includes results which are suggestive of a deficit in schema *abstraction* with respect to the abstraction of sub-lexical/phonemic level representations from lexical knowledge. Finally results also suggest that *reorganisation* may not happen in the speech processing mechanism of children with LI in the same way as in TD children, in terms of a speech processing mechanism which seems to 'fix' at a level of efficiency below that of the TD speech processing mechanism and in terms of the absence of a switch in bias in phonetic/indexical processing despite changes at other levels of processing which trigger this switch in TD.

5.3.2 Implications for the broader trajectory of LI

The first major findings of this study with respect to the broader trajectory of LI is that there may be a number of possible trajectories of development in LI such that some children appear to be able to overcome a late and slow start into word learning whilst others do not. Some children may have an impairment in schema abstraction over and above that which is predicted by their vocabulary knowledge and perhaps it is this which creates a more intractable impairment.

The results of the current study also are indicative of suggestive of how the mutually dependent triad of impairments of lexical knowledge, sub-lexical/phonological processing, and verbal processing capacity may relate to the nature of the broader language trajectory for children with LI in terms of possible earlier causal mechanisms and later grammatical and syntactic deficits.

In terms of causal mechanisms the current results suggest that children with LI may have had an early impairment in the statistical learning mechanism which is crucial for segmentation of the speech stream at the earliest stages of lexical development. Extrapolating backwards from the trajectory described here is of course highly speculative and so this suggestion must be considered with caution but merits further research. It is also likely that the mechanism for a late start into word learning is in fact multi-factorial and/or may differ between children. The emergantist coalition model of early word learning (Hirsh-Pasek et al., 2000) details the cues and constraints used by infants to learn words. Through consideration of different children's abilities to use these cues and their later language learning status, it may be possible to uncover the early causal mechanisms and early ontogeny of LI.

In terms of the relationship between an impaired speech processing mechanism and subsequent grammatical and syntactic deficits, the deficits in the nature of the speech processing mechanism described here could have multiple detrimental effects on broader language learning. Firstly, findings from the word learning task presented here suggest that children with LI do not create highly connected semantic networks during fast mapping in the same way as TD children. That is, conceptual information, which is coded through connections within a semantic network (e.g. semantic category membership, associations between items presented in the same 'event') is not encoded during fast-mapping by children with LI to the same degree as TD children. If such limitations are at play during the learning of a new *verb* then it is possible that difficulties with learning verb argument structure may arise through impaired mapping of conceptual information about the novel verb. That is, in TD children conceptual information about verbs and their arguments may be encoded through connections with representations for the other items which occur within the verb learning context (i.e. the arguments). If the children with LI are less able to make these connections during verb learning, such lexical learning deficits may contribute to impaired learning regarding argument structures and so may play a crucial role in the emergence of grammatical impairments in LI.

A second possible consequence of the inefficient speech processing architecture of children with LI is that a more limited overall processing capacity in conjunction with poorly specified sub-lexical/phonological level representations would result in the morphological and syntactic impairments described and instantiated in Joanisse's emergent connectionist models of LI (Joanisse, 2004, 2009; Joanisse & Seidenberg, 2003). In addition the interactions between morphology and phonology identified by Leonard and colleagues (Leonard et al., 2007a), and predicate argument structure and morphology identified by Pizzioli and colleagues (Pizzioli & Schelstraete, 2008) would also result from such an impairment.

Fundamentally as outlined in Chapter 1, if *grammar* is constructed over development through iterative cycles of uptake-abstraction-reorganisation, then the triad of impairments in *lexical knowledge, sub-lexical/phonological processing, and verbal processing capacity* found in these children will affect grammatical acquisition through their detrimental effect on the first step in this cycle, of 'uptake', in both quantitative and qualitative terms. The other elements of the learning cycle, of abstracting rules and reorganising the processing system, will then be affected by this more limited uptake. Through additional processes of compensation, altered timing of emergence of skills and the properties of critical periods produced by self-organising networks , this slower uptake may not simply create a *slower* trajectory in grammatical development but, an *atypical and uneven profile* and trajectory.

5.3.3 Implications for clinical interventions

The findings from this study suggest that children with LI have difficulties with learning new words which are both a cause and a consequence of the triad of speech processing impairments (lexical knowledge, phonological processing, and verbal processing capacity) and that some children have additional difficulties in abstracting knowledge and reorganising their lexicons in order to create efficient speech processing mechanisms. As identified above these impairments have consequences for the broader trajectory of Language Impairment and so the impairments in word learning and speech processing in this group of children need to be taken seriously.

Of particular importance is the finding that, this triad of speech processing impairments affects not just lexical and sub-lexical/phonemic learning but also semantic learning and that this difficulty in creating semantic networks may have implications for word learning which go beyond its effect on learning individual words, to affect future word learning (Gershkoff-Stowe & Hahn, 2007) and grammatical development.

Tackling the triad of speech processing impairments will involve consideration of the three aspects of the cycle of development; uptake-abstraction-reorganisation, and therapy will need to target all three aspects. With respect to uptake interventions will need to focus on the child but also, perhaps more importantly, on the child's language learning environment. That is, the capacity limitations of the child with LI must be considered in all contexts where vocabulary learning may take place and strategies put in place which will reduce the overall processing load of the task and hence free up processing capacity for learning (Gathercole & Alloway, 2006). In addition strategies and therapy activities which will support deeper and more interconnected semantic learning are recommended, such as the use of gesture by adults interacting with pre-schoolers (Capone & McGregor, 2005) and training analogical reasoning in primary aged children (Masterson & Perrey, 1999).

With respect to abstraction, interventions supporting children to create phonemic level representations should, in turn, support their processing efficiency (De Jong *et al.*, 2000) and reduce the effect of phonological processing impairments on other learning such as morphology (Leonard et al., 2007a) and literacy (Pennington & Bishop, 2009). Indeed existing phonological awareness intervention programmes have shown evidence of such preventative effects for literacy (Gillon, 2000; Gillon, 2002) and word learning (De Jong et al., 2000). However further work is needed to test whether such training also affects morphology acquisition.

With respect to reorganisation it is not yet clear exactly what the drivers of such reorganisation are in TD children. It may simply be that a critical mass of vocabulary knowledge must occur, or that a certain level of sub-lexical/phonological level representation must exist. It is also possible that literacy instruction may be a crucial trigger for such reorganisation (Ziegler & Goswami, 2005). Deficits in all of these probable triggers exist in LI and are therefore likely to delay the process of reorganisation in this group of children. Hence work on uptake and abstraction may be enough to create reorganisation in the speech processing system of the child with LI. However the results presented here suggest that this may not be the case and that the speech processing system of children with LI may 'fix' at an immature level of efficiency. If this is the case then studies designed to uncover the drivers of change in children with TD and LI are recommended to uncover whether it is possible to 'mobilise' reorganisation in an entrenched inefficient system. If it is not possible to do so then compensatory strategies for this persisting inefficiency in processing should be pursued.

5.3.4 Implications for future research

The application of a developmental emergent perspective and methodology has provided new insights into the ontogeny of LI and has the necessary scope and explanatory power to accommodate and explain many of the more recent findings about the nature of LI. Further longitudinal work is warranted using study designs which can tap the process of neuroconstruction of cognition and language and which can explore heterogeneity in individual trajectories previously identified.

With regards individual differences, the findings of the current study suggest that there may be a number of possible trajectories of development in LI such that some children appear to be able to overcome a late and slow start into word learning whilst others do not. Considering similarities and differences between individual developmental trajectories may uncover which factors (both environmental and innate) exert a risk for the development of LI and which factors are protective. In addition, as described in Chapter 1 exploration of individual trajectories holds promise for a more valid explanatory model of heterogeneity and interactivity across development in this group of children. That is the heterogeneity, co-morbidity and change across development characteristic of LI may be better understood if they are described, not as static diagnostic sub-categories, but as changes in patterns of impairment emerging through dynamic interactions across development. Using study designs which allow for individual growth curves to be examined and compared is recommended (Singer & Willett, 2003).

With regards to examining the process of neuroconstruction of cognition and language, longitudinal studies using carefully designed psycholinguistic measures (rather than standardised tests) and with sufficiently frequent and numerous data waves are recommended. For change to be compared between individuals then a sufficiently long time period for change to occur is needed for such comparisons to be made and, in groups where development is slow such time scales may need to be relatively long.

If used in conjunction with intervention studies such methodologies could have the power to uncover the nature of the drivers of change in the TD lexicon and in LI. In this way such drivers could be harnessed for therapy and the nature of developmental change better understood. Once again growth curve modelling is a recommended analytical strategy however, if used in conjunction with microgenetic methodologies (Lavelli *et al.*, 2005) its power for understanding the causal mechanisms for change could be increased and perhaps the length of time needed to observe change reduced.

The novel statistical approach presented here, allowing individual longitudinal trajectories to be compared to a reference normative cross-sectional trajectory, could provide an additional 'compromise methodology' which would allow for questions regarding individual longitudinal change to be asked and answered, and measures of change piloted, in a less resource intensive context than very long prospective longitudinal studies.

The specific findings of the current study suggest that future research into the causal mechanisms of LI should consider the ontogeny of the developing lexicon. These findings suggest that a late and slow start into word learning can have significant long term consequences for language development for some children. Identifying the causes of this late and slow start is vital for our understanding of the ontogeny of LI. There is tentative support from the findings of this study for the suggestion that the children with LI may have had an early impairment in the statistical learning mechanism which is crucial for segmentation of the speech stream at the earliest stages of lexical development. Extrapolating backwards from the trajectory described here is of course highly speculative and so these suggestions must be considered with caution but may be worthy of further research, particularly if younger children than have previously been included in studies of statistical learning in LI can be tested (Evans et al., 2009). It is likely that the mechanism for a late start into word learning is in fact multi-factorial and/or may be different in different children. The emergantist coalition model of early word learning (Hirsh-Pasek et al., 2000) details the cues and constraints used by infants to learn words. Through consideration of different children's abilities to use these cues and their later language learning status, it may be possible to uncover the early ontogeny of LI.

In addition, the specific measures used in the current study and the approach of manipulating the phonological and lexical nature of stimuli in psycholinguistic tasks also hold promise for future research. Indeed, in the light of the current study's suggestion that processing impairments arise from the nature of the speech processing system as a whole, future work manipulating semantic, phonetic/indexical and motor factors in addition to the lexical and phonological factors addressed here may provide new insights into the nature of the developing lexicon and speech processing mechanism.

5.4 Caveats and cautions

This study has provided new insights into the ontogeny of the speech processing mechanism in LI however there are of course methodological considerations and caveats regarding the interpretation and application of its findings.

The first major consideration relates to the participants with LI. This study considers a relatively small number of children with LI (n = 13) and of those children 4 no longer fulfilled the criteria for LI by the end of the study. Such an outcome was anticipated and was considered as an acceptable approach on two grounds. Firstly, the purpose of this study was to consider the early ontogeny of LI. The age of 3 years was chosen to be the youngest possible age at which the chosen behavioural measures could reliably be used and at which children at risk of LI could legitimately be identified (that is, had presented to SLT services). If studies of children with LI only begin at the age of 5 years then causal mechanisms and early trajectories of impairment will never be uncovered. Secondly, there is some evidence to suggest that children with a history of LI, over development, continue to be at risk of later language difficulties and/or remain below the mean in a number of language tasks through to adulthood (Rescorla, 2000, 2002, 2005, 2009; Stothard et al., 1998). Rescorla (2009) and Ellis Weismer (2007) suggest that LI, rather than being a discrete disorder, is simply the extreme of a continuum of language abilities and suggest all children's abilities fall along a "language endowment spectrum". If this is the case and LI is not a distinct categorical phenotype then the use of arbitrary cut-offs in test scores for a diagnosis of LI is called into question. It is recommended however that future prospective longitudinal studies are designed with sufficient power such that comparisons can be made between the children with persisting LI and those with resolving LI to test Recorla and Ellis Weismer's claims. In the current study statistical power was increased through careful task design such that the children were probed on a large number of items for each task, thus increasing the power and sensitivity of the measures.

The second major consideration is the timeframe of the study. Due to resource constraints the period of data collection was 15 – 18 months. Analysis of the individual trajectories suggested, as identified previously, that this length of time may not be long enough to detect differences in *rates of change* between individuals, between individuals and controls and between tasks. This issue was addressed through the analysis of quasi-longitudinal cross-sectional trajectories which provided trajectories spanning a 41 month age range (Thomas et al., 2009). This methodology was chosen as a realistic and practical strategy with which to take the first steps towards mapping the emergence of LI whilst acknowledging that it has less validity than a truly longitudinal data set of individual children.

The final major consideration is that a number of results reported here approach significance. It is likely that both the small numbers of children with LI involved in the study and the fact that many of the key comparisons related to differences in rates of change in scores contribute to these results. That is the ability of the tests to detect difference with respect to rates of change is related both to the degree of difference in the scores and the period of time over which the scores are measured. Hence, had the study been longer and or the age range of the children wider, these results may have reached significance.

Despite these caveats this study does uncover important insights regarding the nature of the developing speech processing mechanism in LI and TD and in addition demonstrates that a longitudinal methodology and perspective adds to our understanding of LI. The findings of this study also suggest that additional studies including more participants, longer timescales and perhaps mixed methodologies (growth curve analysis, microgenetic methodologies, cross-sectional data analysis) could uncover valuable further insights regarding the nature of the development of LI.

5.5 Implications of a developmental emergent approach to LI

5.5.1 The benefits of a developmental emergent approach to LI

As identified in Chapter 1 the benefits of a developmental emergent approach to LI include its ability to accommodate recent research findings regarding the nature of LI within one coherent explanatory framework. The findings of this study also point up potential additional benefits of the developmental emergent approach with respect to therapy; the identification of intervention targets and mechanisms for change.

With respect to the identification of targets, the results presented here underline the importance of *interactivity* between representations and levels of processing both in the moment and across development in typical and atypical development. If we can adequately specify the developmental trajectory of LI and identify links between early impairment and later outcomes it may be then possible to identify which domains should be targeted in early interventions for maximally beneficial long term outcomes.

With respect to mechanisms for change, the principles of a developmental emergent approach presented here could provide a useful framework within which to consider the nature of developmental impairments. This framework could drive both theory and practice through its ability to support the creation of well specified hypotheses about the nature of processing within the developing child and the nature and mechanisms of change in the developmental process. Figure 5.1 summarises this developmental emergent framework.

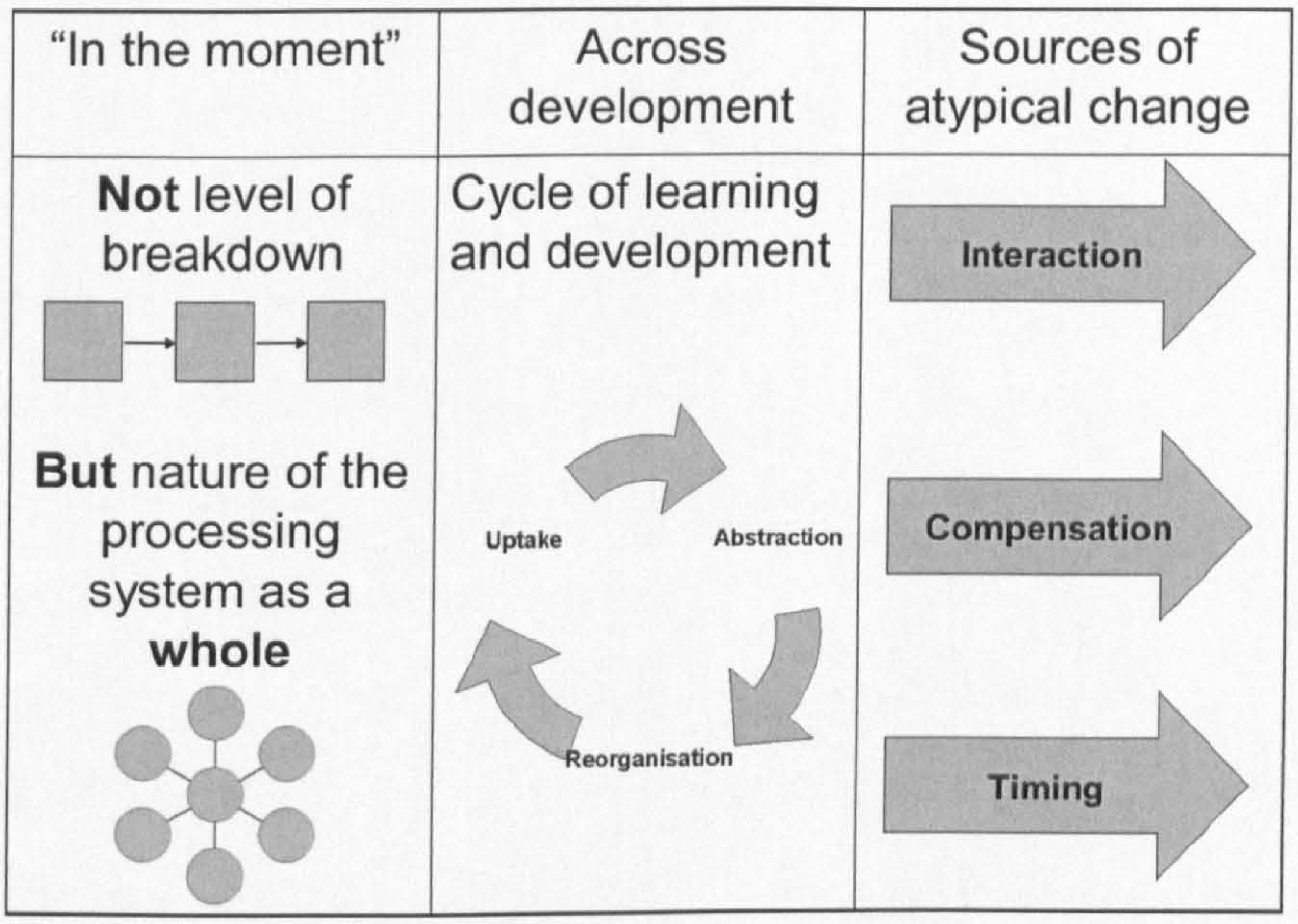

Figure 5.1. The developmental emergent framework: factors to consider with respect to the source and nature of a developmental impairment

Hence to understand the nature of a developmental disorder firstly processing *'in the moment'* will need to be considered. That is the nature of the processing system as a whole will need to be understood in terms of the nature of the representations in the processing system and the nature of the interactions between those levels in the moment of processing. This will obviously differ at different stages in the child's developmental trajectory. Secondly, the nature of change *across development* will need to be understood in terms of how the processing mechanism of the child at a particular point in their developmental trajectory will affect the process of uptake and thence how this uptake will affect the process of change through effects on abstraction and reorganisation. Finally potential sources of atypical change will need to be considered. Impaired *interaction* could result in changes in long term knowledge not triggering the abstraction and/or reorganisation processes in the same way as in TD children. The use of *compensatory strategies* in the context of an atypical processing mechanism could create apparently typical levels of performance in one aspect of processing but could also have maladaptive consequences which affect other aspects of learning (such as was found in the fast mapping skills of the children with LI in this study). Finally the effect of *timing* could affect the trajectory through the effect of critical periods and of mismatches between the child's developmental stage and their environment. That is, when learning patterns which are highly inconsistent (such as are found in phonological and grammatical learning) connectionist networks are liable to become entrenched in a particular pattern of processing and hence plasticity reduces after a certain period of learning (Plunkett et al., 1997; Seidenberg & Zevin, 2006; Thomas & Johnson, 2008; Westermann et al., 2006). This pattern is thought to explain the developmental phenomenon of 'critical periods' in development. It is possible that children with slower development may become entrenched in more immature pattern of processing than TD children. In this way timing of emergence of skills may create an atypical trajectory.

Mismatches in timing, may occur between the child's developmental level and the learning environment in which they are placed and this could create additional difficulties for the child. For example being exposed to direct literacy instruction prior to a critical mass of vocabulary knowledge may not be beneficial to the child.

5.5.2. A re-conceptualisation of the nature of LI and developmental disorders

A developmental emergent approach to LI appears to hold promise for future research and practice. However it raises fundamental questions about the nature of LI which, if widely accepted by researchers and clinicians would have significant implications for practice, with implications for current models of aetiology, diagnosis, assessment and therapy. With respect to aetiology there would need to be a move away from simple one-to-one correspondences between aetiology and diagnoses to an acceptance of continua of outcomes determined through the combined effects of relative risks and protective factors.

With respect to diagnosis new descriptive groupings based on different patterns of developmental trajectory would need to replace diagnoses which are currently based on snapshots at single time points in a child's developmental trajectory. In addition, diagnoses like LI and dyslexia, which rest upon the assumption of residual normality, need to be questioned and replaced by descriptions which consider both developmental change and the nature of the child's strengths and weaknesses across all developmental domains.

With respect to assessment, rather than looking for levels of breakdown within modular 'boxes and arrows' models, the nature of the atypical processing mechanism as a whole must be understood.

With respect to therapy, rather than being based on surface linguistic descriptions of errors, therapy must be based on the cognitive underpinnings of developmental change.

To understand a developing child we must therefore understand the fundamental characteristic of childhood; the nature of change.

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APPENDIX 1

Inclusion and Exclusion Criteria Used by Speech and Language Therapists for Participant Recruitment

Pre-school children

1. **Age:**

Aged between 3;0 and 3;03

OR

Aged between 4;0 and 4;03

2. **Severe language difficulties**

These difficulties may be mixed expressive-receptive or just expressive

A phonological delay/disorder may also be present but the child must also have additional severe language difficulties.

*Severe language difficulties defined as less than 1.25 sd below the mean on a standardised comprehensive language test (e.g. CELF, Reynell).

That is ≤ - 1.25 sd (below the mean) OR a Z score of – 1.25 or less OR a score which falls at or below the 10th centile.

3. **Non-verbal skills within normal limits**

*A score falling at or above 1 sd below the mean. That is a performance IQ of 85 or above OR a Z score of -1 or above OR a score above the 16^{th} centile.

4. **A diagnosis of ASD or Pragmatic Impairment is not suspected at this stage.**

5. **No Hearing impairment or visual impairment**

The child should have passed the 8 month distraction test, and if possible have been seen for a hearing test after referral to SLT and been found to have normal hearing. Where this is not the case parents should have no concerns regarding their child's hearing.

In the case of glue ear, the child should have had fewer than 3 ear infections in the past 12 months.

6. **No physical disability**

This includes an oro-motor difficulty. As this is difficult to entirely rule out with pre-school children, I am working with the following criteria: if the child has difficulties copying oral movements and/or the accuracy of their production of words does **not** improve when imitating a model then please exclude them.

7. **Parental concern and SLT believes they may be "at risk" of SLI**
8. **Exclude children who speak English as an additional language**

* I am aware it is unlikely that you will have tested the children on standardised tests therefore I am happy to take a recommendation based on your clinical judgement and I will carry out the testing prior to entry into the research protocol.

School-aged children

1. Age:

Aged between 5;0 and 5;03

OR

Aged between 6;0 and 6;03

2. Severe language difficulties

These difficulties may be mixed expressive-receptive or just expressive

A phonological delay/disorder may also be present but the child must also have additional severe language difficulties.

Severe language difficulties defined as less than 1.25 sd below the mean on a standardised, comprehensive language test (e.g. CELF, Reynell).

That is ≤ - 1.25 sd (below the mean) OR a Z score of – 1.25 or less OR a score which falls at or below the 10th centile.

3. Non-verbal skills within normal limits

A score falling at or above 1 sd below the mean. That is a performance IQ of 85 or above OR a Z score of -1 or above OR a score above the 16^{th} centile.

4. A diagnosis of SLI by an SLT

5. No hearing impairment and no visual impairment

The child should have passed a hearing test/screen within the past 2 years.

6. No physical disability

This includes an oro-motor difficulty. As I know this is not entirely straightforward I am using the following criteria to distinguish between a difficulty with output phonology and an oro-motor difficulty/dyspraxia. That is, if the child has difficulties copying oral movements and/or the accuracy of their production of words does **not** improve when imitating a model then please exclude them.

7. **No diagnosis of ASD or pragmatic impairment**

I acknowledge that pragmatic difficulties can arise as a result of having speech and language difficulties, however I would like to exclude those children for whom a pragmatic impairment is their primary difficulty.

8. **Receiving some specialist input in school OR attending additionally resourced educational provision OR the SLT expects that such provision will be needed/provided in the near future.**

9. **Exclude children who speak English as an additional language**

APPENDIX 2

List of Measures at Each Assessment Block

Children aged 3 years at the outset of the study

Baseline	Block 1	Block 2	Block 3	Block 4
RDLS III	Spontaneous language sample	Spontaneous language sample	Spontaneous language sample	RDLS III
BAS: Block Build & Picture Similarities	ROWPVT	Semantic knowledge task	ROWPVT	BAS: Block Build & Picture Similarities
Pragmatics questionnaire	EOWPVT	Word learning task	EOWPVT	CCC-2
CDI	Semantic knowledge task	Non-word repetition task	Semantic knowledge task	CDI
Case History	Word learning task	Matched repetition task	Word learning task	Spontaneous language sample
Hearing test	Non-word repetition task	Picture name verification task	Non-word repetition task	ROWPVT
	Matched repetition task	Auditory Discrimination task	Matched repetition task	EOWPVT
	Picture name verification task	DEAP	Picture name verification task	Semantic knowledge task
	Auditory Discrimination task	Sentence repetition	Auditory Discrimination task	Word learning task
	DEAP	Short term & working memory task	DEAP	Non-word repetition task
	Sentence repetition		Sentence repetition	Matched repetition task
	Short term & working memory task		Short term & working memory task	Picture name verification task
			TROG	Auditory Discrimination task
			PIPA	DEAP
				Sentence repetition
				Short term & working memory task

Children aged 4 years at the outset of the study

Baseline	Block 1	Block 2	Block 3	Block 4
RDLS III	Spontaneous language sample	Spontaneous language sample	Spontaneous language sample	RDLS III
BAS: Block Build & Picture Similarities	ROWPVT	Semantic knowledge task	ROWPVT	BAS: Block Build & Picture Similarities
Pragmatics questionnaire	EOWPVT	Word learning task	EOWPVT	CCC-2
CDI	TROG	Non-word repetition task	Semantic knowledge task	TROG
Case History	PIPA	Matched repetition task	Word learning task	PIPA
Hearing test	Semantic knowledge task	Picture name verification task	Non-word repetition task	Spontaneous language sample
	Word learning task	Auditory Discrimination task	Matched repetition task	ROWPVT
	Non-word repetition task	DEAP	Picture name verification task	EOWPVT
	Matched repetition task	Sentence repetition	Auditory Discrimination task	Semantic knowledge task
	Picture name verification task	Short term & working memory task	DEAP	Word learning task
	Auditory Discrimination task		Sentence repetition	Non-word repetition task
	DEAP		Short term & working memory task	Matched repetition task
	Sentence repetition			Picture name verification task
	Short term & working memory task			Auditory Discrimination task
				DEAP
				Sentence repetition
				Short term & working memory task

Children aged 5 years at the outset of the study

Baseline	Block 1	Block 2	Block 3	Block 4
RDLS III	Spontaneous language sample	Spontaneous language sample	Spontaneous language sample	RDLS III
BAS: Block Build & Picture Similarities	ROWPVT	Semantic knowledge task	ROWPVT	BAS: Block Build & Picture Similarities
Pragmatics questionnaire	EOWPVT	Word learning task	EOWPVT	CCC-2
Case History	TROG	Non-word repetition task	Semantic knowledge task	TROG
Hearing test	PIPA	Matched repetition task	Word learning task	PIPA
	Semantic knowledge task	Picture name verification task	Non-word repetition task	Spontaneous language sample
	Word learning task	Auditory Discrimination task	Matched repetition task	ROWPVT
	Non-word repetition task	DEAP	Picture name verification task	EOWPVT
	Matched repetition task	Sentence repetition	Auditory Discrimination task	Semantic knowledge task
	Picture name verification task	Short term & working memory task	DEAP	Word learning task
	Auditory Discrimination task		Sentence repetition	Non-word repetition task
	DEAP		Short term & working memory task	Matched repetition task
	Sentence repetition			Picture name verification task
	Short term & working memory task			Auditory Discrimination task
				DEAP
				Sentence repetition
				Short term & working memory task

Children aged 6 years at the outset of the study

Baseline	Block 1	Block 2	Block 3	Block 4
RDLS III	Spontaneous language sample	Spontaneous language sample	Spontaneous language sample	RDLS III
BAS: Block Build & Picture Similarities	ROWPVT	Semantic knowledge task	ROWPVT	BAS: Block Build & Picture Similarities
Pragmatics questionnaire	EOWPVT	Word learning task	EOWPVT	CCC-2
Case History	TROG	Non-word repetition task	Semantic knowledge task	TROG
Hearing test	PhAB	Matched repetition task	Word learning task	PhAB
	Semantic knowledge task	Picture name verification task	Non-word repetition task	Spontaneous language sample
	Word learning task	Auditory Discrimination task	Matched repetition task	ROWPVT
	Non-word repetition task	DEAP	Picture name verification task	EOWPVT
	Matched repetition task	Sentence repetition	Auditory Discrimination task	Semantic knowledge task
	Picture name verification task	Short term & working memory task	DEAP	Word learning task
	Auditory Discrimination task		Sentence repetition	Non-word repetition task
	DEAP		Short term & working memory task	Matched repetition task
	Sentence repetition			Picture name verification task
	Short term & working memory task			Auditory Discrimination task
				DEAP
				Sentence repetition
				Short term &working memory task

APPENDIX 3

DEAP Phonology Assessment and Additional Items

DEAP Phonology Assessment Items

	Target	IPA		Target	IPA		Target	IPA
1	elephant	ɛləfənt	18	splash	splæʃ	35	toothbrush	tuθbɹʌʃ
2	umbrella	ʌmbɹɛlə	19	square	skwɛə	36	apple	apəl
3	train	tɹeɪn	20	pig	pɪg	37	knife	naɪf
4	swing	swɪŋ	21	gloves	glʌvz	38	van	væn
5	bread	bɹɛd	22	queen	kwin	39	ear	iə
6	duck	dʌk	23	three	θɹi	40	this	ðɪs
7	giraffe	dʒəɹɑf	24	frog	fɹɒg	41	scissors	sɪzəz
8	five	faɪv	25	yellow	jɛloʊ	42	fishing	fɪʃɪŋ
9	teeth	tiθ	26	strawberry	stɹɔbɹi	43	lighthouse	laɪthaʊs
10	watch	wɔtʃ	27	spider	spaɪdə	44	zebra	zɛbɹə
11	orange	ɒɹɪndʒ	28	web	wɛb	45	kitchen	kɪtʃən
12	school	skul	29	sheep	ʃip	46	sausage	sɒsɪdʒ
13	crab	kɹæb	30	snake	sneɪk	47	tiger	taɪgə
14	biscuits	bɪskɪts	31	pram	pɹæm	48	rabbit	ɹæbɪt
15	thank you	θæŋkju	32	feather	fɛðə	49	book	bʊk
16	helicopter	hɛlikɒptə	33	tomato	təmɑtoʊ	50	boy	bɔɪ
17	egg	ɛg	34	monkey	mʌŋki			

Additional Phonology Assessment Items

	Target	IPA		Target	IPA		Target	IPA
1	button	bʌtn̩	5	tractor	tɹæktə	9	hand	hænd
2	box	bɒks	6	banana	bənanə	10	ghost	gost
3	nose	noz	7	fence	fɛns	11	pyramid	pɹəmɪd
4	humpty	hʊmpti	8	tent	tɛnt			

APPENDIX 4

Phonotactic Probability Calculations for Non-word Repetition Stimuli and Mean and SD of Phonotactic Probability Calculations from the Hoosier Mental Lexicon for Each Word Length

Phonotactic Probability Calculations for Non-word Repetition Stimuli

Number of syllables	PP	Non-word	Log normalised PP of syllables*§			Positional segment frequency of word**	Biphone frequency of word**
1	High	nɪs	1.554			0.199	0.019
		sɛm	1.642			0.225	0.014
		hɛs	0.916			0.191	0.011
		pɛd	0.595			0.195	0.008
		baɪn	1.034			0.182	0.007
	Low	hɔɪb	-1.653			0.069	0.000
		jaʊt	-1.791			0.084	0.001
		naʊf	-1.862			0.053	0.000
		gib	-1.862			0.084	0.001
		mɔɪg	-1.862			0.079	0.000
2	High	‘hɪ-sɛm	1.300	1.642		0.269	0.028
		‘hɪ-nɛs	1.300	0.994		0.313	0.018
		‘teɪ-nɛs	1.173	0.994		0.251	0.009
		‘so-nɪs	1.230	1.554		0.351	0.012
		‘sɛ-baɪn	1.243	1.034		0.289	0.012
	Low	‘jo-hɔɪb	-0.614	-1.653		0.079	0.001
		‘gu-jaʊt	0.410	-1.791		0.133	0.001
		‘jæ-naʊf	-2.105	-1.862		0.199	0.015
		‘gaʊ-mɔɪg	-1.287	-1.862		0.097	0.000
		‘hɔɪ-gib	-2.111	-1.862		0.121	0.001
3	High	‘tɪ-sə-pɛd	1.635	1.318	0.595	0.371	0.029
		‘so-sə-pɛd	1.230	1.635	0.595	0.382	0.015
		‘hɪ-nə-sɛm	1.300	1.244	1.642	0.410	0.026
		‘so-tə-baɪn	1.230	1.688	1.034	0.418	0.018
		‘hɪ-sə-sɛm	1.300	1.635	1.642	0.393	0.033
	Low	‘jo-gaʊ-hɔɪb	-0.614	-1.287	-1.653	0.113	0.001
		‘gu-jæ-jaʊt	0.410	-2.105	-1.791	0.187	0.001
		‘hɔɪ-jæ-naʊf	-2.111	-2.105	-1.862	0.147	0.004
		‘jo-jæ-gib	-0.614	-2.105	-1.862	0.148	0.001
		‘gu-jo-hɔɪb	0.410	-0.614	-1.653	0.089	0.001

Number of syllables	PP	Non-word	Log normalised PP of syllables*§				Positional segment frequency of word**	Biphone frequency of word**
4	High	hɪ-sə'-si-baɪn	1.300	1.635	1.261	1.034	0.542	0.035
		sɪ-nə'-teɪ-pɛd	1.467	1.244	1.173	0.595	0.567	0.035
		hɪ-sə'-teɪ-sɛm	1.300	1.635	1.173	1.642	0.487	0.038
		tɪ-sə'-sɛ-baɪn	1.635	1.635	1.243	1.034	0.521	0.032
		hɪ-nə'-teɪ-nɛs	1.300	1.244	1.173	0.994	0.582	0.033
	Low	jo-gu'-gaʊ-hɔɪb	-0.614	0.410	-1.287	-1.653	0.119	0.001
		hɔɪ-gaʊ'-jæ-naʊf	-2.111	-1.287	-2.105	-1.862	0.181	0.004
		gaʊ-gu'-jo-hɔɪb	-1.287	0.410	-0.614	-1.653	0.114	0.000
		hɔɪ-jæ'-jo-gib	-2.111	-2.105	-0.614	-1.862	0.180	0.000
		jo-hɔɪ'-jæ-naʊf	-0.614	-2.111	-2.105	-1.862	0.179	0.004

*CELEX **Hoosier Mental lexicon

§ Log transformed probabilities: 0 represented the mean and +/- 1 represented one SD from the mean. Hence 'high' and 'low' PP can be easily identified.

Mean and SD Phonotactic Probability Calculations from Hoosier Mental Lexicon for Each Word Length (Storkel 2005)

Word Length (syllables)	Word Length (phonemes)	Positional segment frequency		Biphone frequency	
		M	SD	M	SD
1	3	.1347	.0498	.0060	.0052
2	5	.2310	.0605	.0168	.0100
3	7	.3381	.0777	.0294	.0138
4	9	.4685	.0936	.0552	.0288

APPENDIX 5

Non-word Repetition Task Order of Presentation

	Level 1		Level 3
1	nɪs	21	‘tɪsəpɛd
2	baɪn	22	‘gujæjaʊt
3	jaʊt	23	‘jojægib
4	pɛd	24	‘sotəbaɪn
5	hɔɪb	25	‘hɪsəsɛm
6	gib	26	‘jogaʊhɔɪb
7	naʊf	27	‘hɔɪjænaʊf
8	sɛm	28	‘gujohɔɪb
9	mɔɪg	29	‘sosəpɛd
10	hɛs	30	‘hɪnəsɛm
	Level 2		**Level 4**
11	‘gujaʊt	31	sɪnə’teɪpɛd
12	‘sɛbaɪn	32	hɪsə’teɪsɛm
13	‘sonɪs	33	johɔɪ’jænaʊf
14	‘teɪnɛs	34	hɪnə’teɪnɛs
15	‘hɔɪgib	35	hɔɪjæ’jogib
16	‘hɪsɛm	36	hɪsə’sibaɪn
17	‘johɔɪb	37	tɪsə’sɛbaɪn
18	‘jænaʊf	38	jogu’gaʊhɔɪb
19	‘hɪnɛs	39	hɔɪgaʊ’jænaʊf
20	‘gaʊmɔɪg	40	gaʊgu’johɔɪb

APPENDIX 6

Non-word Repetition Mixed ANCOVA Analyses: Tables of Results

2*4*2 Mixed ANCOVA Age Covariate Data Point 1

Source	*df*	*error*	*F*	η^2	*p*
Phonotactic Probability (PP)	**1**	**43**	**56.11****	**.57**	**<.01**
Length in syllables (L)	**3**	**129**	**55.63****	**.56**	**<.01**
Age (A)	**1**	**46**	**12.68****	**.22**	**<.01**
Group (G)	**1**	**46**	**19.94****	**.30**	**<.01**
PP x L	**3**	**129**	**3.21***	**.07**	**.03**
PP x A	**1**	**43**	**4.10***	**.09**	**.049**
PP x G	1	43	.45	.01	.51
L x A	**3**	**129**	**3.77***	**.08**	**.01**
L x G	3	129	1.18	.03	.32
G x A	1	43	1.87	.04	.18
PP x L x A	3	129	1.22	.03	.31
PP x L x G	**3**	**129**	**7.02****	**.14**	**<.01**
PP x G x CA	1	43	1.27	.03	.27
L x G x A	3	129	2.62	.06	.05
PP x L x G x A	**3**	**129**	**5.686****	**.12**	**.01**

$*p < .05$. $**p < .01$.

2*4*2 Mixed ANCOVA Age Covariate Data Point 4

Source	*df*	*error*	*F*	η^2	*p*
Phonotactic Probability (PP)	**1**	**46**	**75.04****	**.62**	**<.01**
Length in syllables (L)	**3**	**138**	**89.25****	**.66**	**<.01**
Age (A)	**1**	**46**	**38.49****	**.46**	**<.01**
Group (G)	**1**	**46**	**19.94****	**.30**	**<.01**
PP x L	**3**	**138**	**27.43****	**.37**	**<.01**
PP x A	**1**	**46**	**4.52***	**.09**	**.04**
PP x G	**1**	**46**	**5.76***	**.11**	**.02**
L x A	**3**	**138**	**6.48****	**.12**	**<.01**
L x G	**3**	**138**	**11.38****	**.20**	**<.01**
G x A	**1**	**46**	**12.68****	**.22**	**<.01**
PP x L x A	3	138	1.26	.03	.29
PP x L x G	3	138	1.8	.04	.15
PP x G x CA	1	46	1.76	.04	.19
L x G x A	3	138	.98	.02	.41
PP x L x G x A	**3**	**138**	**4.11****	**.08**	**.01**

*p < .05. **p < .01.

2*4*2 Mixed ANCOVA Vocabulary Covariate Data Point 1

Source	*df*	*error*	*F*	η^2	*p*
Phonotactic Probability (PP)	**1**	**43**	**50.61****	**.54**	**<.01**
Length in syllables (L)	**3**	**129**	**24.66****	**.37**	**<.01**
Vocabulary (V)	**1**	**43**	**5.62***	**.12**	**.02**
Group (G)	1	43	.02	.00	.89
PP x L	**3**	**129**	**2.72***	**.06**	**.047**
PP x V	**1**	**43**	**7.41****	**.15**	**<.01**
PP x G	1	43	.12	.00	.73
L x V	3	129	.35	.01	.79
L x G	3	129	.73	.02	.53
G x V	1	43	3.07	.07	.09
PP x L x V	3	129	.66	.02	.58
PP x L x G	**3**	**129**	**2.91***	**.06**	**.04**
PP x G x V	1	43	.001	.00	.97
L x G x V	3	129	2.14	.05	.10
PP x L x G x A	3	129	187	.04	.138

*p < .05. **p < .01.

2*4*2 Mixed ANCOVA Vocabulary Covariate Data Point 4

Source	*df*	*error*	*F*	η^2	*p*
Phonotactic Probability (PP)	**1**	**46**	**41.13****	**.47**	**<.01**
Length in syllables (L)	**3**	**138**	**38.78****	**.46**	**<.01**
Vocabulary (V)	**1**	**46**	**7.64****	**.14**	**<.01**
Group (G)	1	46	1.03	.02	.32
PP x L	**3**	**138**	**12.24****	**.21**	**<.01**
PP x V	1	46	2.57	.05	.12
PP x G	1	46	.05	.00	.82
L x V	3	138	1.93	.04	.13
L x G	3	138	.33	.01	.80
G x V	**1**	**46**	**5.38***	**.12**	**.03**
PP x L x V	3	138	1.75	.04	.16
PP x L x G	3	138	1.73	.04	.16
PP x G x V	1	46	1.72	.04	.20
L x G x V	3	138	.55	.01	.65
PP x L x G x V	**3**	**138**	**2.78***	**.06**	**.04**

*p < .05. **p < .01.

APPENDIX 7

Individual Trajectories Statistical Method

Summary Measures for Individual Longitudinal Trajectories of children with LI: descriptions and calculation method

LI Summary Measure	Description	Method of Calculation
Total non-word repetition scores	total percentage phonemes correct (PPC) averaged over the four data points.	mean PPC
Difference between high and low PP scores:	total PPC averaged over the four data points for high PP minus PPC total PPC averaged over the four data points for low PP	mean High PP PPC - mean low PP PPC
Overall rate of progress with respect to vocabulary knowledge:	the gradient of the slope of change in PPC scores with respect to vocabulary growth averaged across the 40 test items (i.e. the main effect of vocabulary)	mean of $\frac{\sum PPC(DP1,2,3,4)}{\sum EV(DP1,2,3,4)}$ (DP = Data Point, EV = Expressive Vocabulary)

LI Summary Measure	Description	Method of Calculation
The nature of the relationship over development between high and low PP scores:	the difference between the average gradient across the 20 test items of the high and low PP slopes with respect to vocabulary growth (i.e. the PP x vocabulary interaction)	mean of high PP $\frac{\sum PPC(DP1,2,3,4)}{\sum EV(DP1,2,3,4)}$ **minus** mean of low PP $\frac{\sum PPC(DP1,2,3,4)}{\sum EV(DP1,2,3,4)}$ (DP = Data Point, EV = Expressive Vocabulary)

Summary Measures for TD children for comparison with individual children with LI: descriptions and calculation method

TD Summary Measure	Description	Method of Calculation
Total non-word repetition scores	TD population estimates were calculated using multiple regression and scores as predicted by expressive vocabulary were then calculated for comparison (i.e. the score predicted by the LI child's expressive vocabulary knowledge if developing as predicted by TD children's data)	Overall mean PPC (TD) + ((LI individual mean EV – TD mean EV) x (TD gradient of slope of change in PPC scores)) $\mu PPCTD + ((\mu EVLI - \mu EVTD) x (\frac{\sum PPCTD}{\sum EVTD}))$ (EV = Expressive Vocabulary)
Difference between high and low PP scores:	TD population estimates were calculated using multiple regression and scores as predicted by expressive vocabulary were then calculated for comparison (i.e. the score predicted by the LI child's expressive vocabulary knowledge if developing as predicted by TD children's data)	Overall mean PPC difference (TD) + ((LI individual mean EV – TD mean EV) x (TD gradient of slope of change in PPC difference scores)) $\mu PPCDIFFTD + ((\mu EVLI - \mu EVTD) x (\frac{\sum PPCDIFFTD}{\sum EVTD}))$ (EV = Expressive Vocabulary)

TD Summary Measure	Description	Method of Calculation
Overall rate of progress with respect to vocabulary knowledge:	TD children's rate of progress with respect to vocabulary scores were calculated using linear regressions created from TD cross-sectional data	mean of $\frac{\sum PPCTD}{\sum EVTD}$ (EV = Expressive Vocabulary)
The nature of the relationship over development between high and low PP scores:	TD children's difference between the slopes for High PP and Low PP scores with respect to vocabulary scores were calculated using linear regressions created from TD cross-sectional data	mean of high PP $\frac{\sum PPCTD}{\sum EVTD}$ **minus** mean of low PP $\frac{\sum PPCTD}{\sum EVTD}$

Standard deviation calculations for Crawford t-test: description and calculation methods

Summary Measure	Description	Method of Calculation
total non-word repetition scores	standard deviation for PPC	$\sigma TDPPC \times \sqrt{rTDPPCEV \times \frac{n-1}{n-2}} \times \sqrt{1+\frac{1}{n}+\frac{\mu EVLI - \mu EVTD}{(n-1)\sigma EVTD^2}}$ (where population standard deviations (σ) have been imputed from standard errors using the formula: $SE \times \sqrt{n}$) $rTDPPCEV$ = correlation between PPC and EV in the TD group
difference between high and low PP scores:	standard deviation for High PP low PP difference	$\sigma TDPPCDIFF \times \sqrt{rTDPPCDIFFEV \times \frac{n-1}{n-2}} \times \sqrt{1+\frac{1}{n}+\frac{\mu EVLI - \mu EVTD}{(n-1)\sigma EVTD^2}}$ (where population standard deviations (σ) have been imputed from standard errors using the formula: $SE \times \sqrt{n}$) $rTDPPCDIFFEV$ = correlation between PPC difference and EV in the TD group

Summary Measure	Description	Method of Calculation
rate of progress with respect to vocabulary knowledge:	standard deviation for rate of progress with respect to vocabulary scores	$\left(\sigma TDPPC \times \frac{\sqrt{(1 - rTDPPCEV^2)} \times \sqrt{\frac{n-1}{n-2}}}{\sigma EVTD \times \sqrt{n-1}}\right) \times \sqrt{n}$ (where population standard deviations (σ)have been imputed from standard errors using the formula: $SE \times \sqrt{n}$) $rTDPPCEV$ = correlation between PPC and EV in the TD group
the nature of the relationship over development between high and low PP scores	standard deviation for difference between the slopes for High PP and Low PP scores with respect to vocabulary scores	$\left(\sigma TDPPCDIFF \times \frac{\sqrt{(1 - rTDPPCDIFFEV^2)} \times \sqrt{\frac{n-1}{n-2}}}{\sigma EVTD \times \sqrt{n-1}}\right) \times \sqrt{n}$ (where population standard deviations (σ) have been imputed from standard errors using the formula: $SE \times \sqrt{n}$) $rTDPPCDIFFEV$ = correlation between PPC difference and EV in the TD group

APPENDIX 8

Results of Individual Crawford t-tests for Non-word Repetition

(1-tailed)

Total non-word repetition scores: Individual t-tests comparing individual non-word repetition score (PPC) to TD population estimates of PPC predicted by expressive vocabulary

Age group	Child	*df*	*t*	*p*
3 years	OB	36	.48	.68
	KF	36	-.72	.24
	ST	36	-.71	.048*
	TB	36	-1.08	.14
	KM	36	-1.55	.07
	RM	36	-1.66	.05
4 years	AM	36	-2.59	.007**
	OM	36	-1.93	.03*
	MH	36	-.079	.22
5 years	MB	36	1.15	.87.
6 years	TG	36	-1.96	.03*
	AF	36	.55	.71
	PB	36	-.61	.27

*p < .05. **p < .01.

Difference between high and low PP scores: Individual t-tests comparing difference in high and low PP scores to TD population estimates of difference in scores as predicted by expressive vocabulary

Age group	Child	*df*	*t*	*p*
3 years	OB	36	1.08	.14
	KF	36	.55	.29
	ST	36	-.026	.60
	TB	36	-.61	.73
	KM	36	.78	.22
	RM	36	-.02	.51
4 years	AM	36	1.63	.06
	OM	36	-.098	.54
	MH	36	-.13	.55
5 years	MB	36	-1.13	.87
6 years	TG	36	1.58	.06
	AF	36	.46	.32
	PB	36	.91	.18

*p < .05. **p < .01.

Overall rate of progress with respect to vocabulary knowledge: Individual t-tests comparing rate of progress for Total PPC to TD children's rate of progress

Age group	Child	*df*	*t*	*p*
3 years	OB	36	1.5	.07
	KF	36	.56	.29
	ST	36	1.48	.07
	TB	36	-.46	.68
	KM	36	.73	.24
	RM	36	.26	.40
4 years	AM	36	-.09	.54
	OM	36	-.91	.82
	MH	36	2.25	.02*
5 years	MB	36	-.073	.77
6 years	TG	36	-.075	.77
	AF	36	.56	.29
	PB	36	-.071	.76

*p < .05. **p < .01.

The nature of the relationship over development between high and low PP scores: Individual t-tests comparing the difference between the slopes for High PP and Low PP scores in individuals with LI (i.e. PP x vocabulary interaction) to the difference between the slopes for High PP and Low PP scores in the TD children

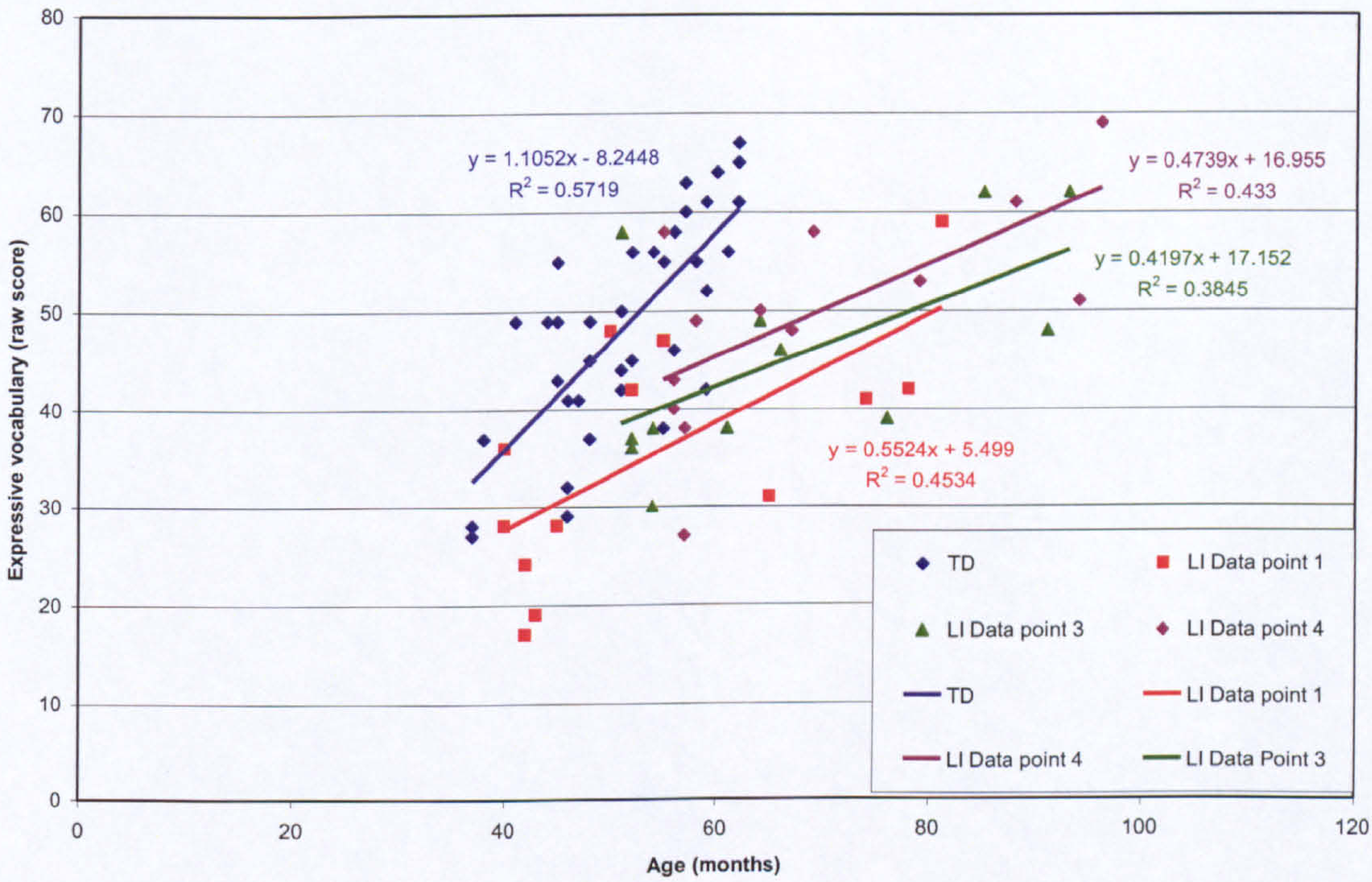
Age group	Child	*df*	*t*	*p*
3 years	OB	36	-1.0	.83
	KF	36	.35	.36
	ST	36	.45	.33
	TB	36	1.56	.06
	KM	36	.80	.21
	RM	36	1.09	.14
4 years	AM	36	-.33	.63
	OM	36	1.53	.07
	MH	36	-1.65	.95
5 years	MB	36	.45	.33
6 years	TG	36	2.35	.01*
	AF	36	.01	.50
	PB	36	-.01	.50

*p < .05. **p < .01.

APPENDIX 9

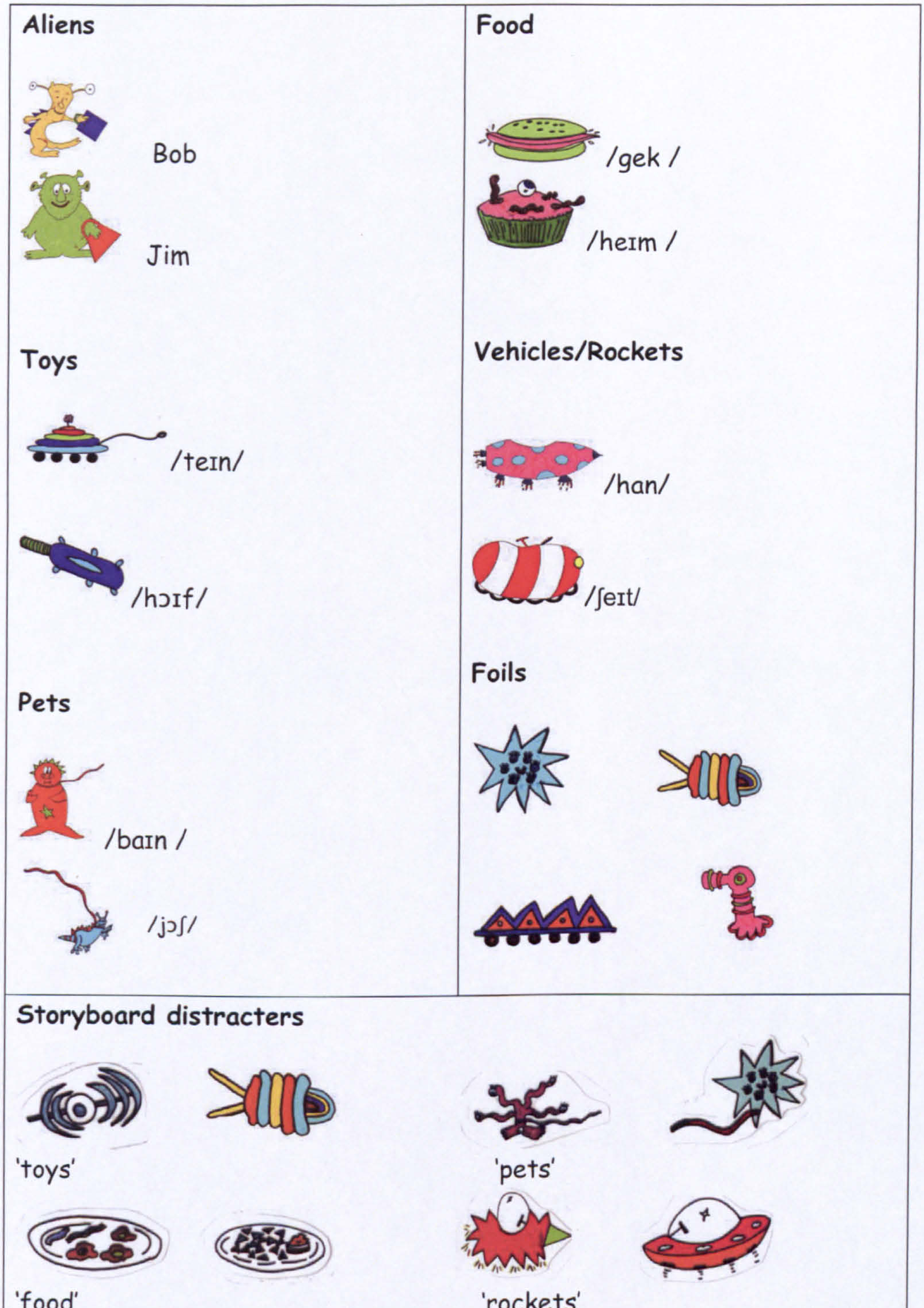
The relationship between age and vocabulary scores for TD and LI groups

Relationship between age and vocabulary scores for TD and LI groups: OLS Regressions



APPENDIX 10

Word-Learning Task Referents and Distracters


Aliens
Bob
Jim
Food
/gek /
/heɪm /
Toys
/teɪn/
/hɔɪf/
Vehicles/Rockets
/han/
/ʃeɪt/
Pets
/baɪn /
/jɔʃ/
Foils
Storyboard distracters
'toys'
'pets'
'food'
'rockets'

APPENDIX 11

Word Learning Story and Storyboard Script

Word Learning Story Script

Page 1	Jim and Bob are Aliens. They live on the planet Plop. There are lots of strange things on the planet Plop. Shall we go and see?
Page 2	Jim and Bob are going shopping What will they buy today?
Page 3	First they visit the toy shop
Page 4	Jim says I want a /teɪn/ Bob says I want a /hɔɪf/ Here is the /teɪn/ Here is the /hɔɪf/
Page 5	Look! Jim has the /teɪn/ Look! Bob has the /hɔɪf/ They are very happy with their new toys
Assessment	Comprehension Probe
Page 5	This one is the /teɪn/ Jim bought the /teɪn/ This one is the /hɔɪf/ Bob Bought the /hɔɪf/ Which toy do you like best? That one is the .... (name) I like the.....................(name other toy)
Page 6	Now they visit the pet shop What will they buy today?

Page 7	Jim says I want a /baɪn / Bob says I want a /jɔʃ/ Here is the / baɪn / Here is the / jɔʃ /
Page 8	Look Jim has the / baɪn / Look Bob has the / jɔʃ / They love their new pets
Assessment	Comprehension Probe
Page 8	This one is the / baɪn / Jim bought the / baɪn / This one is the /jɔʃ / Bob Bought the / jɔʃ / Which pet do you like best? That one is the .... (name) I like the.....................(name other pet)
Page 9	Now they are feeling hungry Time to go to the café
Page 10	Jim says I want a /gek / Bob says I want a /heɪm / Here is the / gek / Here is the / heɪm /
Page 11	Look Jim is eating the /gek / Look Bob is eating the /heɪm / They are enjoying their yummy food.
Assessment	Comprehension Probe
Page 11	This one is the /gek / Jim bought the /gek/ This one is the /heɪm / Bob Bought the /heɪm /

	Which food do you like best? That one is the .... (name) I like the......................(name other food)
Page 12	Now they are getting tired it's time to go home. They go to the plop stop to catch a rocket.
Page 13	Jim says I want to catch a /han/ Bob says I want to catch a /ʃeɪt/ Here is the /han/ Here is the /ʃeɪt/
Page 14	Look Jim is in the /han/ Look Bob is in the /ʃeɪt/ Whoosh away they fly on their rockets
Assessment	Comprehension Probe
Page 14	This one is the /han/ Jim bought the /han/ This one is the /ʃeɪt/ Bob Bought the /ʃeɪt/ Which space ship do you like best? That one is the .... (name) I like the......................(name other spaceship)
Page 15	Now it's time for bed and Jim and Bob are remembering all the things they have done today. They visited a toy shop They and bought a /teɪn/......... ...... and a /hɔɪf/ Here is the /teɪn/ ....and here is the /hɔɪf/ They visited the pet shop They bought a /baɪn /......... .... and a /jɔʃ/ Here is the /baɪn /....... .... and here is the /jɔʃ/

	They visited a café They ate a /gek /..... ..... and a /heɪm / Here is the /gek /..... ..... and here is the /heɪm / Then they caught a rocket home They rode an a /han/..... .... and a /ʃeɪt/ Here is the /han/....... ..... and here is the /ʃeɪt/ Goodnight Jim and Bob

Word Learning Storyboard script

Can you find the toys Jim and Bob bought in the toy shop?

That's right you've found/teɪn/
and you've found the /hɔɪf/
Jim bought a /teɪn/
Bob bought a /hɔɪf/

Can you find the pets Jim and Bob bought in the pet shop?

That's right you've found the /baɪn /
and you've found the /jɔʃ/
Jim bought a /baɪn /
Bob bought a /jɔʃ/

Can you find the food they bought at the café?

That's right you've found/gek /
and you've found the /heɪm /
Jim bought a /gek /
Bob bought a /heɪm /

Can you find the rockets they rode home in?

That's right you've found the /han/
and you've found the /ʃeɪt/
Jim bought a /han/
Bob bought a /ʃeɪt/

APPENDIX 12

Comparison of phonotactic probabilities of stimuli from the present study and of Storkel (2001) using calculated using the Hoosier Mental Lexicon

Comparison of phonotactic probabilities of stimuli from the present study and of Storkel (2001) using calculated using the Hoosier Mental Lexicon

	Storkel (2001)				McKean (2009)			
	High PP		Low PP		High PP		Low PP	
	Positional Segment Frequency	Biphone Frequency	Positional Segment Frequency	Biphone Frequency	Positional Segment Frequency	High PP Biphone Frequency	Positional Segment Frequency	Low PP Biphone Frequency
	0.1657	0.0066	0.0595	0.0004	0.1816	0.0071	0.0321	0.0006
	0.1157	0.0036	0.1072	0.0013	0.1524	0.0076	0.0625	0.0042
	0.2123	0.0053	0.0986	0.0004	0.196	0.0156	0.118	0.0026
	0.1617	0.0066	0.0742	0.0018	0.1698	0.0042	0.1049	0.0037
Mean	0.1639	0.0055	0.0849	0.0010	0.1750	0.0086	0.0793	0.0028
SD	0.0395	0.0014	0.0220	0.0007	0.0185	0.0049	0.0394	0.0016

Results of Two Sample T-Tests comparing phonotactic probabilities of stimuli from the present study and Storkel (2001)

	Positional Segment Frequency	Biphone Frequency
High PP	$t(6) = .51$ $p = .629$ two tailed	$t(6) = 1.22$ $p = .269$ two tailed
	$t(6) = .51$ $p = .315$ one tailed	$t(6) = 1.22$ $p = .135$ one tailed
Low PP	$t(6) = .024$ $p = .816$ two tailed	$t(6) = 2.07$ $p = .084$ two tailed
	$t(6) = .024$ $p = .408$ one tailed	$t(6) = 2.07$ $p = .042$* one tailed

*significant difference

APPENDIX 13

Children with LI Word Learning Comprehension Probe Pattern of Responses at Data Points 1-4

Children with LI: comprehension probe pattern of responses at Data Points 1-4