Action Video Games Enhance Executive Function in Typically Developing Children and Children with Hemiplegic Cerebral Palsy

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Abstract

Hypotheses: 1) Executive Function (EF) in children can be improved by action video games training. 2) Improvement of EF can enhance hand motor function.

Aims: 1) To determine whether children who play Video Games (AVGPs) exhibit similar enhancement of EF as has been reported in adults; 2) To study the effect of action video game genre training on EF and hand motor function for Typically Developing (TD) children; 3) To study the effect of AVG training on EF and hand motor function for children with Hemiplegic Cerebral Palsy (HCP).

Methods:

Aim1:154 TD children aged 6-12 years participated in a cross-sectional study;

Aim 2: 40 Non-Action Video Game players (NAVGPs) aged 8-12 years were randomized to training with AVG or NAVG, in a double blinded study of the effect of AVG training on EF;

Aim 3:9 children with HCP aged 8-12 participated in a pilot study, open intervention study of the effect of AVG training on EF and hand function.

EF was assessed using Cambridge Neuropsychological Test Automated Battery (CANTAB) and hand motor function was assessed using Tyneside 9 holes pegboard. In addition, Assisting Hand Assessment (AHA), Melbourne Assessment 2 (MA2), and Chedoke Arm and Hand Activity Inventory (CAHAI) were used for children with HCP.

Results: EF and hand motor functions were superior in children playing AVGs compared to children who play NAVGs only. Action video game training for 50 hours over 8 weeks significantly improved EF in TD children compared to those training with NAVGs. AVG training was associated with significant improvement in EF in children with HCP. Hand motor function did not show significant improvement after training.

Conclusion: Action video game training can enhance EF in TD and should be investigated further to assess if it has a therapeutic role in improving EF and dexterity in children with HCP.

Dedication

This thesis is dedicated to my family

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Abbreviations

AHA	Assisting Hand Assessment
AVG	Action Video Game
AVGPs	Action Video Game Players
AVGTG	Action Video Game Training Group
BCT	Board Completion Time
BLC	Big/ Little Circle
CAHAI	Chedoke Arm and Hand Activity Inventory
CANTAB	Cambridge Neuropsychological Test Automated Battery
CRT	Choice Reaction Time
DMS	Delay Matching to Sample
EF	Executive Function
HCP	Hemiplegic Cerebral Palsy
HCPG	Hemiplegic Cerebral Palsy Group
MA2	Melbourne Assessment 2
MOT	Motor Screening
NAVG	Non Action Video Game
NAVGPs	Non Action Video Game Players
NAVGTG	Non Action Video Game Training Group
NSM	Non-Strategic Moves
NVGPs	Non-Video Game Players
PTS	Pegs Transfer Strategy
SM	Strategic Moves
SOC	Stocking of Cambridge
SSP	Spatial Span
SST	Stop Signal Task
SWM	Spatial Working Memory
TD	Typically Developing

Chapter 1. Introduction

1.1 Executive Function

Executive Functions (EF) is an umbrella term that refers to the higher-level cognitive skills that regulate and control complex cognitive processes such as working memory, attention and planning. It is believed that the initiation of EF is carried out by the prefrontal cortex of the frontal lobes (Figure 1-1). Impaired EFs, also known as Executive Dysfunction have been associated with damage to the frontal lobes in addition to the cortical and subcortical structures that connect to them. It can include the inability to maintain attention, impulsivity, disinhibition, reduced working memory, inability to plan actions, disorganization, poor reasoning ability, difficulties to generate or implement strategies, difficulty in changing activity and poor shifting between conflict demands (Anderson, 2002).

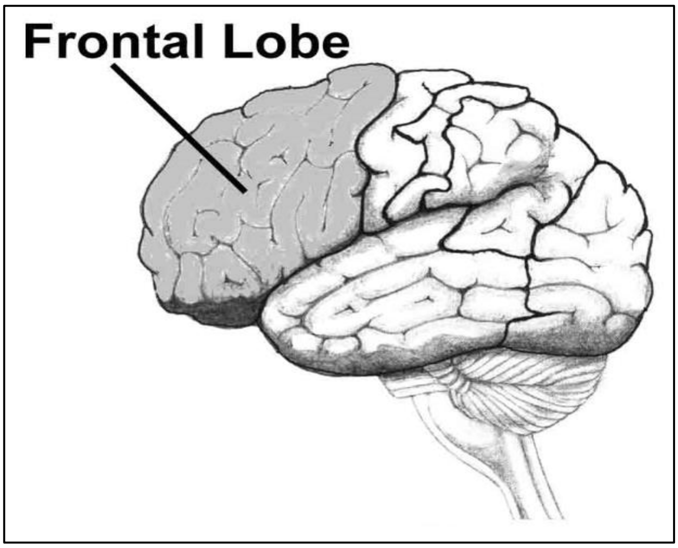


Figure 1-1:Frontal Lobe of the brain (Myers, 2006)

1.1.1 Model of EF

Various theoretical models of EF have been developed and have influenced research and clinical practices. These models and frameworks of EF are important to provide the basis for assessment tools, interpreting test performance and understanding executive function development. Before beginning this study, it was essential to review these models and frameworks of EF to decide which executive functions would be examined for this study.

Luria's Theory

Luria was the first neuropsychologist who observed and described groups of individuals who had suffered frontal lobe damage. His observation led him to make the connections between the frontal lobes, executive functioning and problem-solving. According to Luria, the human brain consists of three linked and interactively functional units. The first unit is located mainly in the brain stem; this unit is responsible for regulating and maintaining arousal of the cortex. The responsibility of the second unit is encoding, processing and storage of information; and covers the temporal parietal and occipital lobes. The third unit is located in the anterior part of the brain (the frontal lobes) and it is responsible for programming, regulating and verifying human behaviour. Luria considered the prefrontal cortex as a superstructure that regulates or controls mental activity and behaviour. He described the major component of executive functioning as anticipation that leads to setting realistic expectations and understanding consequences, planning or organization; execution that results in flexibility and maintain set and self-monitoring that is responsible for emotional control and error recognition. He documented that damage to the frontal lobes lead to disrupted complex behavioural programmes and the inability to regulate behavioural outcomes. He described this phenomenon as an impairment in self-regulation (Luria, 1966).

Supervisory Attentional System

The supervisory attention system is an extension of Luria's theory of frontal lobe functioning. It was first introduced by Norman and Shallice in a larger model of the role of attention in behaviour. This model differentiates actions that are automatic and performed without awareness or interfering with other actions and those that require deliberate attentional resources. Such as actions that involve planning or decision making, troubleshooting, a novel sequence of action, overcoming a strong habitual response and resisting temptation or situations those are dangerous or technically difficult. Norman and Shallice proposed a model that included two complementary processes to deal with these two levels: contention scheduling and supervisory attention (Norman and Shallice, 1986).

Contention scheduling is for responses that are implemented automatically. Schemata are behavioural programs for routine actions. Contention scheduling allows for implementation of schemata for completing an automatic action and inhibiting conflicting schemata. However, schemata are unlikely to exist when the task is novel, complex or involves EF. In these situations additional attention control is required, which is the role of the supervisory attentional system (Norman and Shallice, 1986).

In 1996, Shallice and Burgess extended on this initial model of the supervisory system and argued that it comprises of three stages; consisting of multiple processes, all of which involve the prefrontal cortex. Stage one is for strategy generation in novel situations and involves creating new temporary schemata using the approach of problem-solving. Stage two is the application of the new temporary schema in the unique situation and will involve working memory for the purpose of holding the temporary schema. Stage three is the process of monitored implementation of schema and can lead to modification or even abandonment of the schema (Shallice and Burgess, 1996).

Stuss and colleagues adapted the supervisory system to address anterior attentional functions (Stuss et al., 1995). In this model, the supervisory system is applied when there is no known solution to the task or when the selection between possible schemata may be required as well as inhibition of inappropriate schemata. In this model, five independent supervisory processes are proposed:

1. Energizing schemata are the activation of target schemata and the re-energizing of the schemata as they become inactive, for example, in situations where sustained attention is required.
2. Inhibition of schemata to inactivate inappropriate schemata and prevent these from capturing ongoing behaviour.
3. Adjustment of contention scheduling when the action needs the activation of similar target schemata.
4. Monitoring system ensures that behaviour is appropriate with few errors, that the other competing schemata do not influence behaviour and that the target schemata do not become inactive.
5. The if-then logic analysis utilizes monitored feedback to maintain and alter processes by reenergizing schemata, inhibiting schemata or by adjustment contention scheduling.

In 2000, Burgess and colleagues extended the Supervisory Attention System model to consider multitasking performance in everyday life. According to this proposal there are eight features of multitasking behaviour that include: (1) many discrete tasks for an individual to complete; (2) interleaving period for an effecting performance; (3) engagement in only one task at a particular time; (4) unforeseen interruptions and unexpected outcomes; (5) delayed intentions for the individual to return to a task, which is already running and is not signalled directly by the situation; (6) tasks demanding different task characteristics; (7) selfdetermining targets that constitute adequate performance; (8) no immediate feedback on how well the individual performs. Burgess and his colleagues believed that most laboratory-based tasks do not include all of these features in assessing crucial components of multi-tasking performing in clinical cases (Burgess et al., 2000).

Working Memory Model

Baddeley model of working memory is an important model of EF (Baddeley, 1996, Baddeley, 2002). Working memory plays a significant role in complex activities and is considered an integral component of EF. In this model, working memory is defined as “a limited capacity system allowing the temporary storage and manipulation of information necessary for complex tasks such as comprehension, learning and reasoning” (Baddeley, 2000). Baddeley working memory model was designed to replace the concept of a unitary short-term memory capacity. It included four components; the central executive that’s functions include selective attention, coordinating two or more concurrent activities, switching attention and retrieval of information from long-term memory; the phonological loop which maintains and manipulates speech-based information; the visuo-spatial sketch-pad that holds and manipulates visuo-spatial information and the episodic buffer, which is controlled by the central executive and provides a workspace for the temporary storage of information. Working memory has been studied extensively and is considered a well-validated theoretical model, but it neglects elements of EF such as goal setting, volition, reasoning and planning (Baddeley, 1996, Baddeley, 2002).

Model of Executive (self-regulatory) Functions

Self- regulation is generally thought to be a significant element of executive functioning and a principle component of the model proposed by Barkey (Barkley, 1977). Self-regulation is defined as “any response to alter the probability of the individual’s subsequent response to an event and, in so doing, functions to alter the probability of a later consequence related to that event”. Barkley suggests that self-regulation incorporates the majority of the key components of EF including goal-directed behaviour; devising plans to achieve future-oriented goals; utilization of self-directed speech, rules and procedures; and impulse control. In this model a prerequisite for executive or self-regulatory processes is intact behavioural inhibition. Barkley’s self-regulatory model includes four primary executive domains which are: working memory, self-regulation of affect/motivation/arousal, internalization of speech and reconstitution. This model was essentially developed to explain the cognitive and behavioural deficits associated with Attention Deficit Hyperactivity Disorder (Barkley, 1977).

Components of Executive Functions

Lezak conceptualized EF as consisting of four broad domains which are: volition, planning, purposive action and effective performance (Lezak, 1995). This model is an essential framework for the assessment of EF and determines how clinicians and researchers define and assess executive functioning. Still, it neglects, to some extent, some important executive skills. For example, Lezak acknowledges the role of intact memory; however working memory is clearly understated in her framework of executive function. Moreover, while impulse control is inherent in planning, it is not explicitly stated or discussed (Lezak, 1995).

Problem-Solving Framework

Zelazo and colleagues proposed a problem-solving framework that describes the distinct phases of executive functioning (Zelazo et al., 1997). They refer to this problem-solving framework as a "macro construct," which illustrates the way in which distinct executive processes operate in an integrative manner to solve a problem or achieve the goal state. Zelazo suggested defining executive function as a series of basic processes (e.g., inhibition) but fails to acknowledge the complex strategic and metacognitive processes involved in executive function.

This framework includes four phases that are temporally and functionally distinct:

1. Problem representation, one must recognise and understand the problem prior to developing a plan for solving it.
2. Planning, this involves the selection of actions in specific sequence and selecting the most efficient sequence of steps from many alternatives.
3. Execution, it is important that the sequence of steps can be maintained in memory for a sufficient period to guide the appropriate actions and behaviours. Then the individual must be prepared to perform the steps prescribed in the plan, in order to execute a plan.
4. Evaluation, this final phase occurs if the three previous steps have occurred and relates to the evaluation of the individual's behaviour, as well as monitoring the final solution.

Executive Control System (Anderson Model)

The executive control system is a conceptual framework principally derived from the developmental neuropsychology literature, and is largely influenced by factor analytic and developmental studies (Anderson, 2002). This model hypothesises EF as an overall control system which includes four distinct domains;

1. Attentional control that includes the capacity to attend selectively to specific stimuli and the ability to focus attention for a prolonged period. It also involves the regulation and monitoring of action so that plan can be executed in the correct order, errors are identified, and goals are achieved. Impulse control is also an essential component of this domain.
2. Cognitive flexibility or working memory includes the ability to learn from making mistakes, shift between response sets, plan alternative strategies, divide attention and process multiple sources of information simultaneously.
3. Goal setting, which includes the ability to initiate or the capacity to start an activity and devise a plan to complete the activity. It also covers the capacity to plan.
4. Information processing, related to the efficiency of prefrontal neural networks and evaluated in term of the speed, quantity and quality of output. Impairment in this domain may be reflected by reduced output, delayed responses, hesitancy and slow reaction times.

The Executive Control System Model can be described as a conceptual framework. It covers fundamental and core executive functions that have been conceptualized in a number of models, which are: attention control, working memory, planning and strategic organization.It accounts for the various patterns of impairment considered "executive" and tentatively proposes the neurological networks underlying the model, and provides a structure for the assessment of EF(Anderson et al., 2008). This model is a validated mode designed specifically for a development context(Anderson, 2002). It has been used in many developmental neuropsychological studies that are concerned with executive function and children with cerebral palsy (Bodimeade et al., 2013a, Bodimeade et al., 2013b, Whittingham et al., 2014). This model was appropriate for this study in order to assess executive function ability for typically developing children and children with HCP.

1.1.2 Development of EF in children

Executive function develops throughout childhood and potentially changes throughout the lifespan. There is a correspondence between the functional emergence of executive abilities and the structural maturation of the frontal lobes (Anderson et al., 2008). Both are known to be present in an immature state in the young child and develop through adolescence into early adulthood. Frontal lobe maturation involves dynamic processes controlled by genetic coding and response to environmental stimuli. These include the positive development of grey and white matter and negative mechanism of neuronal cellular apoptosis and pruning of synaptic connections. The balance between positive and negative mechanisms influences neuronal growth and connectivity, and the process of white matter myelination in the anterior frontal lobes is important for the development of the complex circuitry needed for healthy cognitive and executive functions appropriate to the individual's developmental stage(Anderson et al., 2008).

Early Frontal Lobe Development

The frontal lobe is one of the four major lobes of the cerebral cortex. It is located at the front of the brain and is organized in a largely hierarchical manner(Anderson et al., 2008). Based on recent findings from brain imaging research it is evident that the frontal lobes are the last area of the brain to develop. The nervous system starts to develop at 18 days gestation. Neuroblasts in the anterior periventricular reign mature to form neurons of the frontal cortex at approximately six weeks gestation. Neuronal migration is largely complete by 24 weeks. Cortical development during the remaining months of fetal development is largely comprised of cortical organization(Anderson et al., 2008).

At birth, the brain is largely un-myelinated and the majority of its development has been affected and controlled by genetic factors. The basic anatomical structure of the frontal lobes is developed, but is still relatively immature. During the first two years, the majority of brain pathways begin to myelinate and this continues into adult life. By the age of two months, infants start to be actively participating in their environment and show signs of self-exploration and an emerging understanding of their agency. They start to be able to detect the goal structure of an event after personal experience in trying to acquire a desired object at the age of 3 months. The first signs of working memory and attention, in the form of inhibitory control, appear between the ages 7 and 8 months, which are under the management of the dorsolateral and orbital prefrontal cortices (Anderson et al., 2008). Diamond documented that infants of 7.5 months could correctly retrieve objects on a delayed response task when the delay was limited to 1 or 2 seconds. By the age of 12 months, they can maintain the currently hidden place of an object in their mind and inhibit a previously rewarded response for up to 10 seconds. Perfect performance of this skill is seen in children aged 5 years when they can perform this skill at 10-30 second delays (Diamond, 1985).

Preschool Development

In preschool children, both grey and white matter of the frontal lobes steadily grows leading to an increase of its size. At this age, lack of inhibitory control and resistance to interference are the main factors limiting children's performance. Children aged five years old show superior inhibitory skills compared to children aged three and four years old. By the age of seven to nine years old, children show more achievement in performing complex tasks. Major gains in inhibition and sustained attention are seen from 3 to 5 years of age (Diamond and Taylor, 1996).

During the preschool years, greater mental flexibility and improved concept formation can be seen. Children's memory spans increase from four to eight years of age, this gives a base for them to develop more elaborate strategies and shift more efficiently between ideas (Luciana and Nelson, 1998). Verbal and visuospatial working memory systems are considered to be fractionated from early as five years old. Luciana and Nelson observed that spatial working memory increases gradually over the period of five to eight years of age using the Spatial Working Memory Task(Luciana and Nelson, 1998).

Goal-directed behaviors and planning begin to mature in the preschool period. Tower tasks are traditional measures of planning and organization, which have been linked to prefrontal functioning in adults and have used quite extensively in children to document development. Espy found that children aged four to five years could correctly complete more items on the three-disc Tower of Hanoi task than two to three-year-old children (Espy et al., 2001). Luciana and Nelson found that while children aged five to eight years could complete the 2-move trials on the Tower of London as well as some 4 years old children, their performance steadily decreased as the number of moves required increased. Performance on the task is moderated by task difficulty, which distinguishes the performance of children from five to eight years of age, to that of young adults (Luciana and Nelson, 1998).

Preadolescence Development

Significant changes in the cortical grey matter development in the frontal lobes appear during the preadolescent years. There is a preadolescent second wave of cortical gray matter development, peaking at age 11 in girls and 12 in boys. It is the last acceleration in frontal lobe grey matter volume during the individual's lifetime (Rapoport et al., 1999).

Many executive skills enter a maturation phase of development by the late childhood. The ability to shift attentional set is believed to reach adult level by the aged of 10 (Chelune and

Bear, 1986). De Luca and colleagues investigated the route of executive development in individuals ranging in age from 8 to 46 years(De Luca et al., 2003), they focused on various executive domains including cognitive flexibility, working memory, strategic planning and goal setting. They found that there was a progression in all domains except for set-shifting ability which was mature in children of 8 to 10 years old (De Luca et al., 2003).

Visual working memory was tested by Luciana and Nelson using the Wisconsin task (Heaton, 1981)and found that the performance of children on this task reach ceiling level by the age of 7 years old (Luciana and Nelson, 1998). In 2004, Brocki and Bohlin found a decreases in disinhibited behavior from 9 to 11 years and just a little further improvement after that time (Brocki and Bohlin, 2004). Major gains inset-shifting, response inhibition, selective attention and impulsive responding were observed between 8 and 10 years of age (Klimkeit et al., 2004).

All other executive functions show an increase during 9 to 12 years. Working memory undergoes a significant increase in capacity and efficiency (Brocki and Bohlin, 2004). Strategic thinking improves and fluency shows steady increases to age 12 years and above, goal-directed behavior increases with a possible spurt at the age of 12 years old. (Korkman et al., 2001, Welsh and Pennington, 1988).

1.1.3 Assessment of EF

Assessment of EF may rely on the administration of multiple tests; each assesses a specific aspect of function. There are a wide range of common tests used to evaluate executive function. To establish valid measures it is essential that they cover the various components of executive function. EF tests can be traditional neuropsychological assessment instruments (Reitan, 1969, Simon, 1975, Heaton, 1981, Shallice, 1982, Korkman et al., 1998, Gioia et al., 2000, Delis et al., 2001, Emslie et al., 2003, Barkley, 2012, Delis, 2012)or computerized test (Lowe and Rabbitt, 1998, De Luca et al., 2003, Gualtieri and Johnson, 2006, Xie et al., 2015).The assessment of executive function in children using computers has been widely studied (Luciana, 2003). Computerized tests translate the existing standardized test to computerized administration or develop new computer tests and batteries for the assessment of executive function. There are some advantages of computerized test batteries over traditional assessments; for example, computerized tests precisely record accuracy and speed of response and are flexible in terms of immediate adjustment to performance levels; there cost savings regard to materials and supplies, and in the time required of the test administration; able to reduce the need for administration by trained person.

For this study, it is very important to use an assessment batteries to cover the core components of executive functions including working memory, attention control and planning.

In this study we used the Cambridge Neuropsychological Test Automated Battery (CANTAB) to assess the executive functions. The CANTAB is one of the batteries that combine standard cognitive test paradigms and with novel formats. It was first developed 20 years ago (Sakakian et al., 1990); its original format consisted of three batteries of tests designed to assess visual memory, attention and planning. Over the years, the CANTAB has expanded to include the assessment of visual and verbal memory, executive function, attention, decision making, response control and social cognition. It is possible to investigate executive function across the lifespan using the CANTAB. With minimal reliance on language, some tests are totally language independent, culturally blindness, and continuous and immediate adjustment to the level of performance. The CANTAB is well suited to help clarify age-related changes in specific executive abilities (De Luca et al., 2003). Another important parameter of this battery is its tests- retest reliable, it is suitable for repeat administration and tracking of change over time or with interventions (Lowe and Rabbitt, 1998). CANTAB has been used to assess executive function in neurological problems with motor impairment such as brain injury (Maillard-Wermelinger et al., 2009). Tests are scored automatically and data are exported into spreadsheets and statistical analysis packages such as SPSS. This battery will be described in detail in chapter 2.

1.1.4 Interventions for EF

Many approaches have been used in the past decade to improve the EF in children (Diamond and Lee, 2011, Diamond, 2012). The most common approaches are; Cogmed computerized working memory training, which is a computerized training method used to improve different aspect of working memory capacity (Bergman et al., 2011). Improvement in training has been shown to generalise to unpractised EF skills (Thorell et al., 2009, Klingberg et al., 2005) and to remain six months after training (Holmes et al., 2010); Aerobic exercise has been shown to improve prefrontal cortex function and executive functions. (Loprinzi and Kane, 2015, Ma et al., 2015, Hillman et al., 2008,Tuckman and Hinkle, 1986). The benefit of exercise can be more effective when it is combined with martial art (Lakes and Hoyt, 2004), mindfulness practices (Flook et al., 2010, Diamond and Lee, 2011), and the classroom curricula. The curricula most shown to improve children's EF are Montessori (Lillard and Else-Quest, 2006) and Tools of the Mind (Bodrova and Leong, 2007). Recently, playing action video games has attracted attention as a means to improve executive functions in adults.

1.1.5 Action Video Games and EF

There are millions of video games, with different themes and goals. They can be played on various devices such as consoles (e.g., Nintendo Wii, PlayStation), computers or cell phones. Action Video Games (AVG) are a video game genre that emphasizes physical challenges that include hand–eye coordination and decision making with a limited reaction-time. The AVG genre includes diverse subgenres such as fighting games, maze games, multiplayer battle arena games, pinball games, platform games or first person shooter games, which are widely considered the most important action video games. AVGs have been demonstrated to improve a range of visual spatial skills in adults (Achtman et al., 2008, Green and Bavelier, 2007, Green and Bavelier, 2008, Andrews and Murphy, 2006). Players also exhibit better visual short-term memory (Boot et al., 2008), and exhibit more flexibility in switching from one task to another (Boot et al., 2008, Colzato et al., 2010). In training studies, adults who have not previously played action video games showed improvement in EF after a period of action video game play. These studies support a causal link between action video game experience and improvements in perceptual, attentional and cognitive skills (Feng et al., 2007, Green and Bavelier, 2003, Green and Bavelier, 2006b, Green and Bavelier, 2007, Li et al., 2009, Li et al., 2010). There have been very few studies in children and no intervention studies in children. However, children who report playing action video games show significantly increased attentional skills, as compared to those who do not (Dye et al., 2009, Dye and Bavelier, 2010)

1.2 Impairment of Executive function in children with hemiplegic cerebral palsy

1.2.1 Hemiplegic Cerebral Palsy

Cerebral palsy (CP) is defined as a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain (Bax et al., 2005). It can be associated with speech and hearing disorders, visual problems, mental retardation and cognitive defects.
CP is the most common cause of lifelong disability, affecting 2 per 1000 live births (Bax et al., 2005, Krigger, 2006). Hemiplegic Cerebral Palsy (HCP)is the most common form of cerebral palsy, with 44% of cerebral palsy in children being diagnosed as HCP (Himmelmann and Uvebrant, 2014). CP is one of the most common neurologic disorders among Saudi

children with an incidence of 2.3/1000 live births (Salloum, 2011). This incidence relatively high, compared to the incidence in Europe; this may reflect the high consanguinity rates, ranging from 56% to 70% of marriages in the Saudi population (Salloum, 2011).

HCP is impairment of motor control of the half of the body. It arises from lesions to the corticospinal system on the opposite side. It can be caused as a result of stroke, head injury, brain infection, hereditary diseases or malformations of the veins or arteries; especially the middle cerebral artery. The upper limb is usually more involved than the lower limb (Okumura et al., 1997, Mirsky, 1989, Staudt et al., 2004, Cioni et al., 1999). Also, there are other problems that can be associated with hemiplegia such as epilepsy, hearing and visual impairment, speech difficulty, emotional and behavioral problems, specific learning difficulties, perceptual problems and EF deficits (Forsman and Eliasson, 2015).

Recent research has found that children with an early brain insult are at increased risk of having executive dysfunction compared to their Typically Developing (TD) peers (Anderson et al., 2011).Children with CP have consistently been found to have significantly decreased EF compared to TD children (Bottcher and Flachs, 2010, Pirila et al., 2011, Straub and Obrzut, 2009, Whittingham et al., 2014). Overall, children and adolescents with CP have been found to have significant impairments in visual and auditory attention, working memory, planning, inhibition and response time (Anderson et al., 2010, Burnett et al., 2013, Edgin et al., 2008, Pirila et al., 2011, Kolk and Talvik, 2000, Kolk and Talvic, 2002, White and Christ, 2005, Bottcher and Flachs, 2010, Crajé and Aarts, 2010, Krageloh-Mann and Horber, 2007). This may explain why these children are at higher risk of specific learning disabilities affecting reading, spelling and arithmetic(Muter, 1994) and problems in peer relations (Bottcher, 2010).

Deficits in EF will compound movement disorders by impacting on the ability to plan and execute movements, focus attention on salient features of the environment, learn from experience, solve problems, communicate and socialize (Shaheen, 2013). There are very few studies investigating whether impairments in EF in children with cerebral palsy improve with a targeted intervention. One recent study, however, indicated that executive functions may be amenable to intervention, but whether this was associated with a concomitant improvement in motor function was not investigated (Crajé and Aarts, 2010).

1.2.2 Hand motor function of HCP

It is difficult to diagnosed HCP before the age of 3 months, since there are few if any clinical signs. After that age and between 6 and 9 months, the clinical signs of hemiplegia develop progressively including the child does not use one of his hands as much as the other. The hand may be held clenched and the arm held in a typically hemiplegic posture; which is adducted and internally rotated at the shoulder, flexed at the elbow, flexed with ulnar deviation at the wrist and clenched hand with the thumb in the palm. Adopting this posture may lead over time to contractures at the elbow, wrist and shoulder. (Brett, 1991). The quality of upper limb function can be affected by several factors; muscle tone, muscle weakness, postural, tactile and proprioceptive disturbance, bimanual coordination problems and executive dysfunction.

Spasticity is the predominant presentation in the cases of hemiplegia; it is difficult to detect under the age of 3 months but develops over time and affects motor development by impeding motor learning and acquisition of functional skills (Zonta et al., 2013, Ferrari et al., 2014).

Sensory input is an essential component of motor function and motor control. Children with hemiplegia often have associated sensory defects including impairment of tactile perception (sensitivity to pressure), tactile discrimination (spatial discrimination, stereognosis, and proprioception, which includes impairment of proprioceptive information regarding the arm position (Bleyenheuft and Gordon, 2013, Anderson et al., 2008).

1.2.3 Interventional management

HCP cannot be cured, but selective management programs can often improve a child's capabilities. In general, the earlier the management program begins, the better chance a child has overcoming developmental disabilities and learning new ways to accomplish difficult tasks (Basu and Clowry, 2015).

Pharmacological Management

Pharmacological treatment is primarily focused on reducing spasticity (Verrotti et al., 2006). The treatment options include oral medications, such as Baclofen, Benzodiazepines, Dentrolene and Tizanidine; neuromuscular blocking agents such as Botulinum Toxins; chemical denervation using phenol and alcohol; and intrathecal baclofen.(Krach, 2001, Lai et al., 2008, Verrotti et al., 2006, Wallen et al., 2007)

Surgical Intervention

Surgery could be used to reduce dynamic or functional deformity caused by spasticity. There are two main surgical methods; orthopedic surgery to prevent further spinal and limb deformities by lengthen shortened muscles and tendons; and neurosurgery, in particular, the use of Dorsal Root Rhizotomy. (Krekel et al., 2010, Bertelli et al., 2003).

Physical Therapy

Physical therapy is an important aspect of treating children with cerebral palsy. It is the rehabilitation of physical impairment to help children with cerebral palsy to develop coordination, build strength, improve balance, maintain flexibility, maximize independency and optimize physical functioning level (Tecklin, 2015). Therapeutic exercise and strengthening plays an important role in the management of children with CP (Tecklin, 2015). Strength training can increase muscle strength and improve endurance, cardiovascular health, weight management, maintenance of bone mass, self-perception, and gait function (Rogers, 2008, Versvhuren, 2011, Tecklin, 2015). Electrical stimulation is used for pain control, edema reduction, or muscle strengthening; in children with CP neuromuscular electrical stimulation, functional electrical stimulation, and threshold electrical stimulation are most frequently used (Tecklin, 2015).

Conductive Education

CE was developed in the 1940s (Darrah et al., 2004). It is based on the concept that children with motor disabilities learn the same way as those with no disability. The idea is to develop independence in the child's daily activities by facilitating all aspects of the child's development (Blank et al., 2008).

Occupational Therapy

Occupational therapy focuses on the improvement of fine motor control for activities of the daily living. For children with hemiplegia, OT focuses on improving the function of the affected arm and hand, bilateral skills and functional independence. Occupational therapists help hemiplegic children to learn the most efficient ways to use their arms, hands and upper body to be independent. They use different approaches in a play activity session, such as Sensory Integration, sensory-motor, perceptual-motor and cognitive approaches, depending on the children respond to the treatment and to the target goals to achieve (Russo et al., 2007, Novak et al., 2009).

Sensory Integration

The theory of SI was originally developed by A. Jean Ayres in the 1970s to improve daily activity. The SI approach attempts to facilitate normal development and improve the child's ability to process and integrate sensory information including visual, perceptual, vestibular, proprioceptive and auditory stimuli (Schaaf and Miller, 2005).

Serious Video Games

Serious video games provide virtual reality and offer real-time, immersive, computer-based environments with which users interact, explore and carry out motor tasks (Tatla et al., 2015). Serious video games were introduced to rehabilitation programs for cerebral palsy more than 15 years ago and had been shown to improve range of impairments, such as balance, mobility, cognition and upper limbs function (Bonnechère et al., 2014).

1.3 Executive Function of children with HCP

Unlike most children with cerebral palsy, those with HCP usually attend mainstream schools. The few studies including children with HCP indicate that they too have a higher incidence of impairments of EF than age-matched controls (Kolk and Talvik, 2000, Kolk and Talvic, 2002, White and Christ, 2005, Bottcher, 2010, Crajé and Aarts, 2010). This may explain why these children are at higher risk of specific learning disabilities affecting reading, spelling and arithmetic (Muter, 1994) and problems in peer relations (Bottcher, 2010). Some studies claim that executive functioning is unrelated to general intelligence (Friedman et al., 2006, Anderson et al., 2008). On the other hand, many studies indicate an association between some of the executive domains and intelligence (Luciano et al., 2001, Anderson et al., 2008).

1.4 Summary

Everyday activities, including motor function, rely on effective executive function since deficits in executive function lead to poor planning and disorganization, difficulties to focus on and attend to tasks, disinhibition, impulsivity, increased errors without subsequent self-correction, leading to longer times to complete tasks (Whittingham et al., 2014). Therefore, it is very important to investigate if children with hemiplegic cerebral palsy have impairment of executive function. If so therapy focused on improving executive function is likely to improve their ability to undertake activities of daily living, leading to a better quality of life. There is robust evidence that action video games enhance executive function in adults (Achtman et al., 2008, Green and Bavelier, 2007, Green and Bavelier, 2008, Andrews and Murphy, 2006, Boot et al., 2008, Colzato et al., 2010). There are no such studies in children and in particular children with cerebral palsy.

1.5 Thesis aims

My thesis is concerned with the effects of playing action video games on executive function in TD children and assessing whether playing action video games provides an effective intervention to improve executive function in TD children and children with HCP.

The aims of my thesis are to;

1. Undertake a cross-sectional study comparing TD children who play action video games to those who do not play video games or who only play other genres of the video game, to determine whether children who play action video games exhibit similar enhancement of executive functions, as has been reported in adults.
2. Conduct a longitudinal randomised double blinded interventional study to determine for TD children who have never played action video games if a period of playing action video games enhances executive function.
3. Conduct a Pilot interventional study in children with HCP to determine if a period of playing action video games enhances executive function and hand motor function.

Chapter 2. Methods

2.1 Ethical approval

The study protocol was submitted to the Ethical Committee of the Scientific Research Department at the College of Applied Medical Sciences in King Saud University, Riyadh, Saudi Arabia. Ethical approval was received on the 18th of March 2012. The Ministry of Education gave approval for recruitment of normal children from within schools in Saudi Arabia on the 20th of February 2012.

2.2 Recruitment

2.2.1 Typically Developing Children

Children aged 6-12 years were recruited from private and government elementary and secondary schools in Saudi Arabia. Exclusion criteria were a history of a neurological problems, severe visual and hearing impairments, an IQ< 70 and behavioral problems. Moreover, children who were not familiar with the used of touch screens were excluded from the study to eliminate possible bias from children who play video games being more familiar with the use of touch screens.

2.2.2 Children with Hemiplegic Cerebral Palsy

Children age 6-12 years with a confirmed diagnosis of congenital HCP and stable medical condition, were recruited from physical and occupational therapy departments in rehabilitation centres and hospitals in Saudi Arabia. Exclusion criteria: children with severe visual and hearing impairment, an IQ< 70, severe behavioural problems, musculoskeletal surgery in the upper limb in the previous six months and children for whom there was a plan to change their medication or start any medical intervention during the study period. Similar to typically developing children, children who were not familiar with the used of touch screen were excluded from the study.

2.3 Consent

After providing participants and their parents with the study information sheets (see appendix A and B) informed written consent was obtained from the parents on behalf of the child. Also written assent was obtained from the children (see appendix C).

2.4 Environment

The assessments were undertaken in a quiet room in the schools, rehabilitation centres, or hospitals, which the children attended. Each room had a table with an adjustable height and chair. For the sessions with children with HCP, there was a video camera to video children during the assessment of upper limb function for later scoring. The assessment procedure was undertaken on two separate sessions, no more than five days between them.

2.5 Assessment procedure

2.5.1 Video Games play Questionnaire

The questionnaire of Dye et al was used to classify children into NVGPs and AVGPs (Dye et al., 2009). The children and their parents filled in the questionnaire listing the games played by the children in the preceding six months. They were asked to estimate how long they played each game in a typical session and how many sessions they played each game on average per month (see appendix D).

2.5.2 Tests of Executive Function

Executive function was assessed using the CANTAB developed at the University of Cambridge. It was chosen because it uses touch-screen technology and the ability to perform many of the assessments is independent of motor impairment (Table 2-1).The assessments are also independent of language and are culturally blind. Test scores are compiled automatically and exported into spreadsheets. The CANTAB has been used extensively both clinically and for research among different age groups including children and in a variety of neurological conditions (Barnett et al., 2001, Goldberg et al., 2005, Sheppard and Cheatham, 2013, Luciana and Nelson, 2002).

The tests of executive function used in this study were chosen to represent a wide range of executive functions (as described in detail below) and because elements of each assessment except the MOT (which is used to familiarise children with the Cantab system) are independent of motor ability (Table 2-1).

Table 2-1: CANTAB outcome measures chosen and their dependence on motor ability

Tests of EF	**Outcome measures**	
	Dependent on motor abilities because of a requirement for speed or accuracy of movement	**Independent of motor abilities not requiring accuracy of movement or speed of response**
Motor screening (MOT)	Reaction time Accuracy	
Spatial Span (SSP)		Span length SSP total errors
Spatial working memory (SWM)	SWM mean time to last response	SWM total errors
Delay Matching to Sample (DMS)	DMS correct latency	DMS total correct

Tests of EF	Outcome measures	
	Dependent on motor abilities because of a requirement for speed or accuracy of movement	**Independent of motor abilities not requiring accuracy of movement or speed of response**
Choice Reaction Time (CRT)	CRT latency	CRT Total correct trials CRT total commission errors
Big/little circle (BLC)	BLC mean correct latency	BLC Total correct decisions
Stop signal Task (SST)	SST SSRT	
Stoking of Cambridge (SOC)		SOC mean moves required to solve a problem

The children were assessed in a quiet room seated in front the touch-screen and the press pad at a comfortable distance (approximately 30-50cm) to allow them to use them without needing to lean forward. Children were instructed to use the index finger of their dominant hand to touch the screen. The examiner set nearby the subject to demonstrate tests steps.

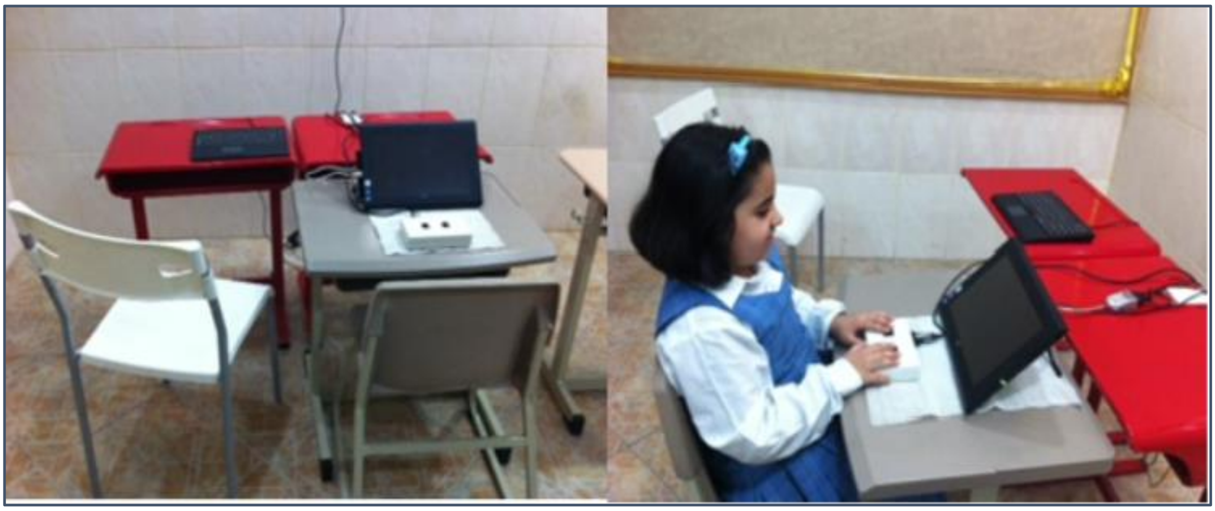


Figure 2-1: Cambridge Neuropsychological Test Automated Battery

I chose the following tests from the battery so as to encompass assessment of the core abilities for executive function outlined in the chapter 1.

The tests of executive function were undertaken in the same sequence for each child.

2.5.2.1 Motor screening (MOT)

The MOT is a training procedure designed to ensure that the participants can respond to the stimuli and to introduce them to the computer and touch screen. It is also a measure of motor reaction time, speed and accuracy. A series of crosses appear in different locations on the screen; the participants use the index finger of their dominant hand to touch the crosses in turn(Figure 2-2). Administration time is around one minute.

Outcome measures

i. *MOT reaction time*: the mean time in seconds taken for the child to touch the cross after it appeared, this is calculated from the response to ten crosses.
ii. *MOT accuracy*: The mean distance between the centre of the cross and the location the child touches on the screen for ten crosses. The distance is measured in pixel units.

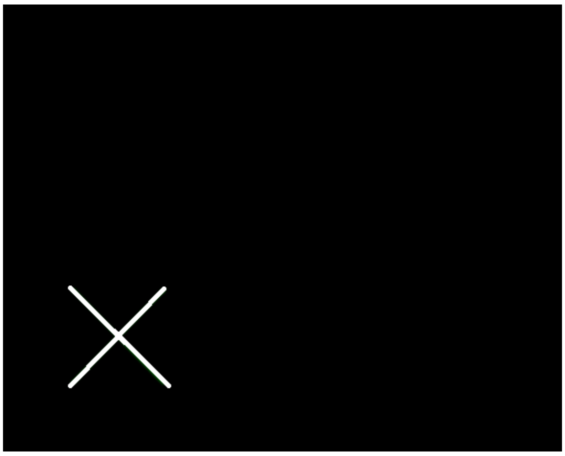


Figure 2-2: Motor Screening

2.5.2.2 Spatial Span (SSP)

SSP is used to assess working memory. A pattern of white boxes is shown in the monitor. A number of boxes are illuminated with a colour in a pre-specified sequence. The participant is then asked to touch the boxes illuminated in the same sequence (Figure 2-3).

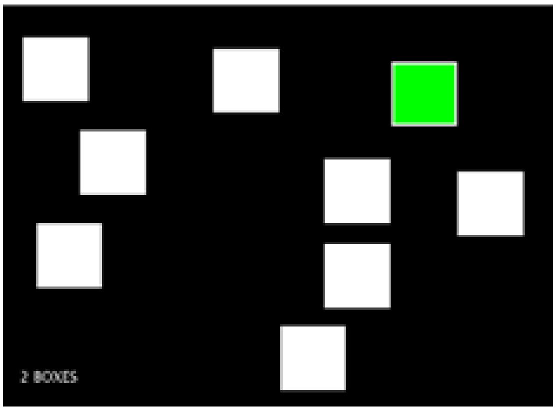


Figure 2-3: Spatial Span

Outcome measures

i. *Span length*: The longest sequence successfully recalled by the child. The child has three attempts at each level. The maximum score possible is 9.

ii. *SSP total errors*: The number of times the child selects an incorrect box. The maximum score possible is 97.

2.5.2.3 *Spatial Working Memory (SWM)*

SWM is testing the ability of the participant to hold and recall spatial information and to manipulate remembered items in working memory. A variable number of coloured boxes are displayed on the screen. Participants are asked to find tokens hidden behind a box, by touching the boxes and using a process of exclusion. The participant should find one blue token in each numbers of boxes and use them to fill an empty column located on the right side of the screen. From trial to trial; the colour and position of the boxes used are changed to depress the use of stereotyped search approaches. The number of boxes is gradually increased (3, 4, 6 and 8 boxes) (Figure 2-4).

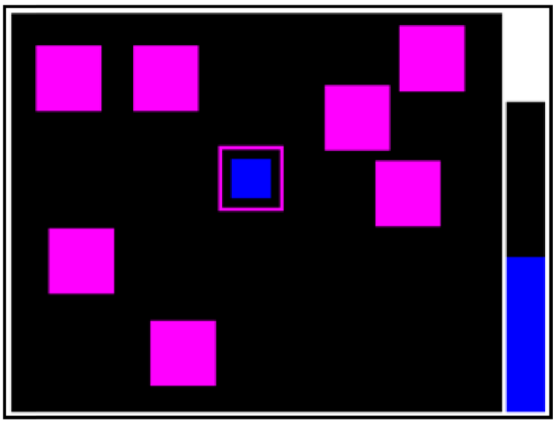


Figure 2-4:Spatial Working Memory

Outcome measures

i. *SWM Total errors:* The number of times a box is selected that is positive i.e. previously found not to contain a token or did contain a token, but it has been found and is in the column on the right.

ii. *SWM Mean time to last response:* Calculated from the time between the problem being presented to the participant and the participant's last screen touch to open a box to locate the final token. A lower score is better.

2.5.2.4 Delay Matching to Sample (DMS)

The DMS is testing visual working memory. On each trial, the children are shown a complex visual pattern for a brief time; each pattern is made up of four sub-elements, each of different colours. After a variable delay, four patterns appear and the participant must select the pattern that is identical to the original pattern. The time between removing the original pattern and the choice patterns is 0, 4 or 12 seconds. The participants are allowed to choose another pattern, if the first choice is incorrect until a correct choice is made (Figure 2-5).

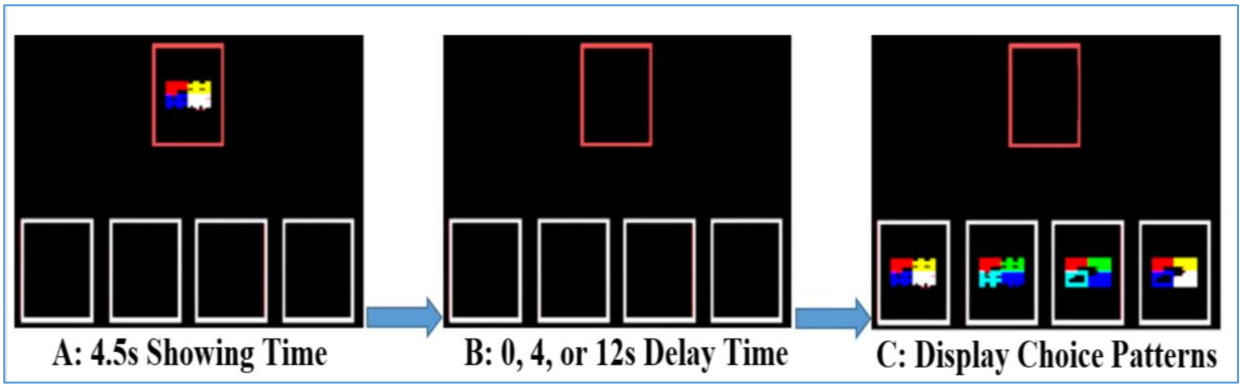


Figure 2-5: Delay Matching to Sample; (A) Time of showing a complex pattern, (B) Delay time and (C) display the choice pattern

Outcome measures

The outcome measures are:

i. *DMS total correct*: The total number of trials when the children were able to select the correct stimulus in their first response. A higher score is better.
ii. *DMS correct latency*: The latency (child's speed of response) in all trials where the child selected the correct stimulus. Lower score is better.

2.5.2.5 Choice Reaction Time (CRT)

CRT is a test of attention and impulse control; it is a two-choice reaction time test. An arrow-shaped stimulus appears on either the left or the right side of the screen. The children are instructed to press the left hand button on the press pad if the stimulus is shown on the left side of the screen, and the right-hand button if the stimulus is shown on the right side of the screen (Figure 2-6).

Figure 2-6: Choice Reaction Time

Outcome measures

i. *CRT latency*: the time in milliseconds from the stimulus appearance to the button press.
ii. *CRT Total correct trials*: The number of trials in which the outcome was correct.
iii. *CRT Total commission errors*: the number of trials in which the press button was pressed before the appearance of the stimulus.

2.5.2.6 Big/ Little Circle (BLC)

BLC is a test of comprehension, learning and reversal. A series of pairs of circles (one is large and the other one is small) are displayed on the screen; for the first 20 trials the participants are instructed to touch the small circle and then to touch the larger circle for the subsequent 20 trials (Figure 2-7). It is one of the attention tests.

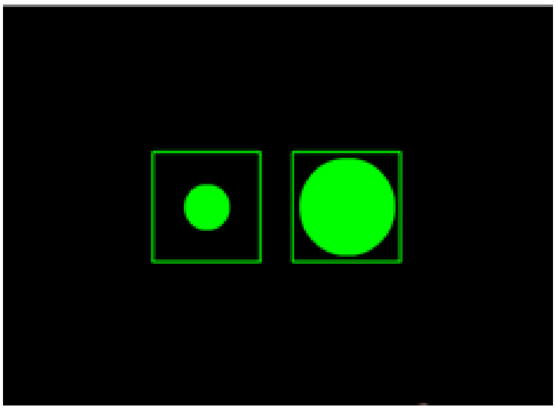


Figure 2-7: Big/Little Circle

Outcome measures

i. *BLC Mean correct latency*: The mean latency in ms to touching the correct stimulus.
ii. *BLC Total correct:* The number of correct responses.

2.5.2.7 Stop Signal Task (SST)

This is an examination of sustained attention and it is considered to be a classic stop signal response inhibition test. It measures the ability of the participants to inhibit a learned response. A white ring is displayed on the screen to alert the subject. After a fixed delay of 500ms, an arrow pointing to the left or the right is displayed within the ring. Children are instructed to press the left button when they see a left-pointing arrow and press the right button when they see a right-pointing arrow, however when they hear an auditory signal (a beep), they should stop their response and do not press any button. The beep is played following the 'stop signal delay' (SSD) period, which is measured from the onset of the arrow stimulus. The timing of the beep changes during the test depends on the participant's past performance. The stopping auditory signal occurs about 50% of the time for each participant. The shorter the SSD, the more likely it is that the participant will be able to hold off responding to the arrow. (Figure 2-8)

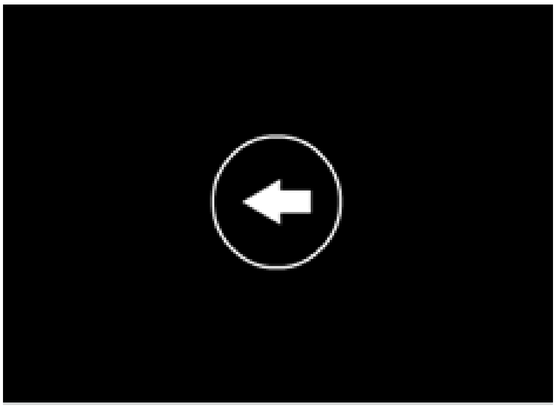


Figure 2-8: Stop Signal Task

Outcome measures

SST SSRT: Stop Signal Reaction Time is the length of time between the go stimulus and the stop stimulus at which the participant can successfully inhibit their response on 50% of the trials.

2.5.2.8 Stocking of Cambridge (SOC)

SOC is a test of spatial planning, spatial working memory and strategies. The child is shown two displays containing three coloured balls. The participant is requested to use the balls in the lower part of the screen to copy the pattern shown in the upper display. The balls should be moved one at a time by touching the required ball, and then touching the location to which it should be relocated(Figure 2-9).

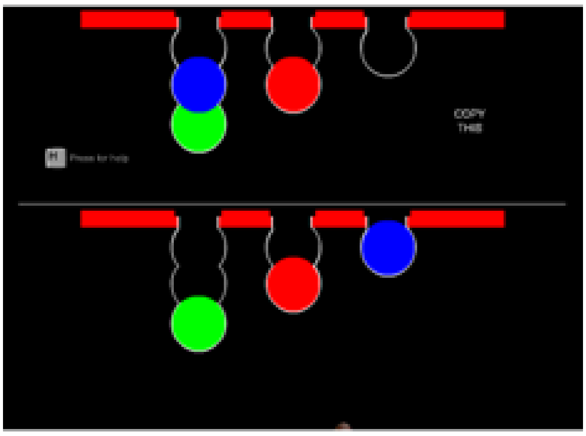


Figure 2-9: Stocking of Cambridge

Outcome measures

SOC mean moves to solve a problem: this measures the mean number of moves the child makes to solve a problem, which at minimum requires two moves, three moves, four moves and five moves. A lower score means better performance.

2.5.3 Assessment of Upper Limbs Motor Function

Cerebral palsy (CP) is defined as a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain (Bax et al., 2005b). The World Health Organization's International Classification of Functioning, Disability and Health speaks of 'activity' as '…the execution of a task or action by an individual', and identifies 'activity limitation' as '…difficulties an individual may have in executing activities'. (World Health Organization, 2001)

The majority of activities during daily living are executed bimanually, for example, getting dressed, cooking, eating and the majority of tool uses. Thus successful completion of everyday tasks requires the cooperative use of both hands. Poor bimanual performance is often the greatest functional impairment for children with hemiplegia and a limited ability to participate in activities requiring two hands is often the critical limiting factor for independence (Charles and Gordon, 2006, Fedrizzi et al., 2013). To be able to assess the severity of cerebral palsy and importantly to evaluate the efficacy of interventions, it is essential to have valid clinical assessment tools that address the capacity to complete these everyday tasks. Bimanual actions represent a complex, highly coordinated skill category and competence to carry out bimanual activities is more than the sum of the function of each hand acting individually. It is surprising therefore that there are currently no validated clinical assessments that assess bimanual abilities.

The clinical assessment tool that comes closest to meeting this need is the Assisting Hand Assessment (AHA) (Krumlinde-Sundholm et al., 2003, Krumlinde-Sundholm et al., 2007b). The AHA, however, assesses the performance of the more affected hand during bimanual activities. It is therefore a uni-manual assessment and does not evaluate bimanual function per se.

The Chedoke Arm and Hand Activity Inventory (CAHAI) is a clinical assessment that has the potential to fulfil both these needs. It is an assessment of bimanual function validated for use in adults with hemiplegia (Barreca et al., 2005, Barreca et al., 2006, Barreca et al., 2004, Murphy et al., 2015). It was developed to be consistent with the World Health Organization's "activity" domain (World Health Organization, 2001) and so test items are based on real-life, bilateral, functional activities and include a wide range of normative upper-limb movements and grasps. Previous investigations have supported the psychometric properties of the CAHAI in adults with hemiplegia including test-retest and inter-rater reliability, minimal detectable change score; validity and sensitivity to change (Barreca et al., 2004, Barreca et al., 2005, Barreca et al., 2006, Murphy et al., 2015). The activities assessed are common to both adulthood and childhood (see below) and the CAHAI has recently been shown to have good psychometric properties in children too(Eyre et al.).

The Melbourne Assessment of Unilateral Upper Limb Function 2 (MA2) is a test of uni-manual capacity assessing only the impaired upper limb by means of various uni-manual items that involve reach, grasp, release and manipulation.(Randall et al., 2001a, Randall et al., 2008, Randall et al., 1999)

The assessments used in the current study were selected in order to assess uni-manual capacity of the more affected arm (MA2), spontaneous uni-manual functional performance of the more affected arm (AHA), functional bi-manual ability (CAHAI) and dexterity of each hand (Tyneside Pegboard).

2.5.3.1 Assisting Hand Assessment (AHA)

The AHA (Krumlinde-Sundholm and Eliasson, 2003) is a performance-based assessment, used to assess the effectiveness of paretic hand and arm functions of children with unilateral disability during familiar bimanual activities. The assessment involves a video-recorded semi-structured play session, lasting approximately 20 minutes. Children played one of two board-game adaptations, in which the same toys are used (Figure 2-10). Toys used in the board-game require the use of both hands (e.g. cymbals, a wind-up music machine, scissors and paper). It is important that no instructions are given about which hand should be used or how. The main objective of the assessment is to observe spontaneous use of the paretic hand during different activities. AHA is a valid, reliable and standardise test, which is sensitive to any changes (Krumlinde-Sundholm et al., 2007a, Holmefur et al., 2007). Assessors must complete a certification process consisting of a three day training course followed by two sets of validation exercises. I have completed these requirements and became a certified assessor before starting data collection – see appendix E.

Figure 2-10: Assisting Hand Assessment

Outcome measures

Twenty-two items are assessed in the AHA (Table 2-2). These are ranked concerning difficulty in line with the assumptions of the Rasch measurement model. Each is rated on a 4-point scale giving a possible raw score range of 22-88 points (Table 2-3). Raw scores can be converted to logits (range -10.26-8.72) or logit-based AHA-units (range 0-100) using a conversion table. The smallest detectable difference for this assessment is approximately 5 logit-based AHA-units (Krumlinde-Sundholm, 2012).

Table 2-2: Items scored on AHA

Rank difficulty	Item	
1	Approaches objects	Easier
2	Holds	↓
3	Stabilises by weight or support	
4	Proceeds	
5	Changes strategies	
6	Coordinates	
7	Initiates use	
8	Moves upper arm	
9	Moves fingers	
10	Orients objects	
11	Stabilises by grip	
12	Releases	
13	Flow in bimanual performance	
14	Chooses paretic hand when closest	
15	Calibrates	
16	Reaches	
17	Varies grasp	
18	Readjusts grip	
19	Grasps	
20	Moves forearm	
21	Manipulates	
22	Puts down	Harder

Table 2-3: Rating scale for AHA

Score	Quality of performance	Affects actions/task outcome
4	Effective, competent, without problem	Performed with good result
3	Somewhat effective, almost good but somewhat deviant	Result is hardly affected, but it is questionable whether the performance was entirely effective
2	Ineffective, performed with difficulty, slowly or lengthily	Performed, but with a partly unsatisfactory or ineffective result
1	Does not do, not performed or unable to perform	Failure, performed in an unacceptable way, or is not performed

2.5.3.2 Chedoke Arm and Hand Activity Inventory (CAHAI)

The CAHAI contains ten real-life items scored using a 7 Point Activity Scale. Scoring represents the ability of participants to perform stabilization or manipulation in activities of daily living (Barreca et al., 2005, Barreca et al., 2006, Rowland et al., 2011). The subject is instructed to sit in an erect posture with their feet flat on the floor, in a chair without armrests in front of a table. The table height is adjusted to be at the level of the last costal rib.

These tasks include:

1- Open a jar of coffee: the participant is asked to open a jar of coffee, using both hands.
2- Use the phone and dial 135: the participant is asked to use a standard phone to dial 135.
3- Draw a line with a ruler: the participant is requested to draw a straight line with a standard pencil and ruler set onto paper using both hands without resting the forearms on the table.
4- Pour a glass of water: the participant is asked to pour some water in a 250 ml glass from 2.3L pitcher filled with water using both of hands.
5- Wring out a washcloth: the participant is requested to wring out a washcloth into a bowl half filled with water, using a wringing action with both hands.
6- Do up five buttons: the participant is given a shirt to wear and asked to do up five buttons using both hands, starting at the top.
7- Dry back with a towel: a towel is placed on the table, and the participant is asked to take the towel and dry his/her back using both hands.
8- Put toothpaste on toothbrush: toothpaste and a toothbrush are placed horizontally on the table. The participant is asked to put the toothpaste onto the toothbrush using both hands.
9- Cut medium resistance putty: the participant is asked to cut putty placed on a plate into five small pieces using a knife and fork located on either side of plate.
10- Zip up the zipper: The participant is asked to zip up a zipper on a poncho using both hands.

Outcome measure

Seven points scale is used to score the ten tasks describe as following:

(7) Complete independence; if the entire task is performed safely, without modification, assistive devices or aids and within reasonable time

(6) Modified independence; if the activity requires any one or more of the following: an assistive device, more than realistic time or there are safety attentions.

(5) Supervision; if the participant requires more help than standby, cueing or coaxing, without physical contact.

(4) Minimal assistance; if the participant expends 75% or more of the effort with minimal physical contacts no more than touching.

(3) Moderate assistance; if the participant expends 50%-75% of the effort, with more physical help than touching or expending

(2)Maximal assistance; if the participant expends less than 50% of the effort, but at least 25%.

(1) Total assistance; if the participant expends less than 25% of the effort.

2.5.3.3 Melbourne Assessment (MA2)

MA2 is a validated and reliable tool for assessing of unilateral upper limb capacity, to evaluate the quality of upper limb movement in children with neurological conditions aged 2.5 to 15 years (Klingels et al., 2008, Bourke-Taylor, 2003, Randall et al., 2001b). The test performances have to be video recorded for later scoring. This test is administrated in a quiet room with no distractions. The child was seated in a comfortable position with their feet flat on the floor and with hips, knees and ankles at 90 degrees, elbows and forearms can be resting on the table top. The assessment takes from 10 to 30 minutes to be completed depending on the child ability to follow instructions.

MA2 test included 14 test items (Figure 2-11), which are;

1- Reach forward; a switch with a smiley face is held perpendicularly to the floor, in front of the child at table height, at the midline of the child and at a distance, which needs maximum reach for the child to be able to touch the smiley face. Then the child is instructed to reach forward with his/her tested hand to touch the smiley face.
2- Reach sideway; the switch is held to the child's side, at a height of the child's shoulder and in line with his/her trunk. The child is asked to reach sideways to touch the smiley face.
3- Grasp of crayon; a crayon is placed on a marked position on the table and the child is asked to pick up the crayon.
4- Drawing grasp; after grasping the crayon the child is requested to copy circle on a piece of blank paper placed in front of him/her.
5- Release of crayon; the child is asked to place the crayon into a small container in front of him/her.
6- Grasp of pellet; the child is asked to pick up a pellet placed in front of him/her.
7- Release of pellet; the child is asked to put the pellet into a small container.
8- Manipulation; A cube with different coloured faces is placed in front of the child. The child is asked to hold the cube in their supinated hand and, using isolated movements of the thumb and fingers of the hand only, to turn the cube over in different directions revealing the coloured faces.

9- Pointing; a sheet with coloured rectangles and a black square in the centre of each rectangle is placed in front of the child and he/she is asked to point with his/her index finger to the black centres.

10- Reach to brush from forehead to back of neck; the child is requested to move their hand with an open palm from their forehead over the top of his/her head to the back of their neck.

11- Palm to bottom; the child is asked to touch there ischial tuberosity with their supinated forearm and flexed wrist.

12- Pronation and supination; the child is asked to hold a magic wand in the palm of the pronated hand and turn the wand over until his/her palm is fully supinated.

13- Reach to opposite shoulder; the child placed the palm of the assessed side flat on top of the opposite shoulder.

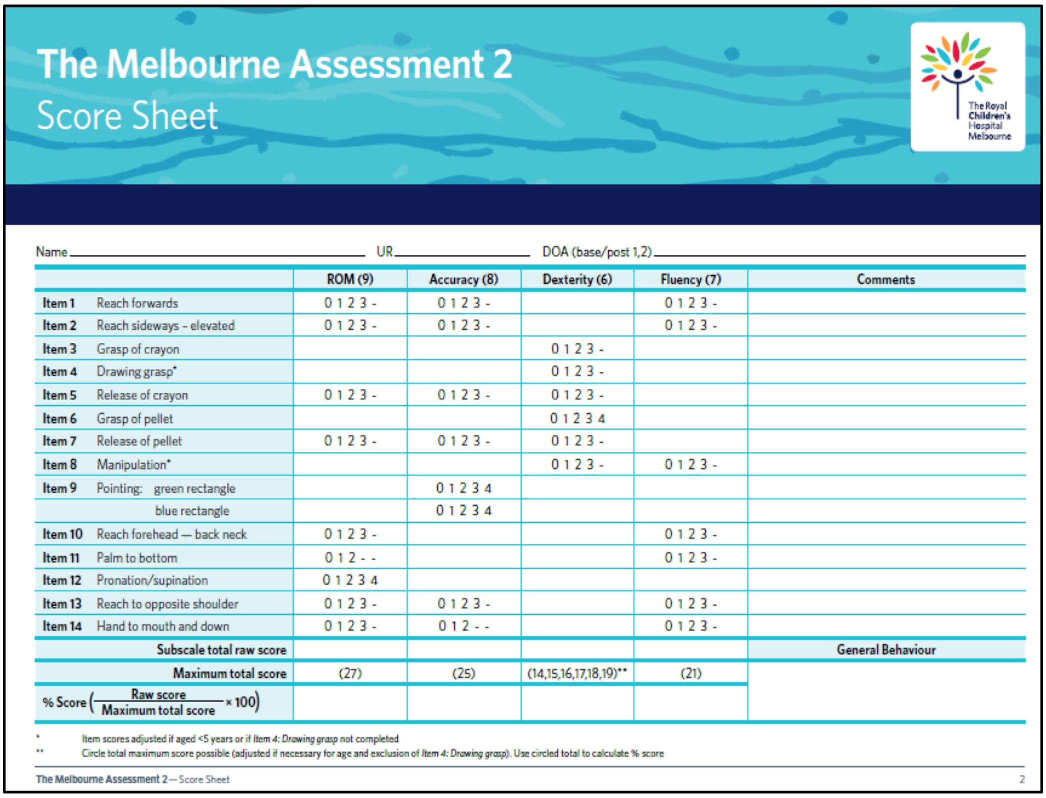
14- Hand to mouth and down; place either a fruit bar or a finger biscuit on the marked position in front of the child and in the horizontal plane to the child, the child take the biscuit it to his/her mouth and bite it.

For items 12, 13, and 14 the camera should be placed 1-1, 5 meters in front of the child.

Outcome measure

Four categories (range of movement, accuracy, fluency and dexterity) are used to assess the quality of movement on the thirteen task items. Each item is scored on a three, four or five points interval scale, with a range of possible raw scores of 0-89. Scores are represented as percentages of the possible total. The MA2 suggests using four subscales due to a lack of evidence of uni-dimensionality in the overall summary score on the original assessment. We have elected to use a single score in this assessment for ease of comparison (Figure 2-12).

Figure 2-11: Melbourne Assessment



The Melbourne Assessment 2
Score Sheet

The Royal Children's Hospital Melbourne

Name ____________ UR ____________ DOA (base/post 1,2) ____________

		ROM (9)	Accuracy (8)	Dexterity (6)	Fluency (7)	Comments
Item 1	Reach forwards	0 1 2 3 -	0 1 2 3 -		0 1 2 3 -	
Item 2	Reach sideways – elevated	0 1 2 3 -	0 1 2 3 -		0 1 2 3 -	
Item 3	Grasp of crayon			0 1 2 3 -		
Item 4	Drawing grasp*			0 1 2 3 -		
Item 5	Release of crayon	0 1 2 3 -	0 1 2 3 -	0 1 2 3 -		
Item 6	Grasp of pellet			0 1 2 3 4		
Item 7	Release of pellet	0 1 2 3 -	0 1 2 3 -	0 1 2 3 -		
Item 8	Manipulation*			0 1 2 3 -	0 1 2 3 -	
Item 9	Pointing: green rectangle		0 1 2 3 4			
	blue rectangle		0 1 2 3 4			
Item 10	Reach forehead — back neck	0 1 2 3 -			0 1 2 3 -	
Item 11	Palm to bottom	0 1 2 - -			0 1 2 3 -	
Item 12	Pronation/supination	0 1 2 3 4				
Item 13	Reach to opposite shoulder	0 1 2 3 -	0 1 2 3 -		0 1 2 3 -	
Item 14	Hand to mouth and down	0 1 2 3 -	0 1 2 - -		0 1 2 3 -	
	Subscale total raw score					**General Behaviour**
	Maximum total score	(27)	(25)	(14,15,16,17,18,19)**	(21)	
	% Score $\left(\frac{\text{Raw score}}{\text{Maximum total score}} \times 100\right)$					

* Item scores adjusted if aged <5 years or if *Item 4: Drawing grasp* not completed

** Circle total maximum score possible (adjusted if necessary for age and exclusion of *Item 4: Drawing grasp*). Use circled total to calculate % score

The Melbourne Assessment 2 — Score Sheet 2

Figure 2-12: MA2 Score Sheet

2.5.3.4 Tyneside 9 holes pegboard test

Nine hole pegboards have been used to assess the speed and dexterity of upper limb function (Gardner and Broman, 1979). This test showed strong construct validity in children and high inter-rater and test-re-test reliability (Smith et al., 2000). The Tyneside 9 holes pegboard is a modified nine holes pegboard test in which two pegboards are placed side by side with the pegs placed upright in one board to make it easier to grasp the pegs. There are three peg sizes (large, medium and small) (Figure 2-13).

At the bottom of each hole, there is an infra-red light source opposite a photovoltaic detector, allowing detection and electronic coding (including timing and peg hole number) of events in which pegs are removed or replaced. This information is recorded on a computer using the custom-written software.

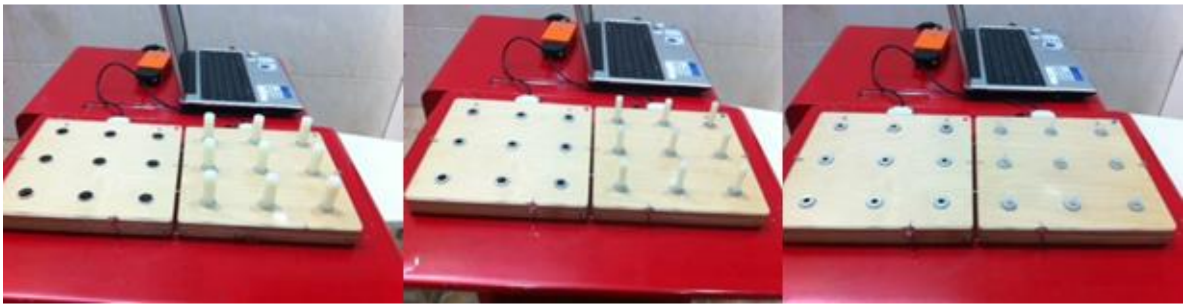


Figure 2-13: Tyneside pegboard illustrating the set up and the three different peg sizes

Participant is seated with the pegboards placed on a table in front of them within comfortable reach and with the midline of the participant; in line with the midline between the two pegboards. Standard instructions are given: namely "Using just this hand" (point to hand), "pick up the pegs one at a time as fast as you can and put them into the holes of the other board in any order. You can start from any hole". A demonstration is provided once to each participant by the examiner and then a practice run was undertaken prior to the recorded test. The peg sizes were present in a standardized order (large, medium and small pegs). The child was asked to undertake the following transfers of all nine pegs of each peg size: 1) left to right with the dominant hand; 2) right to left with the dominant hand; 3) left to right with the non-dominant hand and 4) right to left with the non-dominant hand. For each participant therefore 12 pegboards were completed.

Outcome measure

i. *Board Completion Time (BCT);* the total time in seconds taken for the child to complete the 12 pegboard tests.
ii. *Pegs Transfer Strategy (PTS) ratio;* In this study, we have classified Strategic Moves (SM), as moves to complete the task when the subject moves the pegs (one by one) from one board to the other; by picking up the pegs from the same row or column and filling up the opposite board by the same row or column until all pegs transfer. These moves can be Mirror (e.g. Row to row - picking up from the outside of a row and filling from the outside of a row (Figure 2-14), Match e.g. Colum to column picking up and putting down the pegs in a matched hole each time(Figure 2-15) or pick up from the same Row and fill in the same Column in any order as long as the same row and/or column have been completed before you change rows and columns (Figure 2-16). Other moves than the ones mentioned above are classified as Non-Strategic Moves (NSM), such as random pick up from more than one row or column or random fill up in more than one row or column (Figure 2-17). A peg board

completed using strategic moves scores 1; a board completed using non-strategic moves scores 0. A PTS ratio is calculated for all pegboards, completed by the child, by dividing the summed scores for strategy by the number of pegboard completed i.e. if the child is able to complete all the 12 pegboards using strategic moves than he/she PTS ratio will be 1 (12/12=1) and if he/she complete all the 12 pegboards using non-strategic moves than he/she PTS ratio will be 0 (0/12 = 0).

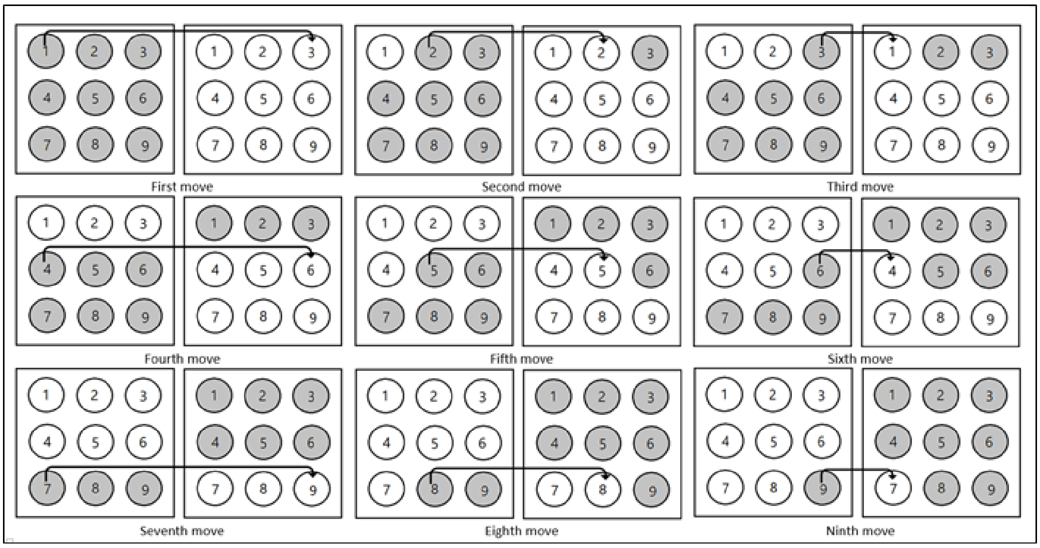


Figure 2-14: Example of Strategic Mirror Moves (Row to Row)

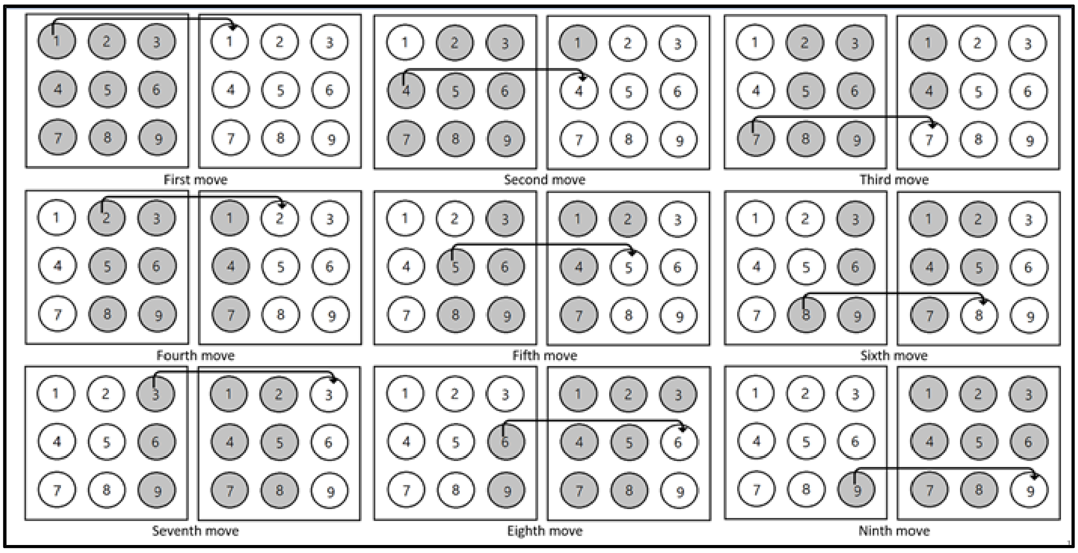


Figure 2-15: Example of Strategic Match Moves (Column to Column)

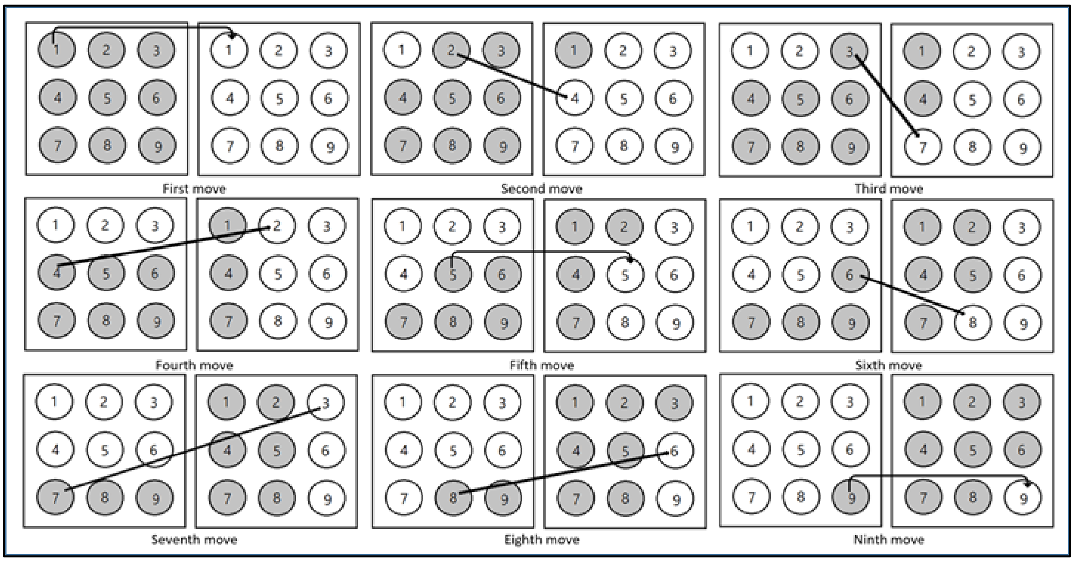


Figure 2-16: Example of Strategic Row to Column moves

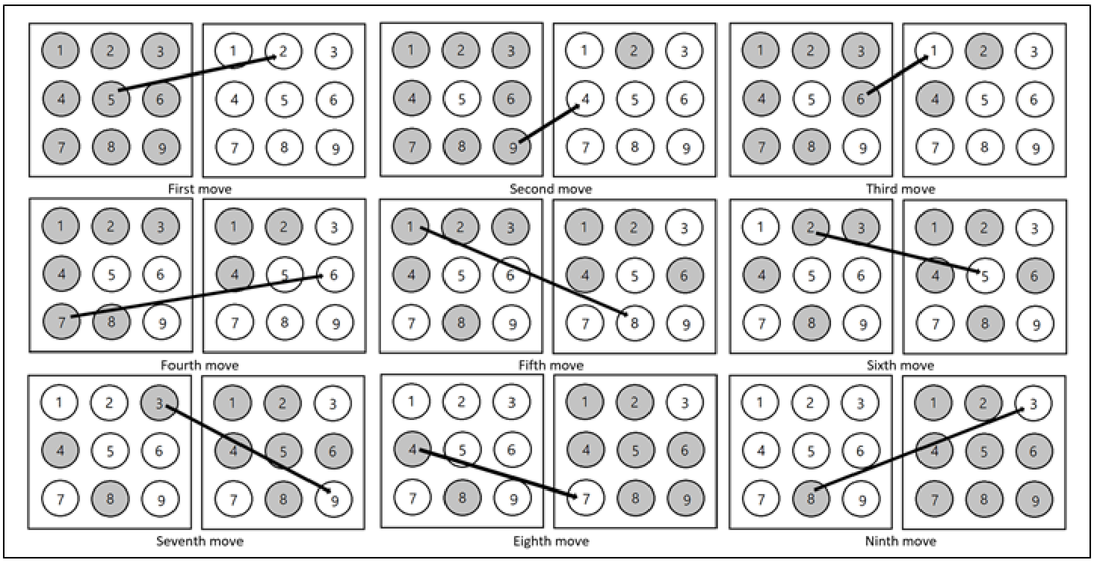


Figure 2-17: Example of Non-Strategic Moves

Chapter 3. Positive Relationship between Duration of AVG Play and Visuospatial Executive Function in Typically Developing Children

3.1 Introduction

In the previous decade, a revolution in digital technologies has been seen with exponential increases in processing power and graphics technology matched by dramatic reductions in cost. This has made the availability of these technologies ubiquitous across a wide range of platforms including tablets and mobile phones. As costs have come down, children's access to these technologies has increased. This is no truer than for video games. In USA, 91% of children between the age of 2 and 17 play video games and up to 99% of boys and 94% of girls play these games (Granic et al., 2014). Another study in the USA revealed that boys play video games for an average of 16 hours per week and girls for 9 hours per week (Gentile, 2009). With 25% of young males reporting playing video games for 4 hours a day or more (Baily et al., 2011).

A more recent 2-year longitudinal study of school-aged children in Singapore found more than 80% reported playing video games. The average amount of time played was 20-22 hours per week over the 2- year period (Gentile et al., 2011).

The rising popularity of video games has instigated a debate among parents, researchers, video game producers and policymakers concerning the balance between the potential helpful/harmful effects of video games on children. A video game genre is a classification assigned to a video game based on its gameplay interaction rather than visual or narrative differences. Specific information-processing skills (auditory processing, executive functions, mental rotation, motor skills and visual processing) are crucial to engagement and success in some video game genres. The action video game genre, for example, emphasizes physical challenges that require hand-eye coordination, fast decision making and reaction-time and speed. Action video games include a variety subgenres, the most popular of which are shooter games, fighting games and platform games. Shooter games focus on the action of the avatar using a firing weapon to defeat enemies without being killed. The most popular game in this subgenre is "Call of Duty". Fighting video games involve a player controlling an on-screen character engaging in violent physical confrontation with an opponent, for example the Tekken video game. Platform games involve the player guiding an avatar through a complex of suspended platforms and obstacles, examples of this genre are the Super Mario video games.

Non-action video games include: Social video games that are played with, against or alongside social-network friends and require social interaction between players e.g. Farmsville; Role-playing video games in which players assume the roles of characters in the fictional setting of a well-defined world and focus on storytelling and character improvements e.g. The Sims. Strategy video games that focus on skillful thinking and planning, where games are won through tactics and usually involve moving one or more characters across a map, utilizing resources and winning specific locations to achieve victory e.g. Starcraft. Puzzle video games that require puzzle solving using logic, pattern recognition, sequence solving, and word completion e.g. Tetris. Many video games can include components of many different genres.

The relationship between playing Action Video Games (AVGs) and enhanced cognitive and visual-perceptual abilities is well documented in adults. AVGs contain common properties such as unpredictability, intense speed, high perceptual, cognitive and motor load, the selection between multiple action plans and an emphasis on peripheral processing (Oei and Patterson, 2013). In particular, AVGs have been demonstrated to improve a range of visual spatial skills (Achtman et al., 2008, Green and Bavelier, 2007, Green and Bavelier, 2008, Feng et al., 2007). Players also exhibit better visual short-term memory (Boot et al., 2008) and exhibit more flexibility in switching between tasks (Boot et al., 2008, Colzato et al., 2010, Cain et al., 2012, Green et al., 2012). Training studies in adults support a strong causal link between AVGs experiences and improvement in perceptual, attentional and cognitive skills (Boot et al., 2011, Green and Bavelier, 2012). There is limited research on the association of video game play and executive function in children. There is evidence to support similar effects as described in adults, since children who report playing AVGs show significantly increased attentional skills as compared to those who do not (Dye et al., 2009, Dye and Bavelier, 2010). There have however not been any interventional studies to demonstrate cause and effect as have been described in adults.

This study:

(1) Asks whether children who play video games exhibit similar enhancement of performance across a broad range of executive functions as has been reported in adult studies

(2) Examines the relationship between the amount of time a child reported playing video games and their performance on executive function test; by looking for a dose effect.
(3) Looks for gender differences.

3.2 Method

3.2.1 Participants

156 healthy children aged 6-12 years, with no history of neurological or behavioral problems, visual or hearing impairment and an IQ score above 70, were recruited randomly from 4 schools in Saudi Arabia (2 public and 2 private schools).

3.2.2 Study design

See Chapter 2 Methods, for a detailed description of the assessment methods and outcome measures.

This study was designed as a cross-sectional study; all assessments were undertaken by me (Maha AlGabbani, the Ph.D. student).The assessments took place in quiet, unused classrooms in the schools where the children have been recruited.

3.2.3 Outcomes

3.2.3.1 Test of Executive Functions

All children undertook the assessment of executive function, using the CANTAB Executive Function Tests including MOT, BLC, DMS, SOC SWM, CRT, SSP, and SST tests (see methods page 22 section 2.5.2).

3.2.3.2 IQ Assessment

The Arabic version of Stanford-Benit Intelligence Scale was used to obtain a global IQ score (Farag, 2011, Roid and Barram, 2004).

3.2.3.3 Video-game Play Data

A Video-Game Play questionnaire used in many previous studies was filled in by the children and by their parents to determine the genre of video games played and the duration of game play in the last six months (Green and Bavelier, 2003, Green and Bavelier, 2007, Dye et al., 2009) – see appendix D. Based on previous studies (Green and Bavelier, 2003, Green and Bavelier, 2007) children were classified as AVGPs if they reported playing >5 h/week of action games on average over the past 6 months. For the dose of video game play, the average number of hours recorded playing per week was calculated from this questionnaire.

3.2.4 Statistical analysis

All data analyses were analysed using SPSS 15 (SPSS Inc, Chicago, Illinois, USA). Data were normally distributed. Significance level was set at $p<0.05$ with full Bonferroni correction for multiple comparisons.

i. Independent sample T-tests were applied to investigate age and IQ differences between children who played AVGs and those who did not.
ii. To assess the effect of Video Game genre on Executive Function test scores, a General Linear Model Analysis of Variance was used with Greenhouse-Geisser correction if required. Between subjects' factors of Age, Gender (boys/girls) and Game Genre (AVG/ NAVG) were used.
iii. To investigate the different between boys and girls on the duration of video game play for each genre, a General Linear Model Analysis of Variance was used with between subject factor Gender and Age included as a Covariate.
iv. To investigate the effect of number of hours of game play in the previous 6 months on Executive Function test scores, univariate analysis was used with the duration of Action or Non Action video game play and Age included as covariates.

3.3 Results

3.3.1 Subjects

156 children were recruited (66 males; mean age 9.2 years range 6.0-12.9 years) (Table 3-1). 2 children (one boy and one girl) did not play video games. Since there were only 2 children that did not play video games these children were excluded from the study and a group called Non Video Game Players (NVG) was not included in the statistical analyses. All comparisons were therefore made between AVG and NAVG groups.

There was no difference in age ($t= 1.07$, $p=0.29$) or IQ ($t=1.18$, $p=0.24$) between those who played AVGs and those who played only social or strategy games (NAVGs). Significantly more boys played AVGs and more girls only played NAVGs (chi-squared 7.781, $p=0.005$).

Table 3-1: Subjects' Characteristics

Subjects' Characteristics	AVGs	NAVGs only	Total
Boys (n)	56	10	66
Girls (n)	31	57	88
Total (n)	87	67	154
IQ mean± SE	110.4±1.38	108.9±1.58	
Age (yrs) mean± SE	9.43± 0.41	9.18 ± 0.43	

3.3.2 Duration of Video game Play

Table 3-2summarizes the estimated duration of video-game play by genre. There was a main effect for Gender. The total duration of video game play and AVGs play for boys was significantly longer than girls, while girls played NAVGs for significantly longer. There was no effect for Age, nor were there Age * Gender interactions. (Figure 3-1).

Table 3-2: Duration of video-game play in hours per week

Game Genre	All Subjects	Boys	Girls	df	F	* p
Action genre mean ±SE maximum	7.2± 0.6	10.9± 0.8 26.5	4.4±0.7 20.3	1	39.1	**<0.001**
Non-action genre mean ±SE maximum	7.2± 0.5	5.2±0.8 31.2	8.6± 0.3 33.8	1	10.6	**<0.001**
Mixed Genre mean ±SE maximum	1.6± 0.7	1.4±0.4 14.5	1.7± 0.8 15.2	1	0.13	0.71
Total Duration mean ±SE maximum	16.8±3.2	20.2±3.1 39.6	14.3± 0.7 33.8	1	27.7	**<0.001**

* comparison of duration of different video-game genre between boys and girls

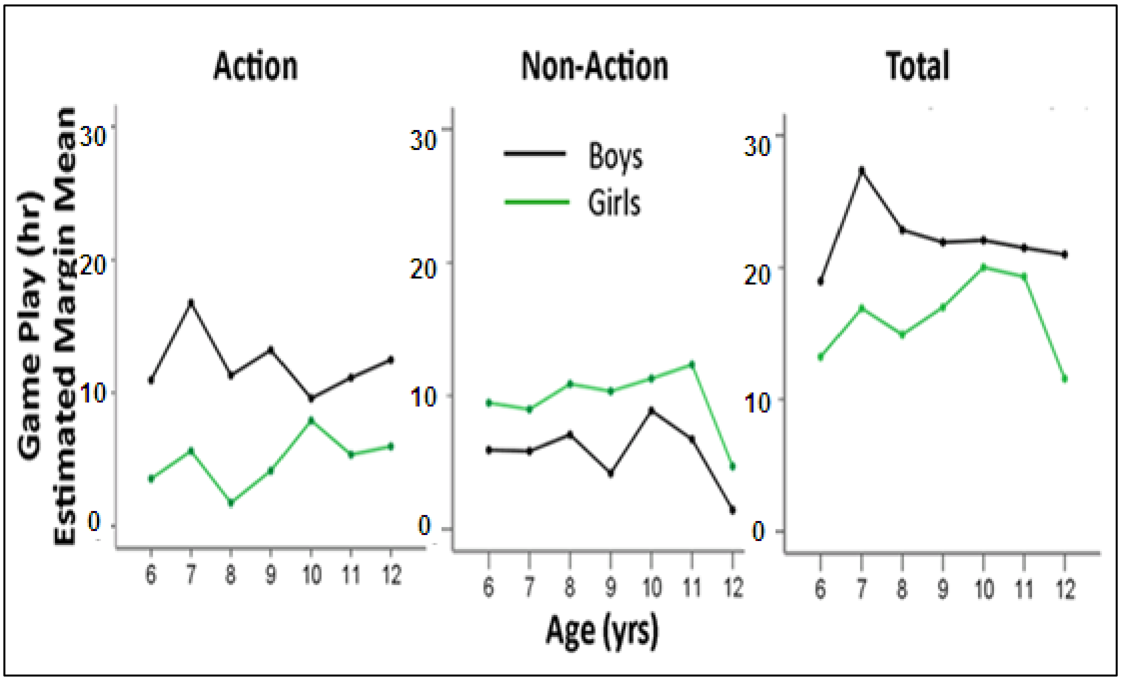


Figure 3-1: Duration of game play per week comparing boys and girls across the age groups

3.3.3 Executive Function Assessments

For all tests of EF, there was a main effect for *Age*. There were no main effects for *Gender*. There were main effects for *Game Genre* (AVG versus NAVG) for the subtests - SSP (span length), SWM (Total errors), CRT (mean latency to correct response), BCL (mean latency to correct response), SST–SSRT, SOC (4 moves) and MOT (mean latency to correct response); (Table 3-3;Figure 3-2). AVG players showed superior performance in all these subtests compared to those who only play NAVGs (Figure 3-2). There were no interactions with *Age* or *Gender.*

Since there were significantly more boys playing AVGs, to exclude the main effect of AVG play simply reflecting gender differences in executive function, we repeated the analysis, but only compared female players of AVG and NAVGs. Main effects for *Game Genre* were again demonstrated and revealed the same pattern of significance as observed for the whole group (Table 3-3).

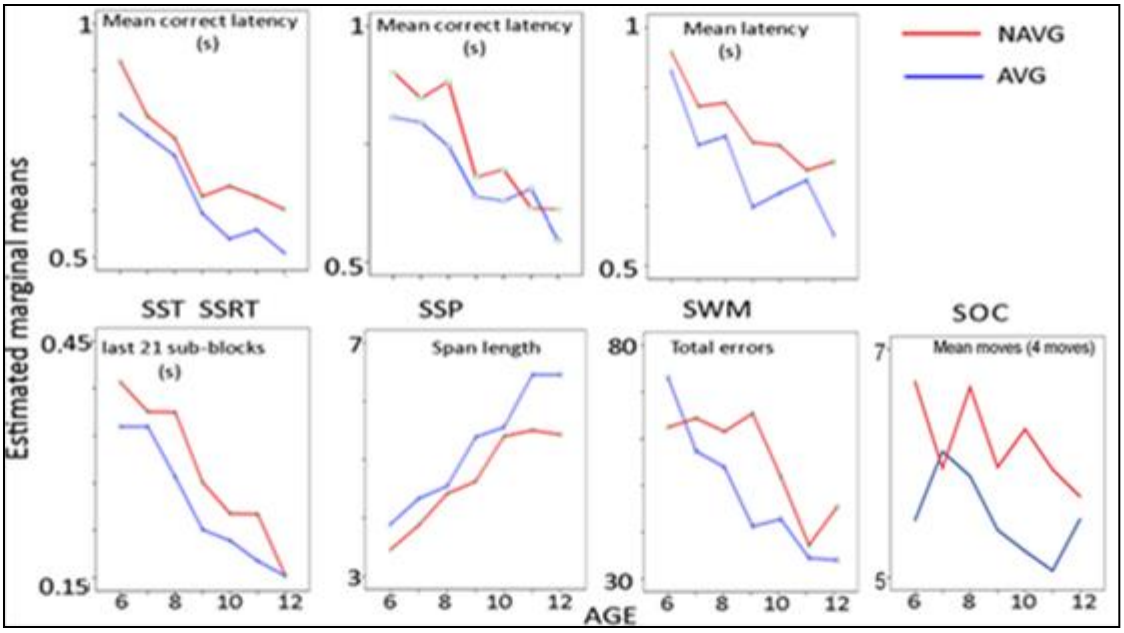


Figure 3-2: Test Scores of executive function comparing AVG and NAVG Groups

Table 3-3: Tests of executive function and attention

Test name		*All subjects (154)			**Girls only (88)		
Visual short term memory		df	F	P	df	F	P
Delayed Matching to Sample (DMS)	Perceptual matching						
	Total correct 0s delays	NS			NS		
	Total correct 4s delays	NS			NS		
	Total correct 12s delays	NS			NS		
Spatial Planning							
Stockings of Cambridge (SOC)	Spatial planning						
	Mean moves (2 moves)	NS			NS		
	Mean moves (3 moves)	NS			NS		
	Mean moves (4 moves)	1	4.354	**0.039**	1	4.379	**0.039**
	Mean moves (5 moves)	NS			NS		
Spatial Short-Term Memory							
Spatial Span (SSP)	Spatial working memory:						
	Span length	1	9.75	**<0.001**	1	8.6	**<0.001**
Spatial Working Memory (SWM)	Spatial working memory						
	Total errors:	1	7.87	**0.006**	1	5.89	**0.018**
Attention							
Choice Reaction Time (CRT)	Latency to correct response	1	18.6	**<0.001**	1	4.66	**0.03**
Big / Little Circle (BLC)	Visual discrimination Ability to reverse rules:						
	Latency to correct response	1	11.45	**0.001**	1	17.3	**<0.001**
Response Inhibition							
Stop Signal Task (SST-SSRT)	Response inhibition:						
	SSRT last 21 sub blocks (ms)	1	6.11	**0.015**	1	8.63	**0.004**
Motor tests							
Motor screening (MOT)	Reaction Time	1	9.53	**0.002**	1	9.1	**0.003**
	Accuracy	NS			NS		

* comparison of EF between AVGPs and NAVGPs for all children

* comparison of EF between AVGPs and NAVGPs for girls only

3.3.4 The Relationship between duration of video-game and executive function

Univariate analysis variance revealed a significant relationship between the duration of action video-game play in the previous 6 months and scores obtained in BLC (mean latency to correct response), SWM (Total errors), CRT (mean latency to correct response), SSP (span length) and MOT (mean latency to correct response). For all variables, increased duration of game play was associated with superior performance (Table 3-4, Figure 3-3). There was no relationship between the length of NAVG play and tests of executive function.

Table 3-4: Relationship between duration of action video-game play and executive function.

Test	**df**	**F**	**p**
BCL (mean correct latency)	1	17.6	<**0.001**
CRT (mean correct latency)	1	15.25	<**0.001**
SSP (span length)	1	15.83	<**0.001**
SWM (total errors)	1	9.26	**0.003**
MOT (mean correct latency)	1	5.3	**0.02**

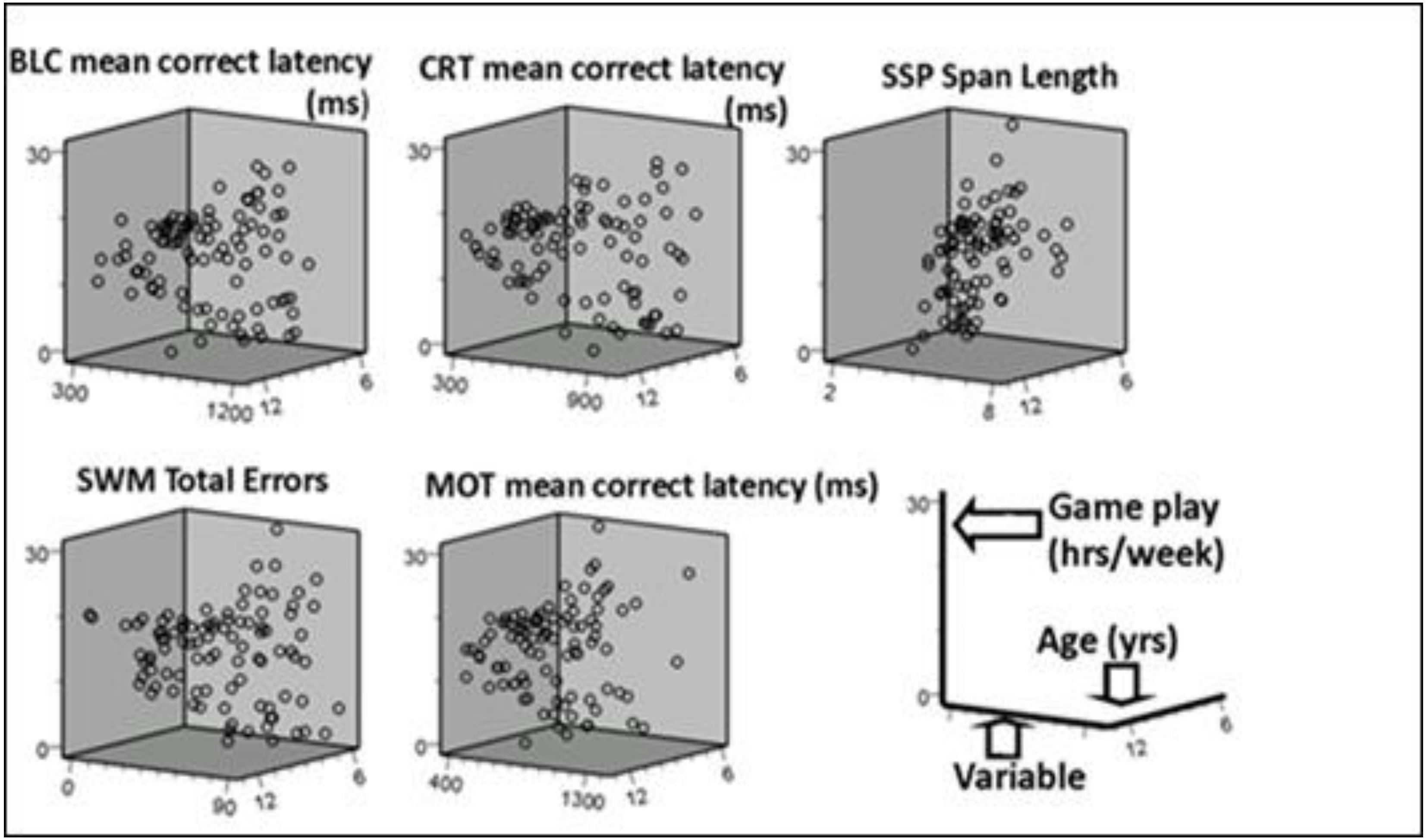


Figure 3-3: Relationship between age, duration of action-video-game play and executive function test scores

3.4 Discussion

This study confirms the recent observations of an exponential increase in the numbers of children playing video games (Gentile, 2009, Rideout et al., 2010b). It is the first study however, to report almost universal use of video games by children as young as 6 years of age. Data to allow classification of children into different socio-economic status were not collected, but we recruited children at random from private and public elementary and intermediate schools in Al-Khobar city, in the Eastern Province of Saudi. The population of children recruited is likely therefore to be representative of the socio-economic mix of children how live in Saudi Arabian cities (General Authority for Statistics, 2013). Furthermore, the children had intelligent scores representative of distribution of children's intelligent scores in Saudi Arabia (Batterjee et al., 2013).The children are therefore likely to be representative of typically children in Saudi Arabia. At recruitment, there was no explicit reference to video games, so it is unlikely that there was bias in our recruitment towards children who play video games.

Only 2 children out of the 156 recruited did not play video games at all. We were surprised by this finding since we had hoped to compare executive function development in three groups of children, namely Non Video Game Players (NVGP), AVG Players (AVGP) and Non AVG Players (NAVGP). The study was of necessity confined to a comparison of AVG players with NAVG players.

Our results are consistent with reports from the USA and Singapore that children who play video games are playing for more than 2 hours per day (Gentile, 2009, Rideout et al., 2010a, Bailey et al., 2011). The results confirm previous observations that boys play video games for longer than girls (20.2 hours/week versus 14.3 hours/week respectively), but the difference is less than has been reported previously with girls in our study playing video games for more than 14 hours per week on average, compared with only approximately 9 hours per week in the previous studies (Gentile, 2009, Rideout et al., 2010a, Bailey et al., 2011). The children also report a very wide range of duration of game play with some boys and girls reporting playing video games regularly for as much as 30-40 hours a week.

There are very limited studies on the effect of AVG play in children. Previously this maybe as results of parental restrictions on video game playing, which lead to an insufficient number of children playing AVGs for statistical analysis. In the past, to overcome this issue, researchers classified children as AVG players if they reported playing any action-based video game for any length of time in the 12 months prior to testing and NAVG players if they only played other types of video game (Dye and Bavelier, 2010, Dye et al., 2009).In our study AVG players reported playing AVG for more than 5h per week, which is similar to the durations reported in the adult study. Moreover, some children reported playing games that were rated from the Entertainment Software Rating Board as “Mature games.”

In this study, we investigated whether children who play AVGs exhibit similar enhancement of performance across a broad range of visual attention and executive functions as has been reported in adults. Our results mirror those observed in adults, revealing superior performance, particularly of spatial visual selective attention for those who play AVGs compared to those who play other genres (Achtman et al., 2008, Green and Bavelier, 2007, Green and Bavelier, 2008, Boot et al., 2008, Colzato et al., 2010). Gender has been a concern in video game research, as more adult males play AVGs than adult female, so to control for this many studies recruited only male participants for cross-sectional analyses (Green and Bavelier, 2007, Li et al., 2010, Li et al., 2015, Wilms et al., 2013, Pohl et al., 2014, Green and Bavelier, 2006b, Cain et al., 2012). In our study, the fact that so many girls in our sample played AVGs provided us with the opportunity to exclude a gender difference in visual attention skills as the explanation for the effect of gameplay, since we could demonstrate the same effect of AVG playing on executive visuospatial functions when we only considered the girls in our study. Moreover, we did an analysis of all executive function test for boys and girls in our AVG players group and it revealed no significant gender differences in all tests. Both males and females have been included in some AVG training studies and no gender differences were found, supporting our findings of no gender differences in children (Boot et al., 2008, Green and Bavelier, 2003, Green et al., 2010). Thus, the observation of differences in visuospatial function was most likely due to the type of gameplay rather than to reflect gender differences.

There are differences of recruitment methods between our study and those of adults. Most studies of adults recruited subjects explicitly on the basis of their gameplay (Table 3-5). This is likely to introduce bias such that the most avid video game players are likely to volunteer and be recruited into the studies (Boot et al., 2011).In our study, we adopted a covert recruitment strategy. Children were recruited without mention of video games until completing all assessment tests. Also, for the majority of adult studies, a comparison was made between AVG players and those who did not play video games at all(Table 3-5), rather than as in this study where the comparison has to be, of necessity, between the effects of playing different genres of video games. This difference is likely to have reduced our ability to detect differences in executive function and supports the conclusion that playing AVGs has a powerful effect on the development of selected executive functions in children

Table 3-5: Subjects classification according to video game playing in cross section and training studies

studies	*cognitive measures*	*Subjects classification according to video game playing*	*Type of recruitment*
Studies comparing AVG players (AVGP) and non-players (NVGP)			
(Pohl et al., 2014)	Masking stimuli	AVGP: played AVG at least 8 to 10 h per week during the last year. NVGP: played no video games	Overt
(Mishra et al., 2011)	Attention skills	AVGP: minimum of 5 h/week of action game played for the previous year NVGPs: play no AVG over the past year.	Overt
(Irons et al., 2011)	Visual attention	AVGP: play AVGs between 4 and 20 hr a week. NVGP: play no video game	Unspecified
(Karle et al., 2010)	Task switching (attention)	AVGP: played AVG at least 4 h per week, and at least 1 h per session, for 6 months or more. NVGP: very little or no video game experience	Overt
(Colzato et al., 2010)	Task switching (attention)	AVGP: played AVGs at least four times a week for a minimum period of 6 months. NVGP: little to no videogame experience	Overt
(Murphy and Spencer, 2009)	Visual attentional	AVGP: played AVGs more than 4h per week in the past six months. NVGP: played no video games in the past six months.	Unspecified
(Boot et al., 2008)	Visual attention Memory	AVGP: played 7 or more hours of action video games per week for the past two years NVGP: played no video games.	Overt
(Feng et al., 2007)	Mental rotation, and Useful field of view	AVGP: played AVGs for more than 4 hr per week NVGP: played no video game within the past 3 years.	Overt
(Green and Bavelier, 2006b)	Enumeration, object tracing (memory)	AVGP: play a minimum of 3–4 days a week of AVG for the previous six months. NVGP: was little or no video game usage in the past six months.	Unspecified
(Castel et al., 2005)	Search, attention cuing	AVGP: played action video more than 4h per week for the past 6 months. NVGP: no or less than one hour a month of playing videogames.	Unspecified
(Green and Bavelier, 2003)	Various visual and attention skills	AVGP: played AVGs more than 4h per week for the previous 6 months. NVGP: had little or no video-game usage in the past 6 months	Unspecified
Studies comparing AVGP and NAVG players (NAVGP)			
(Cain et al., 2014)	Attention skills	AVGP: played AVG for more than 5h per week in the last 6months. NAVGP: played AVG less than 2h per week in the last 6months, in addition to other genres.	Overt
(Blacker and Curby, 2013)	Visual short-term memory	AVGP: played more than 5h per week of action games over the past year NAVGP: played AVGs less than 1h per week and less than 5h per week of other type of games	overt

studies	*cognitive measures*	*Subjects classification according to video game playing*	*Type of recruitment*
(Cain et al., 2012)	Switching task (attention)	AVGP: played at least 6h per week of AVG NAVGP: played less than 2h per week of AVG	Overt
(Li et al., 2010)	Resistance to masking	AVGP: played at least 5 h of AVG per week during the past year NAVGP: little or no AVG experience in their past year, but play other type of video game	Unspecified
(Green et al., 2010)	Decision making (planning)	AVGP: played more than 5hr a week of action video in the previous 6 months NAVGP: played little or no action-game in the previous 6 months, they played other kinds of video games.	Unspecified
(Dye et al., 2009)	Attention skills	AVGP: played action-based video game for any length of time in the 12 months prior to testing NAVGP: play other types of video game in the 12 months prior to testing.	Overt
(Green and Bavelier, 2007)	Visual acuity (attention)	AVGP: played more than 5hr a week of action video in the previous 6 months NAVGP: played little or no action-game in the previous 6 months, they played other kinds of video games.	Unspecified
Subject classified as AVGP and NVGP (play little AVG and did not mention if they play other type of games			
Wilms et al (2013)	Visual short-term memory	Experienced players: played action games for more than 15h a month. Casual players: played AVGs 4-8h a month. Non-player: less than 2h per month.	Overt
(Hubert-Wallander et al., 2011)	Visual search and attention	AVGP: played more than 5h per week of action videogame over the previous year. NVGPs: played one or less hour per week of action videogame over the previous year.	Overt
(Donohue et al., 2010)	Temporal judgment	AVGP :play AVG more than 4.5 h per week within the past 6 months NVGP: played AVG less than 1.5h per week within the past 6 months.	Covert
(Li et al., 2009)	Contrast sensitivity	AVGP: expert AVG players NVGP: non- AVG player	Unspecified
(Bialystok, 2006)	Response time (attention)	For this study they use1to 10 point scale, 10 for expert and 0 indicate low proficiency AVGP: at least 6 out of 10 NVGP: remaining participants.	Unspecified

3.4.1 Effect of AVGs on executive function tasks

Visual and Spatial Short-term Memory

Visual short-term memory is necessary for obtaining visual knowledge. Previous work has shown a visual short-term memory advantage among AVGPs compared with both NVGPs and NAVGPs (Boot et al., 2008, Wilms et al., 2013, Blacker and Curby, 2013).Similar to these other studies assessing visual short-term memory using the DMS test, our primary measure in this test was the accuracy of identifying the correct item in the test display rather than the speed of choosing it. In this study, we used a complex, colorful pattern as the masking stimuli with an encoding duration of 4.5s. We calculated the number times the subject identified the correct item after progressively increasing delays of 0s, 4s, or 12s (Figure 2-5). Our results are not consistent with previous studies in adults because we found no difference overall between AVGPs and NAVGPs in visual short-term memory, although it should be noted that the AVGPs showed superior performance when the delay was intermediate i.e. 4s. However, the difference between our tasks and tasks used previously by other researchers may explain this difference. The masking stimulus in our test is a colorful complex square shaped pattern, which is more complex compared to the bright and colorful lines used by Boot et al.(Boot et al., 2008) or the simple colored squares or the gray novel shapes used by Blacker and Curby (Blacker and Curby, 2013). Moreover, the encoding duration in the previous studies was shorter than in our study, ranging between 100ms (Boot et al., 2008) to 1018ms (Blacker and Curby, 2013). The time between covering the stimuli and showing the choice pattern was relatively longer in our study (4s, and 12s), whilst in other studies it did not exceed 9s.

Wilms et al.,(Wilms et al., 2013) did not find a superior performance for AVGPs, which is similar to our results; although, they used the same encoding duration used by Boot et al (Boot et al., 2008). The difference between the Wilms and the Boot study is that Boot et al compared AVGPs with those who do not play video games. Whilst in Wilms et al, similar to us, compared AVGPs with NAVGPs. It is possible that playing video games per se increases short-term visual memory, irrespective of the game genre.

In contrast to short-term visual memory, we found a superior performance of spatial short-term memory for AVGPs. The only other previous study to investigate video game play and spatial short-term memory did not find superior performance for adult AVGPs (Boot et al., 2008). The fact we observed superior performance in two separate assessments of spatial memory, namely in the SSP and SWM tests, supports our finding is unlikely to have occurred by chance. It may be that playing AVGs has an effect on the development of spatial memory in childhood rather than enhancing performance in adulthood.

Planning and solving problems

In our study, we tested the ability to plan and solve a spatial problem using Stocking Of Cambridge test (SOC test), which is a computerized version of the Tower of London planning task (Shallice, 1982). Problems are graded in difficulty, involving two, three, four and five minimum moves set. We measured the average number of moves for each moves set. Our results showed that there is no difference in problem-solving skills for the first two easiest moves sets between AVGPs and NAVGPs. When the problems become more challenging in the four moves set, AVGPs outperform NAVGPs. However, there was no difference between both groups in the most difficult, five moves set. Although many researchers have demonstrated that AVGs are an effective tool for training different executive functions, only a few studies have addressed the relationship between video game play and skill in problem solving. Researchers (Adachi and Willoughby, 2013, Steinkuehler and Duncan, 2008) suggested that only some types of video games may increase problem-solving skills. Strategic and role-playing games teach the players first to gather information and then think of a plan before attempting to take actions and solve problems. AVGs also required a certain level of strategic planning to gather information about how the targets move, formulate a plan regarding when and how to attack without being detected or adapt a strategy through trial-and-error fashion. One study (Steinkuehler and Duncan, 2008) showed positive effects of playing virtual role playing video game, such as *World of Warcraft*, on problem-solving skills. It was a correlational study making it impossible to detect whether playing the game improved problem solving or people with better skills are drawn toward this type of open-ended role-playing game. Recent research studied the longitudinal relationships between strategic video games, AVGs and problem-solving skills(Adachi and Willoughby, 2013).They found that adolescents who reported playing strategic video games had improved their problem-solving skills, compared to those who played AVG. Our AVGPs reported also playing strategic and social video games in addition to AVGs. Our NAVGPs played a mixture of strategic and social video games. Therefore, both groups played strategic video games. Unfortunately, not having a third group of non-video game player in our study makes it difficult to detect if playing video games, which include strategic video games, improves problem-solving.

Attention Skills

Our results showed that AVG play enhances attention abilities. Children were required to make a fast decision to indicate the direction of an arrow-shaped stimulus in the CRT test or the size of a circle in the BLC test. AVGPs responded more quickly to visual information than NAVGPs, without a decrease in accuracy and they continued to act fast even when the rules were reversed (task switching).Similar results in children have previously been reported (Dye et al., 2009, Dye and Bavelier, 2010). Moreover, our results are consistent with those observed in adult studies, where AVGPs were compared both with NAVGPs (Cain et al., 2014, Wilms et al., 2013, Dye et al., 2009, Bialystok, 2006) and subjects playing no video games (Castel et al., 2005). A range of different tests have been used in adult studies to detected attention ability, all recording the reaction time to the correct response to a stimulus. The stimulus can be, like the stimulus that we use in our study, an arrow-shape and indicate its direction (Dye et al., 2009, Bialystok, 2006), letters and indicate if T or F is used (Cain et al., 2014) square and indicate it's color (Bialystok, 2006) or a circle and react to its appearance (Castel et al., 2005). According to our results and the results of previous studies, AVGPs consistent showed faster reaction times without loss of accuracy.

Additionally, in our study AVGPs showed superior performance compared to NAVGPS when the test required task switching. Our finding is consistent with previous studies in adults. One study compared AVGPs with NAVGPs (Cain et al., 2012); and the others compared AVGPs to NVGPs (Karle et al., 2010, Colzato et al., 2010).

Response inhibition

AVGs, especially First Person Shooter Games, require the players to monitor and react rapidly to fast moving visual, auditory stimuli and inhibit incorrect actions, such as shooting teammates instead of enemies (Colzato et al., 2013).In this study I used the classic Stop Signal response inhibition test (SST test) to estimate the ability of children to successfully inhibit unwanted responses, finding that AVGPs outperformed NAVGPs. This result is in line with the result of adult studies (Colzato et al., 2013) that used the same paradigms, but compared AVGPs to NVGPs.

3.4.2 Positive Relationship between Duration of AVG Play and Visuospatial Executive Function in Children

To support a causal link between game play and the improved executive functions discussed above, I demonstrated a dose-response relationship, such that at any age the children playing AVGs for longest displayed superior performances and there did not appear to be a ceiling effect (Figure 3-3). Our finding was consistent with Wilms study (Wilms et al., 2013) who tested the cognitive impact of playing AVG on adults. These researchers found that playing AVGs improved the encoding speed of visual information into visual short-term memory and the improvement depended on the time devoted to gaming. These findings support the conclusion that playing AVGs accelerates the maturation of these executive functions in children. In the next study reported in Chapter 4, I test this with an interventional study.

3.4.3 Effects of age on executive function and visual attention skills

The results of this study showed that there was a main effect for age for all tests of executive function. This finding replicates the results of previous developmental studies (De Luca et al., 2003, Luciana and Nelson, 2002). Moreover, other studies of executive functions demonstrate that maturation of executive functions continues until late adolescence (Davidson et al., 2006, Luciana et al., 2005, Luna et al., 2004, Lyons-Warren et al., 2004, Zhong et al., 2013).

3.5 Summary

In this study, I found that playing AVG is associated with the superior performance of attention control, working memory, planning and solving problems, which are the core abilities of executive functions for most executive function models that influence on everyday activities (previously discussed in chapter 1). This finding is consisting with the finding of previous cross-sectional comparisons in adults. In addition, demonstrating a dose-response relationship showed that those playing longest have the most superior performance. These results raised interesting questions whether is it possible for AVGs to have a role for therapy intervention for children with limited executive function.

Moreover, it is important to clarify whether children develop superior executive function skills because of playing AVGs or whether children with superior executive function skills prefer playing AVGs and therefore play for long periods. For this reason, I conducted a longitudinal training intervention study to clarify this issue.

Chapter 4. The Effect of Video Game Training on Executive Function and Hand Motor Function in Typically Developing Children: Double Blinded Randomized Controlled Trial

4.1 Introduction

Our previous study showed that playing AVGs was associated with superior performance of key EF skills in children and this result was consistent with other studies in adults predominantly(see Chapter 3).There is a main concern for all previous studies, including our study, that AVGPs have inherently better executive function and attention abilities. As a result of their greater ability, they are successful in playing AVGs and therefore play these games more often, whereas NAVGPs have limited ability, which leads them to avoid playing AVGs. To control for this possibility, in this study NAVGPs underwent AVG training to investigate if a causative relationship exists between AVG experience and higher executive function skills. Several training studies have reported in adults a positive enhancement in different aspects of executive function after training with AVG for a period of time as it is clear from the table, no studies to date have examined the effect of AVG training on EF in children. The purposes of this study were to analyze the effect of AVG training on executive function and hand motor function of TD children compared to a similar time period of NAVG training (Table 4-1)

4.2 Method

4.2.1 Participants

A pre-screening questionnaire was used to recruit NAVGPs for this study using the video game questionnaire. The questionnaires were collected from a further 300 girl students, since our previous study revealed that almost all boys play AVGs. The inclusion criteria were not playing AVGs in the last 12 months,(ii) no history of neurological or behavioral problems, (iii) no reported visual or hearing impairment, (iv) an IQ score above 70 (v) and had not participated in the cross sectional study reported in Chapter 3.

Table 4-1: AVG Training Studies

Study	Cognitive benefit	VGP classification of Adult Participants	Training Game (s)	Duration
(Green and Bavelier, 2003)	Various visual/ attention	NVGPs	AVG: Medal of Honor, First Person Shooter (FPS) NAVG: Tetris	1 hr per day for 10 days
(Green and Bavelier, 2006a)	Useful field of view and attention	NVGPs	AVG: Unreal Tournament (FPS) NAVG: Tetris	30 hrs over 4-6 weeks
(Green and Bavelier, 2006b)	Enumeration and object tracking	NVGPs	AVG: Medal of Honor (FPS) NAVG: Tetris	1 hr per day for 10 days out of 15 days
(Green and Bavelier, 2007)	Visual acuity	NAVGPs	AVG: Unreal Tournament (FPS) NAVG: Tetris	30 hrs over 4-6 weeks
(Feng et al., 2007)	Mental rotation and Useful field of view	NVGPs	AVG: Medal of Honor (FPS) NAVG: Ballance	10 hrs over 4 weeks
(Li et al., 2009)	Contrast sensitivity	NVGPs	AVG: Unreal Tournament and Call of Duty (FPS) NAVG: the Sims2	50 hrs over 9 weeks
(Li et al., 2010)	Resistance to masking	NAVGPs	AVG: Unreal Tournament and Call of Duty (FPS) NAVGT: the Sims2	50 hrs over 9 weeks
(Wu and Spence, 2013)	Visual and dual search	NAVGPs	AVG: Medal of Honor (FPS) or Driving-Racing game NAVG: Ballance	10 hrs over 3 weeks
(Oei and Patterson, 2013)	cognitive control, visual and attention skills, and memory	NVGPs	AVG: Modern Combat Sandstorm (FPS) NAVG: Hidden-object game, Matrix, Match-3, or the Sims3	20 hrs over 4 weeks

4.2.2 Study design

This study was designed as a randomized, double blinded controlled study. The participants were blinded to the purpose of the study and were not aware that different genres of games were being used as training. All assessments were undertaken by me. I was blinded to which training games were used by the participants. The assessments took place in a quiet, unused classroom in the children's schools. The video game training took place in children home.

4.2.3 Apparatus

The Nvidia Shield Portable Gaming Console was used for video game training (Figure 4-1).It is a 5-inch tablet display and console-grade game controller. 40 Nvidia Consoles were uploaded with either 6 action video games (20 consoles) or with 6 social/strategy games (20 consoles) - see appendix F for the game names by genre. All of the video games chosen are single-player games. We did not include any multiplayer video games. Multiplayer video games require players to use networking technology which we couldn't guarantee that all children have an access to it.

Figure 4-1: Nvidia Shield Portable Console Gaming

4.2.4 Randomization and Blinding

4.2.5 Blinding

The games were uploaded by Dr. William Blewitt (Research Associate in Computing Science, Newcastle University), who was the only person who knew what game genre was on each console. The consoles were distributed by a colleague of mine, who also collected the consoles at the end of the training period, downloaded the game play duration data and forwarded it to Mr. Blewitt who created the data spreadsheet.

All the Nvidia shields looked the same and were only identified by their serial number. I and my colleague were blinded as to the genre of the game on each console until completion of the study and all the data had been complied onto a spread sheet.

4.2.6 Randomization

The children who indicated on their questionnaire that they had not played Action Video Games in the previous six months were allocated to 5 blocks by their completed year of age (8, 9, 10, 11, 12). Each child was given an ID number with no particular order. The ID numbers were sent to my supervisor Prof. Janet Eyre who used a computer program to generate 8 random ID numbers in each age group block to select the 40 children for inclusion into the study (8 from each age group block).

The Nvidia consoles were also divided into 5 age group blocks by Dr Blewitt, each block containing 4 consoles with AVGs and 4 consoles with NAVGs. For each age group block, consoles were selected at random and given to participants by my colleague, so that for each age group block there were 4 participants playing AVGs and 4 participants playing NAVGs.

4.2.7 Training

For both groups, training consisted of playing the video games on their Nvidia Shield Console for one to two hours per day to complete a minimum of 50 hours of playing within 8 weeks. Re-assessment sessions took place within 2 days of the child returning the consoles.

Action video Game Training Group (AVGTG)

Children of this group had the choice of playing 6 different action video games, which included; Lego City, Sonic 4 episode2, Angry Birds, Beach Buggy,where is my Water and Diversion. These games were chosen to be similar to those played by action video players in the first study according to the game play questionnaire and because they were age appropriate games.

Non Action Video Game Training Group (NAVGTG)

For this group, children played non action video games listed in the game play questionnaire which included; Candy Crash, Pancake Maker, Smurfs' Village, Unicorn Pet, Doptrix and Juice Cubes. These were chosen to be similar to those played by non-action video players in the first study according to the game play questionnaire and because they were age appropriate games.

4.2.8 Monitoring

Children were given a video game play diary and have been asked to keep a record of duration of play sessions by date (see appendix G). To reduce potential response bias, we carefully designed this diary to simple and clear and to ask open ended questions. Thus the children were simply asked to record the duration of time playing the video games each day. In addition, each console had a software app that was intended to record the hours of game play by date.

4.2.9 Outcomes

The outcome measures are explained in detail in Chapter 2. The assessment sessions took between 45-60 minutes.

Test of Executive Function.

All children undertook the assessment of EF, before and after training, using the following CANTAB.EF tests: MOT, BLC, SWM, CRT, SSP and SST tests.

IQ Assessment

The Arabic version of Stanford Benit Scale of intelligence was used to obtain a global IQ score.

Assessment of Upper Limb Motor Function

Tyneside 9 holes pegboard test were used to assess the hand motor function. For this part of the study, we only used the large peg size.

4.2.10 Statistical Analysis

All data analyses were performed using SPSS 15 (SPSS Inc, Chicago, Illinois, USA). Data was normally distributed. Significance was set at 0.05, with full Bonferroni correction for multiple comparisons.

i. Independent sample T-tests were implemented to investigate age, IQ, baseline EF scores, pegboard data and hours of game play training differences between groups.
ii. To investigate the distribution of training over the 8 week period. *Time* (Training week) was the within-subject factor; *Genre* (AVG/ NAVG) was the between-subject factor.
iii. To assess the effects of training, a General Linear Model Repeated Measures Analysis of Variance was used with Greenhouse-Geisser correction if required. *Time* (Pre/ Post

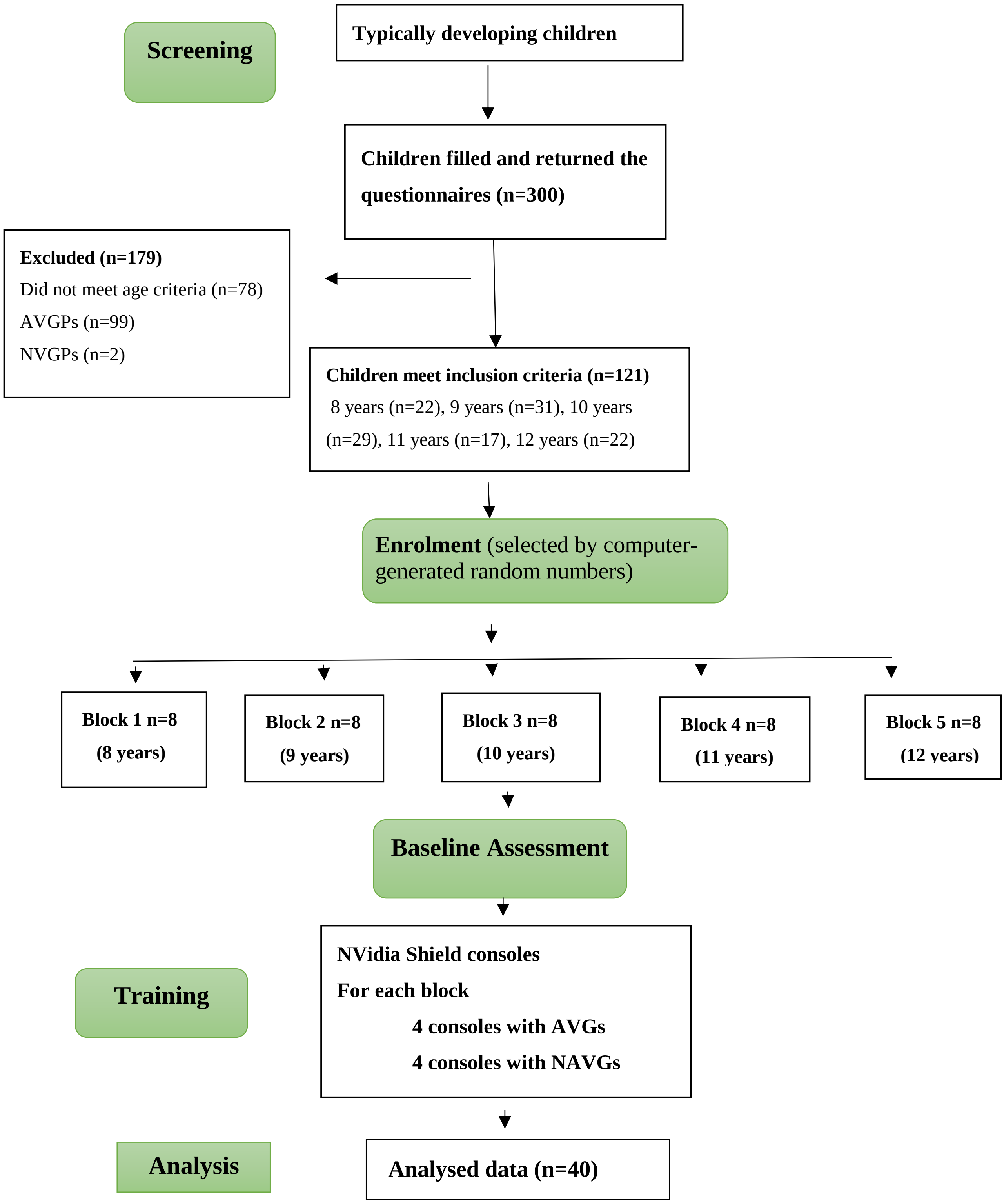
Training,) was the within-subject factor; *Genre* (AVG/ NAVG) was the between-subject factor.

4.2.11 Sample size

A power analysis was conducted using G power and it revealed that at least 16 children per group were needed to have sufficient power (0.8) to detect an effect size (0.9) utilizing an analysis of variance with two comparison groups and testing a one-tailed hypothesis. The effect size have been determined from the results of our previous study (chapter 3)

4.3 Results

4.3.1 Participants Flow and characteristics



40 children were enrolled (all girls; mean age 10.5 years range 8.25-12.67 years; mean IQ 104, range 85-127). There were no differences in age, IQ, EF scores and peg board data at baseline nor in the duration of game play training between the two training groups (Table 4-2).

Table 4-2: Groups comparison at baseline

	AVGTG	**NAVGTG**	**df**	**F**	**P**
Number	20	20			
Age (yrs.) mean ± SE	10.55 ±0.31	9.95±0.31	38	0.18	0.83
IQ mean ± SE	104.8 ±2.81	104.5±2.15	38	2.55	0.933
Total duration of game play training (hours mean ±SE) Range:	66.6± 10.92 52-260	55.55±3.78 52-121	38	2.8	0.35
EF scores (at baseline)					
MOT(ms) mean ±SE	631.89±22.34	613.49±25.57	38	0.54	0.6
SSP (n) mean ±SE	5.45±0.26	5.45±0.19	38	0.4	0.53
SWM(errors) mean ±SE	39.8±4.12	39.95±4.04	38	0.12	0.73
CRT (ms) mean ±SE	496.16±18.6	502.48±21.41	38	0.09	0.77
BLC (ms) mean ±SE	676.86±20.5	708.46±21.58	38	0.36	0.55
SST-SSRT (ms) mean ±SE	297.11±17.44	307.78±21.8	38	0.57	0.45
Pegboard data at baseline					
BCT (s) mean ±SE	49.71±1.07	49.4±1.05	38	0.06	0.84

4.3.2 Dose of training hours

All children completed the minimum required video game training hours within the 8 week training period, based on data from the video game play diary (Figure 4-2). Unfortunately, the data on game play could not be retrieved from the software app on the NVidia Shield because of a software problem.

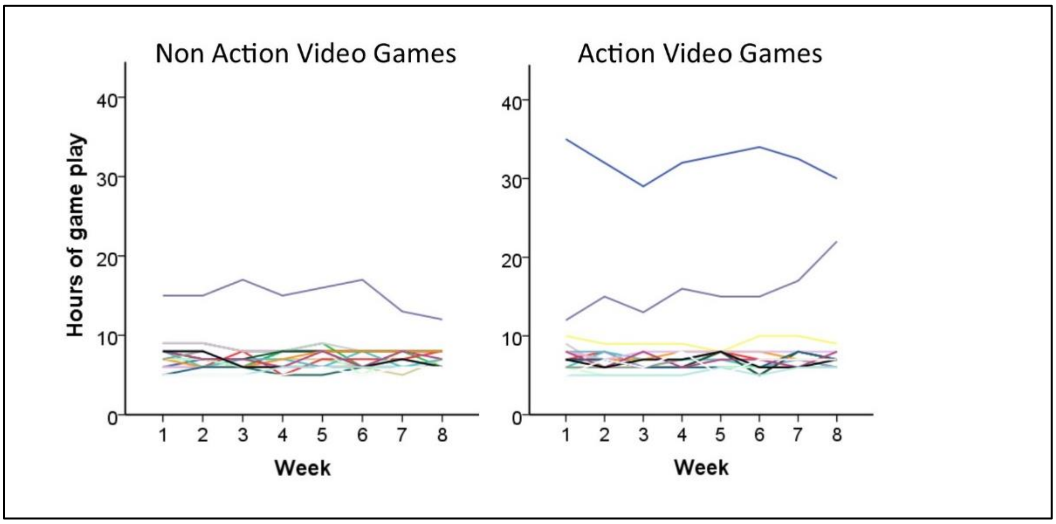


Figure 4-2: Self-reported hours played per week by game genre used in training. Each line represents a subject.

Repeated measure ANOVA revealed there were no main effects for Genre (F=0.994, p=0.325), indicating the intensity and duration of game play was similar between the two genre groups over the training period.

4.3.3 Executive Functions

Repeated measure ANOVA revealed there were no main effects for Genre. There were main effects for Time (pre, post training) for SSP, SST and a trend for MOT, with post-training executive functions being significantly improved (Table 4-3).
Reanalysis including training hours as a covariate revealed a main effect for the number of training hours for SST (F= 4.33 p= 0.03), with increased training hours being associated with greater improvement in EF. There were Genre*Time interactions for CRT and SSP. Paired T tests revealed a significant effect of training for AVGTG for SSP (t=-4.68, p<0.001) and CRT (t=1.71 p=0.05), but no significant training effect for NAVGTG (Figure 4-3).

Table 4-3: Effect of action video game training on executive function

EF	AVGTG		NAVGTG		Time		Genre		Genre*Time	
	Pre	Post	Pre	Post	F	p	F	p	F	P
BLC (ms) Mean ±SE	676 ±21	646 ±29	708 ±21	711 ±29		NS		NS		NS
MOT (ms) Mean ±SE	692 ±14	631 ±20	671 ±18	613 ±23	3.62	0.07		NS		NS
SWM (errors) Mean ±SE	39.8 ±4	39.8 ±4	40.0 ±4	36.9 ±4.5		NS		NS		NS
CRT (ms) Mean ±SE	496 ±18	470 ±20	502 ±21	511 ±19		NS		NS	2.71	**0.05**
SSP (n) Mean ±SE	5.45 ±0.25	6.20 ±0.29	5.45 ±0.18	5.65 ±0.27	9.81	<0.01		NS	3.20	**0.04**
SST (ms) Mean ±SE	297 ±17	266 ±22	307 ±21	272 ±24	6.17	0.02		NS		NS

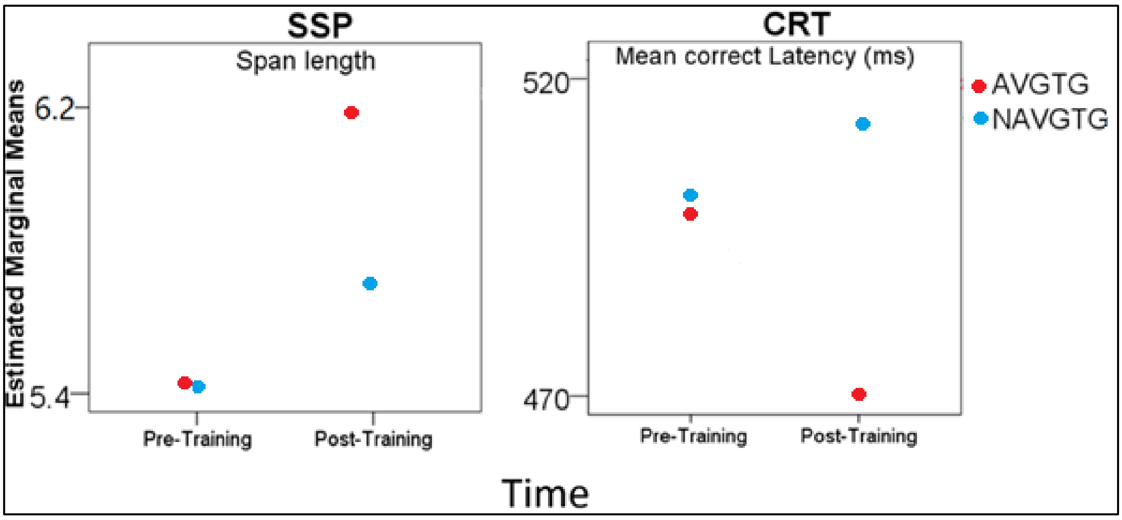


Figure 4-3: Training Effect on SSP and CRT

4.3.4 Hand Motor Function

For Board Completion Time (BCT), there was a main effect of time (pre, post training). There was no main effect for Genre (Table 4-4). Reanalysis, including training hours as a covariate, revealed no main effect for the number of training hours. There were no Genre*Time interactions for BCT. This led us to do a regression analysis for healthy children to find out if the improvement related to maturation. Linear Regression analysis showed that there is a significant linear relationship of the board completion time with the age (coefficient: - 3.4, 95% CL: 0.29, P<0.001) over one year. We expected the reduction of completion time over two months to be 0.65s. In this study, completion time was reduced by approximately 1.55s after AVG training and 1.38s after NAVG training; and these were larger reductions than predicted for maturation alone.

Table 4-4 : Effect of Training on hand motor function

Pegboard data	AVGTG		NAVGTG		Time		Genre		Genre*Time	
	Pre	Post	Pre	Post	F	p	F	p	F	p
BCT (s) Mean ±SE	49.71 ±1.06	48.23 ±1.01	49.41 ±1.06	48.03 ±1.01	5.87	0.02		NS		NS

4.4 Discussion

Video games classified as within the Action genre have several characteristics including unpredictability, high perceptual, cognitive and motor load, extreme speed and the ability to switch attention between multiple action plans while ignoring distractors (Oei and Patterson, 2015). The majority of researchers select First Person Shooter (FPS) games for action video game training, since these are the most extreme examples of action video games in this genre. We trained children on age appropriate video games, so we could not include FPS games in the selection of action video games for training and this may have reduced our power to observe effects reported in adults (Oei and Patterson, 2015).

At the beginning of this study, we had planned to investigate the effect of video game play on a group of children who do not play any video games, as has previously been studied in adults. The result of the pre-screening revealed that nearly all children are playing video games, so the study as we had initially planned it was not possible. Instead, we recruited children who do not play AVGs. Some studies in adults have also used this group of subjects in their training studies (Green and Bavelier, 2007, Li et al., 2010, Wu and Spence, 2013).

Only girls were included in this study because very few boys do not play AVG and no gender differences were found in EF scores between boys and girls who play AVGs in the first study reported in Chapter 3. Participants were allowed to train at their home in their own leisure time (Green and Bavelier, 2003, Green and Bavelier, 2007). Allowing the children to train during their own time had the advantage of being more applicable to the normal way of playing video games.

4.4.1 Effect of AVG training on executive function tasks

The first aim of this study was to determine whether playing action video games as training enhanced EF performance in children. Children in the AVGTG after training showed a greater improvement in attention (CRT) and short term memory (SSP) than children in NAVGTG. This finding supports a causal link between action game-play, attention ability and short term memory revealed in the cross sectional study (Chapter 3, section 3.3.4, page 45). This finding, was also consistent with the majority of other studies in adults which report significant improvements in attention and short term memory (Green and Bavelier, 2003, Green and Bavelier, 2006a, Oei and Patterson, 2013, Oei and Patterson, 2015).

Response inhibition (SST) and spatial working memory (SWM) was found to be improved in both groups, regardless of the game genre and the degree of improvement was related to the number of hours of game play for SST. Oei and Patterson also found that spatial working memory improved after video game training irrespective of genre, but there were no data on game play duration (Oei and Patterson, 2013).

4.4.2 Hand motor function

Since AVGs require fast responses the second aim of this study was to investigate the effect of video games on hand function, as assessed by a nine-hole peg board. There was a significant decrease in the time to complete the peg board (BCT) using large pegs for both AVGTP and NAVGTG. However, the reduction of BCT was greater than expected from maturation, suggesting playing video games may have led to the reduced BCT. Since BCT using the large pegs is unlikely to be limited by dexterity in TD children, this finding may support a decrease in motor response time for children who play video games. This conclusion is supported by recent findings in adults, where it was found that playing AVG can enhance the visuomotor control (Li et al., 2016, Gozli et al., 2014). Li and his colleagues found that training with action video game (driving or FPS games) for 5 or 10 hours decreased the response delays on both lane-keeping and visuomotor-control tasks(Li et al., 2016).

Game play analytics

Unfortunately, the app written to record each subject’s game play time with each game on the console failed to work. Although we were able to rely on the diaries recorded by the player, in game, app recorded data would have provided objective validation of the diary data. More importantly the data may also allowed more detailed analysis of whether particular games were more effective in improving executive functions.

The science of game analytics has in games for entertainment has gained a tremendous amount of attention in recent years. Introducing analytics into the game development cycle was driven by a need for better knowledge about the players, which benefits many divisions of a game company, including business, design, etc. Game analytics is, therefore, becoming an increasingly important area of business intelligence for the industry. Similar analytics for serious games in the future will allow identification how people interact with the actual game system and the key features of a game which mediate the effect desired. There will be many challenges to developing analytics for serious games including determining what to track, and how to analyze the data but it has the potential to allow personalization of game design to meet the desired aims of the intervention (Drachen et al.,2013)

Chapter 5. Can Action video games improve EF and Hand Motor Function in children with hemiplegic cerebral palsy? Open Trial Pilot Study

5.1 Introduction

Cerebral Palsy arises from a non-progressive brain lesion and describes a group of neurodevelopmental conditions that start in early life and persist into adulthood. Brain lesions in CP often affect the periventricular white matter. In the case of HCP the most common lesion type is unilateral infarction of middle cerebral artery, which supplies some cortical and subcortical areas believed to support executive function in addition to motor function (Bottcher and Flachs, 2010).

The brain injury in HCP is not only associated with motor impairment, but also with deficits of executive function (Bottcher and Flachs, 2010). Despite most children with HCP having an IQ within in the normal range (Bax and Gillberg, 2010), they have been demonstrated to have abnormalities of executive function that lead them to perform significantly worse on measures of attention, cognitive flexibility, setting goals and processing information compared to TD children (Piovesana et al., 2015, Bottcher, 2010, Bottcher and Flachs, 2010).These changes are observed regardless of the side of the lesion (Bodimeade et al., 2013a).

Children with hemiplegia show overall executive function deficiencies across all domains of executive function (Anderson et al., 2010, Bodimeade et al., 2013b). Everyday functioning relies on EF, it reinforces the ability to obtain new skills and learn new information and apply them to the world. It also helps to develop functional independency (Whittingham et al., 2014).

Many studies have reported a relationship between executive function and motor performance in TD children (Cameron et al., 2013). Abnormality of executive function impacts on the ability to plan and execute movement, to focus attention on main features of the environment, to learn from experience, to solve problems (Shaheen, 2013) and to coordinate movement (Piek et al., 2004).Thus impairment in EF will compound motor impairment and increase the disability of children with cerebral palsy.For these reasons it is important to include interventions to improve executive function as part of the overall therapy program for these children.

Using video games to deliver physical therapy programs for children with cerebral palsy has been showed to be effective in improving a wide range of motor impairments such as balance, gait and upper limb function (Bonnechère et al., 2014, Zoccolillo et al., 2015).The results of the previous study (see chapter 4) showed that it was possible to enhance attention (CTR) and memory (SSP) in TD children by playing action video games.

Recent reviews of studies investigating children with cognitive impairment, particularly Attention Deficit Hyperactivity Disorder, reported that it is possible to enhance different domains of executive function including working memory, attention skills, speed of processing information, using computerized cognitive training, virtual reality training and serious gaming (Van Heugten et al., 2016). Computerized working memory training such as Cog-Med and Jungle Memory, were shown to improve working memory in healthy children and adults (Melby-Lervåg and Hulme, 2013). Another review investigated the effect of Computer-Based Cognitive Retraining, Virtual Reality training and Non-Invasive Brain Stimulation to improve working memory in acquired brain injury such as stroke and head injury in adults (Spreij et al., 2014).They concluded there was evidence of significant improvement of the memory function after training.

In this study, the main aim is to undertake a preliminary study to see if action video games can also be used with the specific aim of improving executive functions in children with cerebral palsy; and whether any improvement is reflected in increased motor function of the hand and upper limb.

Aims

Aim 1: To compare executive function ability between children with HCP and TD children.

Aim 2: To undertake a pilot study comparing the effect of playing action video games on executive function, comparing the response of children with HCP and TD children.

Aim 3: To determine if improvement in executive function is reflected in increased motor ability of the upper extremity.

5.2 Method

5.2.1 Participants

Children with Hemiplegic Cerebral Palsy Group (HCPG): Children aged 8-12 years with a confirmed diagnosis of HCP were recruited from the rehabilitation centers in the Disabled

Children's Association, Prince Sultan Rehabilitation Center and King Fahad University Hospital in Dammam, Saudi Arabia.

The exclusion criteria were:

- severe visual and/or hearing impairment,
- an IQ< 70,
- severe behavioural problems,
- a change or planned change in their medication during the study period or in the 3 months preceding the study,
- a medical or surgical intervention for the upper limb such as Botulinum toxin therapy or musculoskeletal surgery during the study period or in the3 months preceding the study.

Typically developing children: The children who participated in the video game training study and played AVGs (AVGTG), reported in Chapter 4 section 4.2.7.1 page 67, provided the comparative data.

5.2.2 Study design

This study is a pilot study and we followed the MRC guidelines for pilot studies (Craig et al., 2006).This was an open study. All the children with cerebral palsy played action video games and were aware of the objectives of the study. Their data were compared with data from TD children playing AVGs as described in Chapter 4.

5.2.3 Apparatus, Video Game Training and Monitoring Method.

The AVGs loaded onto the Nvidia Shield Portable Console, which have been described in detail in Chapter 4 section 4.2.3 page 66, were also used in this intervention study. Children with HCP were asked to play action video games for one hour per day to complete a minimum of 50 hours of play over 8 weeks.The dates and duration of game play during the intervention were recorded using the video game training diary.

5.2.4 Outcomes for children with Hemiplegic cerebral palsy

All the assessments summarized below are described in detail in Chapter 2 section 2.5 page 29. All assessments were undertaken by me. The assessments took place in a quiet therapy room in the rehabilitation departments where the children were recruited. Each child was assessed two times, at baseline (pre-training) and after completing video game training (post-training). Each of these assessments was undertaken over two different sessions no more than 5 days apart. Each session took between 50-70 minutes.

Tests of Executive Function

All children undertook assessments of executive function, using the CANTAB.The Executive Function Tests were MOT, BLC, SWM, CRT, SSP and SST tests

IQ Assessment

The Arabic version of Stanford Benit Scale of intelligence was used to obtain a global IQ score.

Assessments of hand and upper limb function.

The following assessments were undertaken: Tyneside 9 holes Pegboard, CAHAI, MA2and the AHA.

Video-game Play Data

At the end of the baseline assessment, the Video-Game Play questionnaire was given to the children with HCP and their parents to complete. Children who reported playing action video games or not playing video games at all over the past 6 months were excluded from the training study.

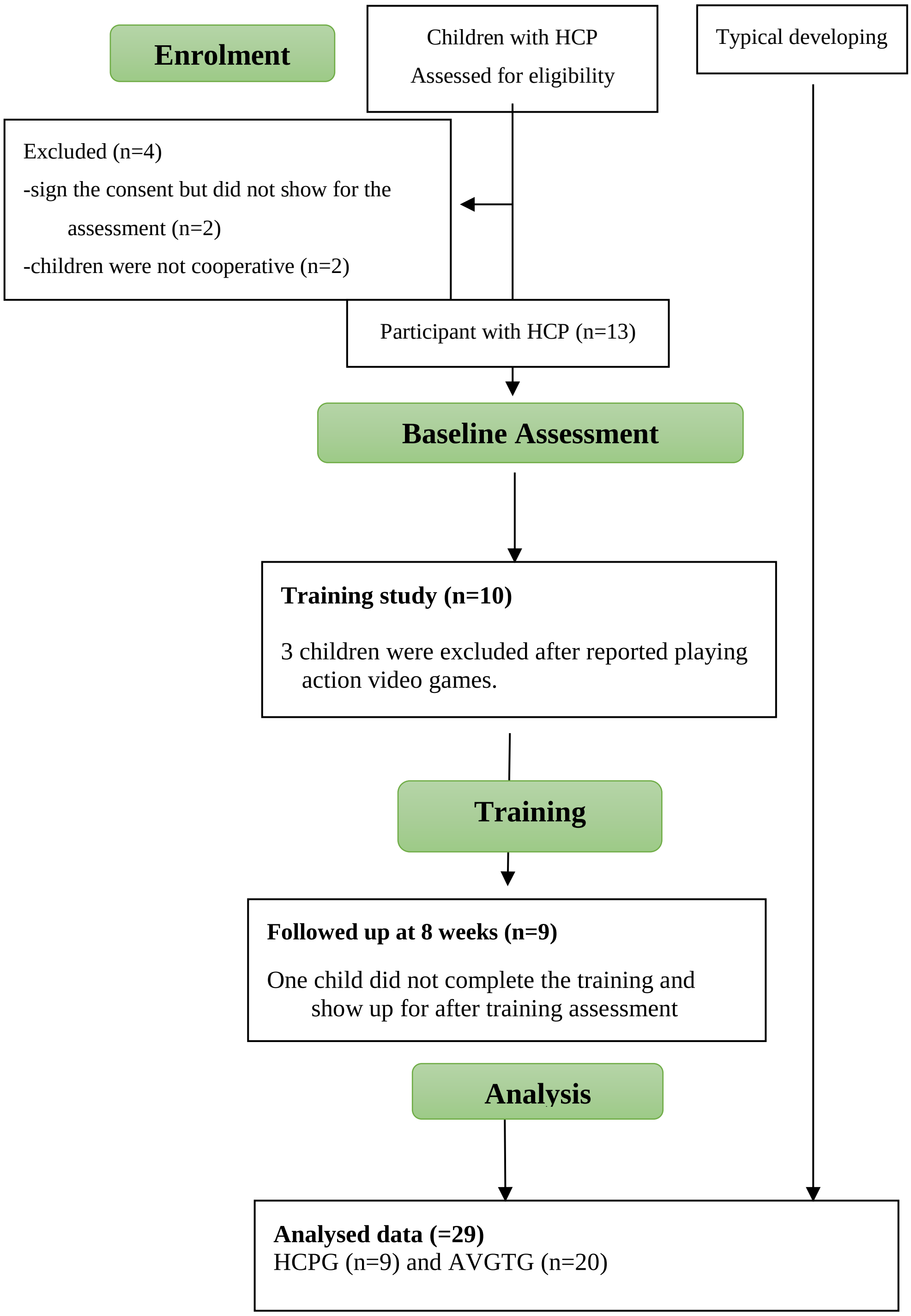
5.2.5 Statistical Analysis

All data analyses were performed using SPSS 15 (SPSS Inc, Chicago, Illinois, USA).Data was normally distributed. Significance was set at 0.05, with full Bonferroni correction for multiple comparisons.

i. Independent sample T-tests was implemented to investigate age, IQ, hours of game play and baseline EF differences between groups.
ii. To assess the effects of training a General Linear Model Repeated Measures Analysis of Variance (ANOVA) was used with Greenhouse-Geisser correction if required. *Time* (Pre/Post Training,) was the within-subject factor; *Group* (TD /HCP children) was the between-subject factor and *Total game play training time* was a covariate

5.3 Results

5.3.1 Participants Flow and characteristics



9 hemiplegic children completed the training program. The characteristics of the participants are summarized in Table 5-1.

Table 5-1: HCPG characteristic

Participant	Age (years)	IQ	Gender	Hemiplegic side
1	8.00	109	Boy	Right hemiplegia
2	8.17	97	Girl	Left hemiplegia
3	8.42	106	Boy	Right hemiplegia
4	9.17	103	Boy	Right hemiplegia
5	9.75	94	Girl	Left hemiplegia
6	10.50	97	Girl	Left hemiplegia
7	10.50	94	Girl	Right hemiplegia
8	10.91	83	Girl	Right hemiplegia
9	11.91	91	Girl	Right hemiplegia
mean ± SE	9.7±0.45	97±2.66		

There were no differences in age, IQ or duration of game play during the intervention between the two training groups (Table 5-2).

Table 5-2: Participants' characteristic

	AVGTG	**HCPG**	**df**	**T**	***p**
n	20	9			
Age (yrs.) mean ± SE	10.55 ±0.34	9.70 ±0.45	27	1.51	0.14
IQ mean ± SE	104.8 ±2.81	97.1 ±2.66	27	1.68	0.10
Hours of game play during intervention mean ± SE	66.60 ±10.92	43.89 ±2.49	27	1.37	0.18

* comparison between AVGTG and HCPG at baseline

There were significant differences for EF baseline scores between HCPG and AVGTG, with the HCPG having poor scores than the AVGTG (Table 5-3).

Table 5-3: Comparison of EF between TD children and children with HCP

EF Test		AVGTG	HCPG	df	F	*p
MOT mean±SE	Reaction time	692±21	820.±50	27	1.73	**<0.001**
	Accuracy	10.23±0.49	13.2±0.82	27	0.30	**0.003**
SSP mean±SE	Span length	5.45±0.25	4.0±0.23	27	1.72	**0.002**
	Total error	13±1.28	10.67±1.12	27	1.141	0.266
SWM mean±SE	Total errors	39.8±4.1	68.22±3.42	27	1.91	**<0.001**
	Mean time to response	25.72±0.79	32.12±0.95	27	0.16	**<0.001**
CRT mean±SE	Latency to correct response	496±18	787.94±39.88	27	2.86	**<0.001**
	Number of correct response	99.2±0.3	94.4±1.57	27	23.34	**0.016**
BLC mean±SE	Latency to correct response	676±21	887.8±30.88	27	0.089	**<0.001**
	Total correct	40±0	39.67±0.24	27	28.5	0.195
SST-SSRT mean±SE	Response inhibition	297±17	403±36	27	1.62	**0.006**

* comparison of EF between AVGTG and HCPG at baseline.

For the 29 participants at Baseline, there were significant correlations between the times to complete the Tyneside Peg Board and the Tests of EF tabulated in Table 5-4 below.

Table 5-4: correlations between BCT and EF

EF test	Pearson Correlation	P
MOT Latency (ms)	0.51	0.005
BLC Correct Latency (ms)	0.55	0.002
CRT correct latency (ms)	0.53	0.003
SST SSRT (last 21 sub-blocks ms)	0.40	0.032
SST SSRT (last half ms)	0.458	0.012

5.3.2 Duration of video game play

The video game play questionnaires for children with HCP who completed the baseline assessment (13 children), reveal that children with HCP play video games for a total duration that is similar to TD children. However, children with HCP play AVG significantly less than TD children, and spend more time playing NAVG. Since in TD children boys play significantly longer durations of AVG, I repeated the analysis looking at boys only. A similar pattern of duration was revealed with HCP boys playing significantly fewer hours of AVG, but boys with HCP also played all genre of video games for approximately one third of the duration of TD boys Table 5-5.

Table 5-5: Comparison of age and duration of game play by genre between TD children and children with HCP.

Genre	**All Subjects**				**Boys only**			
Group	***TD***	***HCP***	***F***	****p***	***TD***	***HCP***	***F***	*****p***
N	154	13			66	7		
Age Mean ±SE	9.2 ±0.16	9.5 ±0.43	0.19	0.66	9.25 ±0.24	8.8 ±0.59	0.23	0.63
Duration of genre play (hrs/week)								
Action mean ±SE maximum	7.2 ± 0.6	1.95 ±1.16	6.66	**0.01**	10.9 ± 0.8 26.5	3.6 ±2.0 13.8	8.81	**0.004**
Social/ Strategy mean ±SE maximum	7.2 ±0.5	10.6 ±1.99	2.84	0.09	5.2 ±0.8 31.2	7.9±2. 7 23.2	1.02	0.31
Mixed mean ±SE maximum	1.6 ±0.7	1.0 ±0.57	2.01	0.16	1.4 ±0.4 14.5	1.8±1. 0 6.3	2.08	0.16
Total mean ±SE maximum	16.8 ±3.2	13.6 ±1.84	2.73	0.10	20.2 ±3.1 39.6	13.5 ±2.8 23.2	8.27	**0.005**

***** comparison of age and duration of game play by genre in hours per week, the data are presented for all children

** comparison of age and duration of game play by genre in hours per week, the data are presented for boys only

5.3.3 Effect of action video game training on executive function tasks

There were main effects for: (1) Group (TD versus HCP) for all EFs with TD children having higher executive function pre and post training than those with HCP. (2) Time (pre and post training) for SWM (time), and SSP and a trend for CRT (mean correct latency) with EFs showing an improved test score after training for both groups see (Table 5-.

There were Group*Time interactions for SWM errors, CRT commission and CRT correct. Paired T tests did not reveal a significant effect of training for AVGTG for these EFs in typically developing children in contrast to the HCP group where there were significant improvements for all three (Figure 5-1).

Table 5-6: Effect of action video game training on executive function tasks.

EF	AVGTG		HCPG		Group		Time		Group*Time	
	Pre	Post	Pre	Post	F	p	F	p	F	p
	20	20	9	9						
SWM (errors) mean±SE	39.8 ±4	39.8 ±4	68.2 ±3.4	59.3 ±3.3	15.39	**<0.001**	1.22	0.179	2.88	**0.050**
SWM (time s, mean±SE)	25.7 ±0.8	24.4 ±0.9	32.1 ±0.9	29.9 ±1.4	14.6	**<0.001**	5.78	**0.012**	0.587	0.225
CRT (Latency ms, mean±SE)	496 ±18	470 ±20	787 ±39	722 ±53	52.7	**<0.001**	2.46	0.064	0.789	0.761
CRT (commission)	0 ±0	0.1 ±0.1	1.6 ±0.8	0.2 ±0.2	11.5	**0.001**	1.93	0.088	5.641	**0.012**
CRT (correct)	99.2 ±0.3	98.5 ±0.4	94.4 ±1.6	97.1 ±0.92	18.4	**<0.001**	0.63	0.277	5.794	**0.016**
SSP (n) mean±SE	5.5 ±0.3	6.2 ±0.3	4.0 ±0.2	4.7 ±0.2	10.8	**0.001**	6.89	**0.007**	0.417	0.524

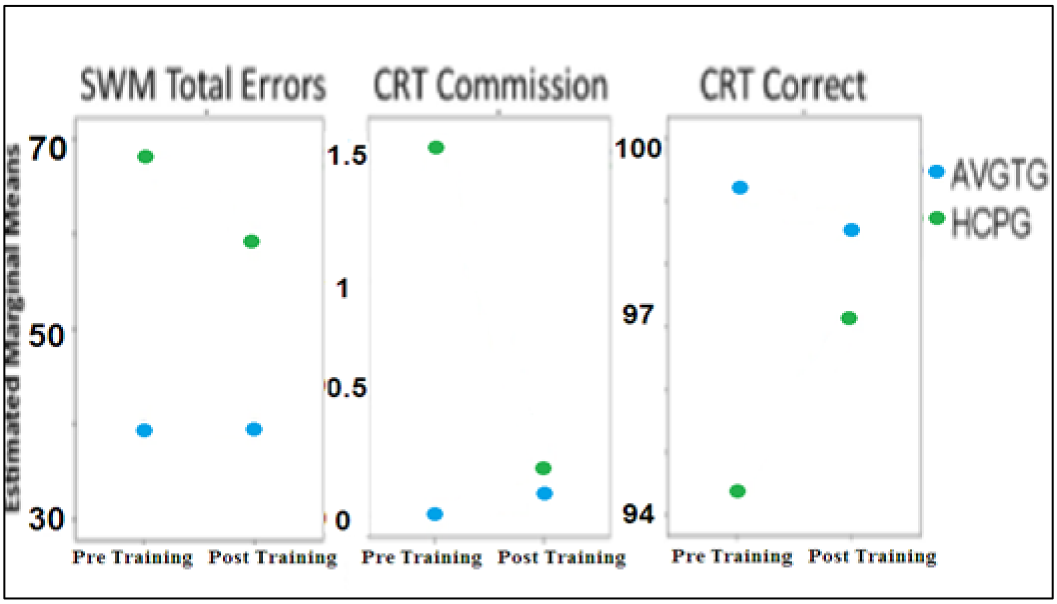


Figure 5-1: Effect of training on SWM and CRT

5.3.4 Upper limb function

5.3.4.1 Tyneside 9 holes pegboard

There was no main effect for Time nor a Time*Group interaction for the BCT.

5.3.4.2 Chedoke Arm and Hand Activity Inventory, Melbourne Assessment and Assisting Hand Assessment.

No subject achieved a difference greater than the minimal detectable difference for any of the testes of upper limb function. The range in differences pre and post training for MA2 was -4 to +1; for the AHA was -4 to +1 and for the CAHAI was -4 to 0.

5.4 Discussion

Our results showed that test scores for EFs of children with HCP were significantly lower than typically developing children on all executive domains tested in this study including attention controls well as working memory. This finding was consistent with other previous research comparing children with CP (including HCP) with typically developing children (Bodimeade et al., 2013b, Bottcher and Flachs, 2010, Bodimeade et al., 2013a). (Bodimeade et al., 2013b)compared children with HCP with typically developing children in a similar way to the current study. He examined all domains of executive function using the Executive Control System Model (Anderson Model). Despite using different assessment tests, they also found that scores for attention, cognitive flexibility (including working memory), goal setting and information processing were significantly lower. Many studies have revealed that IQ and EF are highly correlated in children with low IQ (Anderson et al., 2010, Bodimeade et al., 2013b, Whittingham et al., 2014). In this study we selected children with HCP who had IQs within the normal range but still observed impaired executive function.

Previous studies have highlighted the important of executive function on everyday activities for children with HCP (Whittingham et al., 2014). Even so, evidence-based interventions aiming to improve EF for children with CP are lacking. Cognitive training programmes do, however, exist for other patient groups (Van't Hooft et al., 2007). studied a group of children with traumatic brain injury, attending a broad based cognitive training programme and found encouraging long-term effects on complex tasks of attention and memory. (Grunewaldt et al.,2013) found that a preschool version of the same computer-based working memory training programme seemed effective in preterm born very low birth weight children at age 5–6 years, not only on working memory tasks but also by having a generalizing effect regarding memory and learning. Both these groups of preterm children included some children with CP.

These observations are supported by studies that demonstrate that it is possible to improve executive function with targeted non game based interventions for healthy children and adults

(Melby-Lervåg and Hulme, 2013), children with cognitive impairment such as Attention Deficit Hyperactivity Disorder (Van Heugten et al., 2016) or in acquired brain injury such as stroke and head injury in adults (Spreij et al., 2014).

Previously (see chapter 3 and 4), we found that typically developing children who regularly played action video games had superior EF performance compared than with children playing only non-action video games and furthermore, action video game training enhanced working memory and attention. Our findings in this study extends the potential benefit of playing action video game on attention and working memory to children with HCP, were they showed a greater improvement in EF when playing action video games than did typically developing children. This may have been because children with HCP had much lower levels of performance in EF tests at baseline and thus much greater potential for improvement.

It is important to note that the CRT allows measurement of attention independent of motor speed by measuring error rates rather than speed of response. Thus children with HCP did not react faster to the stimuli, but they improved their attention to the direction of the arrows and also reduced the commission errors. Similarly spatial working memory; SWM was demonstrated to be improved by a decrease in the number of errors choices; a measure also independent of speed or of motor function.

Children with HCP do play video games as much as typically developing children. However, they play action video games much less than typically developing children, even when we looked at boys only. It is possible that commercial action video games are too demanding in terms of speed of response for children with HCP and that’s why they are not motivated to play them.

These observations together with our study suggest that action video games may have a role in increasing executive function in children with HCP. Bespoke action video games designed specifically for children with motor impairment are likely to be required in an intervention program.

This study was limited by the sample size of hemiplegic children. It was very challenging to find hemiplegic children in physical therapy departments above age 6 years old. In all the rehabilitation departments that I recruited hemiplegic children from, they discharged children when they reach 6 years old, despite their continuing disability. Home based therapy, which can be self-managed using video games, is likely to make a major contribution to providing continuing therapy program for these children.

Upper limb motor function tested by four hand assessments, Tyneside pegboard test, CAHAI, MA2 and AHA showed that there was no differences pre and post-training. However, this may reflect the relatively short period of training in our intervention. It is possible that with longer training an effect might be observed. Previous studies of the efficacy of upper limb interventions for HCP reveal that treatment amount and frequency (dosage) may be the key to successful training (Sakzewski et al., 2014, Gordon et al., 2011).Future research examining the relationship between the enhanced EF following an intervention using action video game and upper limb motor function, should address longer video game training time.

5.5 Summary

Children with HCP showed lower EF ability compared to typically developing children, despite having similar IQs. This study provides preliminary evidence that action video game training can improve EF, particularly attention and memory in children with HCP.Specially designed games that have all the features of AVGs, but are appropriate for children and responsive to the level of motor ability in children with CP, could provide a promising intervention to improve EF in children with HCP.Future research using a randomised, double blinded, controlled study design is needed, with a larger sample size to investigate whether action video game training should be included in rehabilitation programs for children with HCP.

Chapter 6. Dexterity Measured Using the Tyneside 9 Holes Pegboard

6.1 Introduction

Hand motor function or manual dexterity is the ability of the individual to coordinate hand and fingers movements in order to manipulate small objects in a timely manner. It is an important motor function across the life span. Skill in upper limb function affects all activities of daily living (such as eating, grooming, and typing), involvement in leisure activity and work performance (e.g., joiners, secretaries, surgeons).Therefore it has a major impact on quality of life (Wang et al., 2015). Fine hand motor skills were found to be correlated with academic activities and handwriting quality in typically developing children (Volman et al., 2006). Impairment of hand motor function has been demonstrated to be the cause of major disability in children with HCP (Baranello et al., 2016).

There are many assessment tests of manual dexterity, most of them are standardized and widely used for children (Duff et al., 2015).The most commonly used tests for children are Box and Block, Grooved Pegboard Test, Jebsen Taylor Hand Function Test, Functional Dexterity Test, Purdue Pegboard and the Nine Hole Peg Test, (Duff et al., 2015). Regardless of the measuring purposes of the tests (placing, displacing, manipulating, or turning); the main measuring outcome is the completion time in seconds or minutes.

The Nine Hole Peg Test evaluates important fine motor functions, including reaching, grasping, carrying, inserting, and releasing with the time taken to complete these tasks as the outcome measure (Smith et al., 2000). This test has been validated in a study population of 826 children aged between 5 and 10 years. High inter-rater and test-re-test reliability was established, and strong construct validity was obtained (Smith et al., 2000).

Manual dexterity tests have been widely accepted as a useful evaluating method. Despite their widespread use, there were no reports of the effect of the strategy used to complete neither a task on completion time nor whether different groups of children (e.g. different age groups, those with cerebral palsy) may adopt different strategies.

We mentioned earlier (chapter 5, section 5.1 page 64) that there is the relationship between motor function and executive function in the form of planning and executing movement, learning from experience and solving problems, and as a consequence abnormality in executive function can have a detrimental effect on the outcome of hand motor function assessments.

In this study we aimed to consider for the Tyneside Peg Board the effect of:

1- Peg transfer strategy on completion time performance.
2- Gender, age, peg's size on completion time and strategy.
3- Video game genre played by children on strategy and completion time.

We also aimed to compare completion time and peg transfer strategy between typically developing children and children with HCP.

6.2 Method

6.2.1 Participants

The 154 typically developing children aged from 6-12 years, who had participated in the cross-sectional study (see chapter 3) and 13 hemiplegic children age from 6-12 years who participated on training study (see chapter 5) were included in this study.

Additional data of 134 children (74 hemiplegic children age 6-19 years and 60 typically developing children age 13-18 years) collected by Professor Eyre's research group in other research studies were also included in the analysis.

6.2.2 Study Design

This study was designed as a cross-sectional study. It is comprised of 2 parts:

1. To study the effect of different variables including video game play genre on the Tyneside Nine Hole Pegboard Test board completion time and peg transfer strategy in 154 typically developing children.
2. To compare Tyneside Nine Hole Pegboard Test board completion time and peg transfer strategy of 214 typically developing children and 87 children with HCP.

6.2.3 Hand Motor Function Assessment

Details concerning the Tyneside Nine Hole Pegboard Test and the measurement of BCT and PTS can be found in (Chapter 2 Methods section 2.5.3.4 page 33).

6.2.4 Statistical analysis

All data analyses were performed using SPSS 15 (SPSS Inc, Chicago, Illinois, USA).Data was normally distributed. Significance was set at 0.05, with full Bonferroni correction for multiple comparisons.

i. To assess the effect of different variables on BCT, a General Linear Model Analysis of Variance was used with Greenhouse-Geisser correction if required. Between subject factors of Game Genre (AVGPs/NAVGPs), Gender (boys/girls), Handedness (dominant hand/non dominant hand), Peg size (Large/Medium/Small) and Pegs Transfer Strategy (SM/NSM) were used. Completed Year of Age was included as covariate.

ii. To assess the effect of different variables on PTS, a General Linear Model Analysis of Variance was used with Greenhouse-Geisser correction if required. Between subject factors of Game Genre (AVGPs/NAVGPs), Gender (boys/girls), Handedness (dominant hand/non dominant hand), and Peg size (Large/Medium/Small) were used. Completed Year of Age was included as covariate.

iii. To assess the differences between typically developing children and children with HCP on BCT and PTS, a General Linear Model Analysis of Variance was used with Greenhouse-Geisser correction if required. Between subject factors of Diagnosis (TDC/ HCP) was used.

6.3 Results

6.3.1 Subjects

For (i) and (ii) above data of 154 typically developing children (66 boys; 87 AVGPs; mean age 9.2 years range 6.0-12.9 years) were analysed.

6.3.2 Board Completion Time

There were main effects for *Age*, with BCT decreasing with age; *Gender*, with girls having shorter BCT than boys; *Handedness*, with BCT shorter when using the dominant hand; *Game Genre*, with AVG players having short BCT than NAVG players; and *PTS*, with strategic peg moves having shorter BCT than not-strategic peg moves. Peg size did not significantly influence BCT. There were no significant interactions (Table 6-1).

Table 6-1: Board Completion Time; comparison between the various independent variables.

variables		**Mean ± SE**	**F**	**df**	**P**
Pegs Transfer Strategy	Strategic Move	13.87±0.06	4.99	1	**0.026**
	Not-Strategic Move	14.3±0.01			
Gender	boys	14.2±0.11	23.68	1	**<0.001**
	girls	13.68±0.08			
Game Genre	AVGPs	13.07±0.08	54.83	1	**<0.001**
	NAVGPs	15.09±0.08			
Age	6	17.57±0.17	1186	1	**<0.001**
	7	15.48±0.15			
	8	14.62±0.2			
	9	12.75±0.19			
	10	13.31±0.16			
	11	11.98±0.23			
	12	11.39±0.17			
Peg's size	Large	13.64±0.12	2.27	2	0.10
	Medium	14.01±0.11			
	Small	14.09±0.12			

6.3.3 Pegs Transfer Strategy

There were main effects for *Gender*, with girls being more likely to adopt a strategic approach to board completion; and *Game Genre*, with AVG players more likely to adopt a strategic approach to board completion. There were no main effects for Handedness, Peg size and Age. There were no significant interactions (Table 6-2). There was a significant correlation between BCT and PTS, r= -0.224, n= 301, p= <0.001.

Table 6-2: Pegs Transfer Strategy; comparison between different independent variables.

variables		**Mean ± SE**	**F**	**df**	**P**
Gender	boys	0.45±0.017	38	1	**<001**
	girls	0.58±0.011			
Game Genre	AVGPs	0.55±0.011	17.5	1	**<001**
	NAVGPs	0.47±0.17			
Age	6	0.5±0.021	1.728	1	0.2
	7	0.45±0.019			
	8	0.57±0.023			
	9	0.44±0.028			
	10	0.61±0.02			
	11	0.52±0.028			
	12	0.52±0.02			
Peg's size	Large	0.49±0.17	0.6	2	0.56
	Medium	0.51±0.17			
	Small	0.52±0.17			

Subjects completed 12 boards in a fixed sequence (Board number). Firstly, they completed 4 boards with large pegs; secondly they completed 4 boards with medium pegs; and thirdly they completed 4 boards with small pegs. To asses if there was a change in PTS with board number, we used a General Linear Model Repeated Measures ANOVA; within subject factor *Board Number* and between subjects factor *Game Genre.* There was a main effect of *Game Genre,* with AVGPs being more strategic and a *Genre*Board* interaction with AVGPs becoming more strategic with board number whilst NAVGPs showed no change in strategy with board number (Table 6-3,Figure 6-1).

Table 6-3: comparison between video game genres; PTS among different board number

	Large pegs **Mean ± SE**	Medium pegs **Mean ± SE**	Small pegs **Mean ± SE**	**F**	**df**	***P**
AVGPs	0.497±0.38	0.517±0.35	0.575±0.38	3.95	2	**0.05**
NAVGPs	0.526±0.42	0.507±0.43	0.522±0.38	0.01	2	0.94

* Comparison of PTS between different board number in a fixed sequence (large, medium than small pegs).

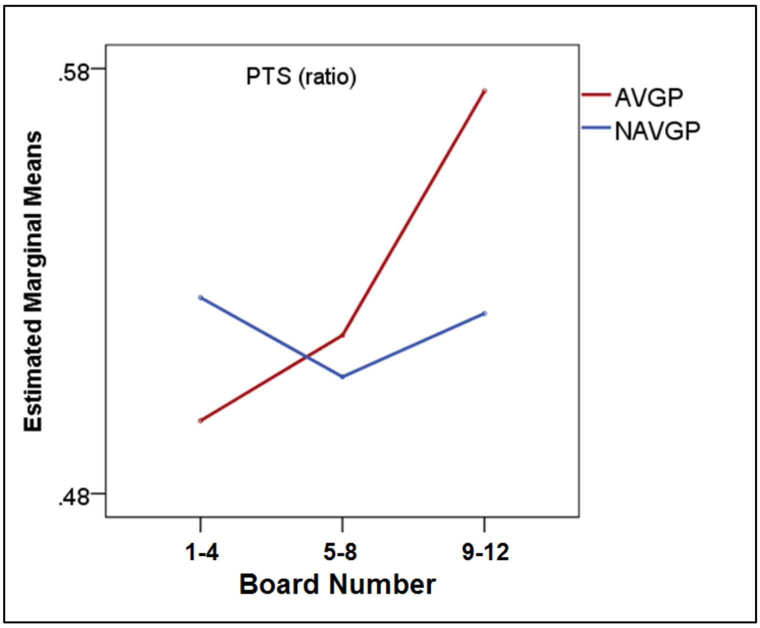


Figure 6-1:Effect of game genre on learning strategy

6.3.4 Comparison between TD children and children with HCP

Data from 301 children (214 typically school aged developing children, mean age 10.89 years range 6-19 years and 87 school aged children with HCP mean age 10.62 years range 6-19 years) were included in the analysis of this part of the study. There was no significant difference in age between typically developing and children with HCP (p=0.49).Table 6-4shows the age and gender distribution of the subjects.

Table 6-4: Subject's Characteristics

	TD children		Total number	children with HCP		Total number
Age group	Boys	Girls		Boys	Girls	
6	10	13	23	4	0	4
7	10	14	24	4	5	9
8	11	13	24	12	3	15
9	10	12	22	9	4	14
10	10	13	23	5	9	14
11	7	10	17	3	3	6
12	8	13	21	3	2	5
13	1	2	3	4	2	6
14	3	3	6	2	1	3
15	8	6	14	1	1	2
16	12	7	19	2	0	2
17	4	4	8	1	0	1
18	0	2	2	3	1	4
19	1	7	8	2	1	3
Total	95	119	214	55	32	87

There was a main effect of *Diagnosis* on BCT and PTS when subjects were completing the boards with their non-dominant hand, with typically developing children being faster and more strategic than children with HCP (Table 6-5).

Table 6-5: comparison between different diagnosis on PTS and BCT

	TD children	**children with HCP**	**dr**	**F**	***P**
PTS mean ±SE	0.61±0.02	0.45±0.03	1	16.4	**<0.001**
BCT mean ± SE	150.43±6.5	440.8±10.49	1	148.83	**<0.001**

* Comparison between TD children and children with HCP based on the data of 12 pegboards (6 boards completed using the dominant hand and 6 board using non-dominant hand)

There was also a main effect for *Diagnosis* on BCT and PTS when subjects were completing the boards with their dominant hand, with typically developing children (TDC) being faster and more strategic than children with HCP (

Table 6-6)

Table 6-6: Comparison between diffrenet diagnosis on PTS and BCT using the dominant hand

	TD children	children with HCP	dr	F	*P
PTS mean ±SE	0.64±0.02	0.46±0.04	1	19.47	**<0.001**
BCT mean ± SE	73.84±1.42	98.32±2.64	1	98.32	**<0.001**

* Comparison between TD children and children with HCP based on the data of 6 pegboards completed using the dominant hand only

6.4 Discussion

Dexterity is an important component that therapists must consider during a comprehensive assessment of upper extremity function (Grice et al., 2003). One of the most commonly tools used for assessing dexterity is the Nine Hole Peg Test, which was originally introduced in 1971 as part of a study on strength and dexterity (Kellor et al., 1971).

Studies using the nine hole pegboard have demonstrated that dexterity improves with age through childhood; regardless of age group, females complete the nine hole pegboards faster than males; finally dominant hands are more dexterous than non-dominant hands (Smith et al., 2000, Poole et al., 2005, Grice et al., 2003, Bala and Katić, 2009, Wang et al., 2015, Duff et al., 2015, Morley et al., 2015)

Our results using the Tyneside Pegboard for the BCT are consistent with these findings. In addition to measuring the time needed to complete the board test, we were also able to record and analyse the pattern of peg removal and insertion. This enables us to identify gender differences in these patterns. According to our definition of strategic moves (chapter 2 section 2.5.3.4 page 34), we found that the BCT was significantly shorter when a strategic approach to the peg moves was adopted. Females were more likely to adopt a strategic pattern but this does not explain the significantly short BCT observed in females since both gender and the pattern of peg removal were identified as independent main effects influencing BCT.

We found that for typically developing children, AVGPs were more likely to adopt a strategic approach to the peg transfer as well as being faster on BCTs than NAVGPs. AVGPs were also more likely to move from a non-strategic approach to a strategic approach as they progressed through the peg boards, indicating an increased capacity to learn compared with NAVPs. Our result appears inconsistent with that of Adachi and Willoughby(Adachi and Willoughby, 2013)who found that adolescents who reported playing strategic video games showed increased problem-solving skills compared to action video game players. However, in our study AVGPs also played strategic video and were not exclusively playing AVGs games, as those studied by Adachi and Willoughby did. Adachi and Willoughby however report that AVG players progressively adapted their strategies in a trial-and-error manner, which is consistent with our observation that AVG players became progressively more strategic as they moved through the board sequence.

As a result of hand motor function impairment, children with HCP needed longer time to complete the Tyneside pegboard test with their non-dominant hand compared to typically developing children - this finding was expected. Our study also showed that children with HCP had longer BCTs, even when they used their less effected hand or dominant hand. This result is consistent with other studies that found that the function of both upper limbs is impaired in children with hemiplegia (Steenbergen and Meulenbroek, 2006, Steenbergen et al., 2013, Basu and Eyre, 2012). Children with HCP were also less strategic when moving the pegs compared to typically developing children, when using either hand.

Finally both typically developing children and those with HCP adopted the same strategy for moving pegs with their dominant (less affected hand) and their non-dominant or hemiplegic hand. This finding would support strategic planning for peg removal is part of generalised executive functioning rather than being part of the role of the motor cortex, where lateralised findings would be expected in children with HCP.

Chapter 7. General Discussion

7.1 Overall summary

More than four decades have passed since video games became widely available to the public and playing video games has become the most preferred past-time of choice for children and adults. Early video game studies indicated that action video game play enhances executive functions for the adult. However, there are very limited studies on children (Dye and Bavelier, 2010, Dye et al., 2009).

Based on previous studies (Green and Bavelier, 2003, Green and Bavelier, 2006a, Green and Bavelier, 2006b, Green and Bavelier, 2007, Green et al., 2012, Li et al., 2009, Li et al., 2010, Wilms et al., 2013, Blacker and Curby, 2013, Castel et al., 2005, Karle et al., 2010, Colzato et al., 2013, Cain et al., 2012, Cain et al., 2014, Wu and Spence, 2013, Oei and Patterson, 2013, Oei and Patterson, 2015, Dye and Bavelier, 2010, Dye et al., 2009), we had four specific hypotheses related to improvement of executive function after playing action video games by children. First, children playing action video games would have enhanced executive function, as had been showed in adults, compared with those playing only non-action video games. Second, children's who only played non-action video games would have enhanced executive function after a period of playing action video games. Thirdly, children with HCP would benefit from executive function training using action video games. Fourthly, hand motor function would improve as a result of improving executive functions.

7.2 Summary of Key finding

7.2.1 Effect of action video game on executive function of children

We found that children playing AVG have a superior executive functions of attention, memory, response inhibition and planning compared with children playing only NAVG (Algabbani et al., 2014) (see appendix H). These findings extend the findings in adult studies to cover children too. Furthermore, the executive functions of attention and working memory ability improved after a brief 3 month training period with action video games in TD children who had not previously played AVGs.

The training comprised 50 hours playing commercial AVGs that can be purchased from any video game store. The games were played unsupervised at home using a commercial video game console. This makes such training available to everyone at relatively low cost since children can be trained in their home without supervision from a therapist.

The finding of this and other studies of potentially beneficial effects of playing action video games should counterbalance societal concerns that playing action-based games may lead to increased aggressiveness and/or poorer academic performance(Anderson and Dill, 2000).In a recent study (Straker et al., 2014) discussed the evidence-based guidelines for the use of general electronic games by children. They reported that there are mixed concerns about the effect of video games on children's health and development, but they concluded that appropriate use of video game had been associated with positive effects on behavior and physical and psychosocial aspects of health.

7.2.2 Effect of action video game training on executive function and hand motor function for children with HCP

As expected, we found that the executive function of children with HCP was impaired when compared with TD children, matched for age and IQ. Since it has been demonstrated that EF is important for everyday life activities, including motor function, these findings emphasize the need for routinely assessing the EF of children with HCP during their initial assessment, before planning a rehabilitation program and the need to include EF training as part of that program if required.

Video games for motor rehabilitation were first used in rehabilitation programs for cerebral palsy more than 15 years ago (Tatla et al., 2015), and have been shown to improve a range of impairments such as balance, mobility, and upper limb function (Bonnechère et al., 2014). Children with HCP play video games as much as TD children, however, they play AVG significantly less than TD children. The pilot study revealed that it is possible to use AVG training for children with HCP and indicated that there might be positive effects. The pilot study showed that adding action video games to the rehabilitation program for children with HCP has promise as a rehabilitation intervention to improve executive. Our finding justifies a randomized double blinded trial with sufficient power to assess its effectiveness.

7.2.3 Tyneside9 holes Pegboard Test to measure hand motor function using both BCT and PTS outcomes measures

In this study, we found that, in addition to the pegboard test's conventional outcome measure, the time to complete the pegboard, the Tyneside9 Holes Pegboard Test was able to detect electronically the strategy used to transfer the pegs from one board to the other. Previous studies within our research group has demonstrated that this test is manageable by children with HCP who have an active grip in their paretic hand and is sensitive to change across the age range and deficits in hand function performance with either hand (Basu et al., 2012).My research demonstrates that this test is able to detect that children with HCP were less strategic when moving the pegs than TD children and it may also become a useful test assess the effect of interventions designed to improve executive functions.

7.2.4 Summary

The most significant finding of this study was that playing commercial action video games significantly improved executive function in children, compared to playing non-action video games. This result extends the results of earlier studies in adults to include children. While action video games offer much promise for improving executive function, limited research has explored its outcome benefits clinically. We believe that our findings are very relevant to applications in clinical and educational fields. Furthermore, it raises the potential of including action video game training as a therapeutic intervention for children with HCP.

7.3 Future work

From our study, different lines of research can be pursued:

1- Children with HCP are at high risk of attention deficit disorder with or without hyperactivity and working memory deficits(Løhaugen et al., 2014).Recent studies suggested that the decrease of executive function ability for children with HCP lead to difficulties in everyday life (Whittingham et al., 2014, Bodimeade et al., 2013a, Bodimeade et al., 2013b).Even so, there is a lack of interventions aiming to improve deficits in their executive function. Our pilot study with children with HCP indicated the possibility of enhancing attention and working memory using commercial action video games training. Children were able to complete action video game training using these commercial video games. These findings should be pursued with a longitudinal randomized placebo controlled, double-blinded trial, with larger sample size, to investigate the effect of playing action video game on improving executive function.

Recruiting children with HCP was the major challenge for this study. For a future study, we need to add more recruitment centers and methods for identifying children. Examples include the use of advertisements, such as flyers posted in the rehabilitation centers, pediatric clinics, or neurology clinics; social media, such as Facebook or Twitter; and clinical networks, such as another therapists. Further investigations can also be carried out in this larger sample to study the relationship between executive function and hand motor function and the possible benefit of improving motor function through the improvement of executive function.

2- Following the observation of enhancing executive function (attention and working memory), after action video game training, a larger randomized double blinded training trail can be conducted to have sufficient power to investigate whether there are also changes in other aspect of executive function (e.g. planning and solving problems, response inhibition, and visual short-term memory).In our study, we recruited children who didn’t play action video game but they played other game genres such as strategic, social, or role play. Some researchers (Adachi and Willoughby, 2013, Steinkuehler and Duncan, 2008) suggested that different game genres may enhance different aspects of executive function such as strategic games may improve problem-solving skills. The best way to study the effect of different types of game genre on executive children is by recruiting children who do not play any video games and then randomly allocating them to training with different game genres. Unfortunately, this is not possible because video games are becoming a part of everyday lives. An option may be to recruit children who only play video games for a brief period each week.

3- According to our results, the Tyneside 9 holes pegboard is a promising test to detect strategic planning for fine hand movements. For future work, the validity of this observation can be confirmed by correlation with other validated strategic and planning assessments such as SOC.

Chapter 8. Appendix

8.1 Appendix A: Information Sheet for the Parents

Project title: comparison between Executive Function and hand motor function between Typically Developing children and children with Hemiplegic Cerebral Palsy.

I would like to invite your child to participate in a research study. Please read this information sheet. I will answer any questions to help you decided whether you want your child to participate.

Thank you for reading this.

Purpose of the research

Studies suggest that children with hemiplegic cerebral palsy have a higher incidence of impairments of executive function than age matched controls. Deficits in executive function will compound their movement disorder by impacting on the ability to plan and execute movements, focus attention on salient features of the environment, learn from experience, solve problems, communicate and socialize. In this study I will compare the executive function and hand motor function between typically developing children and hemiplegic children and study the effect of some children life styles on executive function and hand motor function.

Participants

Children aged from 6-12 years, both sex, IQ>70 and have no behavioural problems or severe visual or hearing impairments.

Typically developing children: no history of neurological problem.

Children with Hemiplegic Cerebral Palsy: confirmed diagnosis of congenital hemiplegic cerebral palsy.

Assessments

I will assess the children in their school during school time or in the rehabilitation department for hemiplegic children. The assessment will be completed in two sessions, no more than 5 days between them.

Executive function assessment:

I will use the Cambridge Neuropsychological Test Automated Battery (CANTAB), which uses a Touch-screen technology to assess executive function. Tests will assess children attention, memory, planning, inhibition ability and solving problems.

Hand motor function tests

The Chedoke Arm and Hand Activity Inventory (CAHAI): The CAHAI contains 10 real-life items (Open jar of coffee, Use the phone and dial, Draw a line with a ruler, Pour a glass of water, Wring out washcloth, Do up five buttons, Dry back with towel, Put toothpaste on toothbrush, Cut medium resistance putty and Zip up the zipper).

Tyneside9 hole pegboard test: this test will be used to assess unilateral speed and dexterity of hand motor function. I will ask your child to transfer different size pegs from one board to the other.

Additional hand motor function test for hemiplegic children

I will video tape your child while performing these tests.

Melbourne Assessment (MA2): I will ask your child to do some activities (such as grasp, put things on container and reach to different direction).

Assisting Hand Assessment: I will ask your child to play a card game, which requires hand activities to proceed to the end of the game.

By the end of the assessment I will ask you to fill a questionnaire regarding some aspect of your child' lifestyle.

Risks for the research

There are no risks to participate in this study.

Privacy of participants

Individual participants' personal information will not be discussed with anyone. Each child will have a research number ID; the data will refer to the research number ID and not the child name. I will use the data collected for the research purposes only.

Contact for more information

Mrs Maha Al-GabbaniTel: 0500599503email: malgabbani@ksu.edu.sa

8.2 Appendix B: Information Sheet for the parents (Training Study)

Project title: comparison between Executive Function and hand motor function between Typically Developing children and children with Hemiplegic Cerebral Palsy.

I would like to invite your child to participate in a research study. Please read this information sheet. I will answer any questions to help you decided whether you want your child to participate.

Thank you for reading this.

Purpose of the research

Studies suggest that children with hemiplegic cerebral palsy have a higher incidence of impairments of executive function than age matched controls. Deficits in executive function will compound their movement disorder by impacting on the ability to plan and execute movements, focus attention on salient features of the environment, learn from experience, solve problems, communicate and socialize. In this study I will compare the executive function and hand motor function between typically developing children and hemiplegic children and study the effect of some children life styles on executive function and hand motor function.

Participants

Children aged from 6-12 years, Girls, IQ>70 and have no behavioral problems or severe visual or hearing impairments.

Typically developing children: no history of neurological problem.

Children with Hemiplegic Cerebral Palsy: confirmed diagnosis of congenital hemiplegic cerebral palsy, with a stable medical condition.

Assessments

I will assess the children in their school during school time or in the rehabilitation department for hemiplegic children. The assessment will be completed in two sessions no more than 5 days between them. Children will be assessed two times; before starting the training program and after completing the training (after 8 weeks).

Executive function assessment:

I will use the Cambridge Neuropsychological Test Automated Battery (CANTAB), which uses a touch-screen technology to assess executive function. Tests will assess children attention, memory, planning, inhibition ability and solving problems.

Hand motor function tests

<u>Tyneside9 hole pegboard test:</u> this test will be used to assess unilateral speed and dexterity of hand motor function. I will ask your child to transfer pegs from one board to the other.

Additional hand motor function test for hemiplegic children

I will video tape your child while performing these tests.

Melbourne Assessment (MA2): I will ask your child to do some activities (such as grasp, put things on container and reach to different direction).

Assisting Hand Assessment: I will ask your child to play a card game, which requires hand activities to proceed to the end of the game.

Training program

I will ask your child to play video games that have been uploaded in an Nvidia Shield portable Console Gaming for 8 weeks and to complete 50 hours of video game playing.The video games are age appropriate to your child.

Risks for the research

There are no risks to participate on this study.

Privacy of participants

Individual participants' personal information will not be discussed with anyone. Each child will have a research number ID; the data will refer to the research number ID and not the child name. I will use the data collected for the research purposes only.

Contact for more information

MrsMaha Al-Gabbani

Tel: 0500599503email: malgabbani@ksu.edu.sa

8.3 Appendix C: Consent Form

CONSENT FORM

نموذج إقرار

عنوان البحث باللغة العربية

مقارنة المهارات التنفيذية للمخ ومهارات اليد الحركية بين الاطفال العاديين والاطفال المصابين بالشلل الدماغي الطولي

RESEARCH PROJECT TITLE

comparison between Executive Function and hand motor function between Typically Developing children and children with Hemiplegic cerebral palsy

PrincipalInvestigator:
Maha F Algabbani

الباحث الرئيس:
مها فهد القباني

Co-Investigator(s):
Prof. Janet Eyre-Newcastle University UK
Dr. Hana Al-Sobayel -King Saud University

الباحث المشارك:
البروفيسورة جانيت أير- جامعة نيوكاسيل/ المملكة المتحدة
د. هناء السبيل- جامعة الملك سعود

SPONSOR: King Saud University\ External Joint Supervision Program

الداعم: جامعة الملك سعود/ برنامج الإشراف الخارجي المشترك

You are being asked to participate voluntarily in a Research Study. If you decide to take part in this study, please sign this consent form and return it.

نرجو منك المشاركة في هذه الدراسة البحثية وعند موافقتك بذلك نرجو منك التوقيع على هذه الورقة وإرجاعها إلينا

STUDY PURPOSE: this study is a part of PhD research for Maha Algabbani.

الغرض من الدراسة: هذة الدراسة جزء من بحث الدكتوراة للباحثة مها القباني وذلك من خلال برنامج الإشراف الخارجي المشترك ما بين جامعة الملك سعود – المملكة العربية السعودية و جامعة نيوكاسيل – المملكة المتحدة.

STUDY PLAN: to study the effect of video games on executive function and hand motor function for children.

الهدف من الدراسة: دراسة تاثير ألعاب الفديو علىالمهارات التنفيذية العليا والمهارات الحركية لليد عند الأطفال

BENEFITS: The result of this study may not benefit you directly, but in the future with God's will the patients will benefit from the knowledge acquired.

الاستفادة المرجوة من الدراسة: إن الاستفادة من هذه الدراسة قد لا تعود عليك مباشرة ولكن قد تكون لنتائج هذا البحث تأثيرات على معالجة المرضى الآخرين.

SIDE EFFECT: There are no side effects. You participation in this study does not have any further risks or discomfort to you.

الآثار الجانبية: لا توجد هناك أي أضرار جانبية من هذه الدراسة ومشاركتك لا تسبب أي إزعاج أو مخاطر مستقبلاً

REFUSAL: If you refuse to participate, there will be no penalty or loss of benefits.

عدم الرغبة في المشاركة: إذا رفضت المشاركة في هذه الدراسة فإنك لن تتعرض لأي جزاء أو فقدان للمزايا العلاجية

CONFIDENTALITY: Your participation in this study will be kept confidential. The results of this research may be published, however, your identity will never be revealed.

سرية المعلومات: إن مشاركتك في هذه الدراسة ستكون في غاية السرية. قد يتم نشر النتائج هذا البحث لأغراض أكاديمية ولكن لن يتم الكشف عن هويتك في أي حال من الأحوال.

APPROVAL: I fully understand the information and the consent form.

الموافقة بالمشاركة: استوعبت المعلومات في هذا النموذج, لذا أوافق بالمشاركة في هذه الدراسة. كما أنني لا أمانع من استخدام العينات المتحصل عليها من هذه الدراسة بأن تستخدم في دراسات مستقبلية من قبل الباحثين.
لقد تم شرح هذا النموذج للمتبرع بواسطة أحد الباحثين قبل طلب التوقيع منه.

I sign freely and voluntarily. A copy has been given to me.

أوقع أنا بمحض إرادتي وحريتي وقد تم إعطائي نسخة من الإقرار.

Investigator or Associate: **أسم الباحث أو من ينوب عنه:**

Signature: **التوقيع:**
Date: **التاريخ:**

Patient Name: **أسم المشارك في البحث او من ينوب عنه:**

Signature: **التوقيع:**
Date: **التاريخ:**

Witness Name: **أسم الشاهد:**

Signature: **التوقيع:**
Date: **التاريخ:**

If you have any further concerns or questions, you can contact Mrs. Maha Algabbani Tel # 0500599503e-mail MALGABBANI@KSU.EDU.SA

عند الرغبة في أي استفسار عن هذه الدراسة يمكن أن تتصل بالباحثة مها القباني على تليفون رقم 0500599503 أو عن طريق البريد الإلكتروني MALGABBANI@KSU.EDU.SA

8.4 Appendix D: Video game play questionnaire

Video Game Play Questionnaire

Name_______________________________Date of birth___________________Sex______
Do you play any types of video games?□Yes□ No
If yes, what type of game platforms do you play?
□ Hand held game such as Game boy □ XPOX□ Play station□ Wii□ Internet base video game
Other____

Mention the most six game that you play during the last 6 months, how many times, and for how long

1- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

2- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

3- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

4- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

5- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

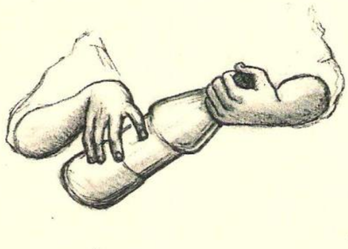
6- ____

How long do you play per day	□ < 1hour	□ 1-2 hours	□ 3-4 hours	□ > 4 hours
How many times per week	□daily	□ 1-3 days	□4-6 days	
How many months	□1-2 months	□ 3-4 months	□ 5-6 months	

8.5 Appendix E: AHA certificate

Assisting Hand Assessment

AHA



CERTIFICATE

This is to verify that

Maha F Al-Gabbani

has completed the requirements of rater training and calibration for the Assisting Hand Assessment.

Rater No.: 1029

Stockholm 2012-11-08

Lena Krumlinde Sundholm, PhD OT
Course leader

8.6 Appendix F: Training Video Games

<table>
<tr><th colspan="3">Action video Games</th></tr>
<tr>
<td>

Lego City</td>
<td>
Sonic</td>
<td>

Angry Birds</td>
</tr>
<tr>
<td>
Beach Buggy</td>
<td>

Where is my Water?</td>
<td>
Diversion</td>
</tr>
</table>

<table>
<tr><th colspan="3">Non Action video Games</th></tr>
<tr>
<td>

Candy Crash</td>
<td>

Pancake Maker</td>
<td>
Smurfs'Village</td>
</tr>
<tr>
<td>
Unicorn Pet</td>
<td>
Droptrix</td>
<td>
Juice Cubes</td>
</tr>
</table>

8.7 Appendix G: Video Game training Diary Sheets

My Training Diary

Name :

Week()	Date	Duration of play	Comments
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			

Week()	Date	Duration of play	Comments
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			

Week()	Date	Duration of play	Comments
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			

Week()	Date	Duration of play	Comments
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			

8.8 Appendix H: published paper

Positive Relationship Between Duration of Action Video Game Play and Visuospatial Executive Function in Children

[1&3] Al-Gabbani M., [2]Morgan, G., [1]Eyre, J. A.
[1]Institute of Neuroscience, Newcastle University, UK
[2]School of Computing Science, Newcastle University, UK
[3]College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Abstract— **The average child in the developed world now spends more than 2 hours per day playing video games. The present study asks: (i) whether children who play video games exhibit enhancement of performance across a broad range of executive functions; (ii) whether there are gender differences; (iii) if there is a relationship between the amount of time a child reports playing video games and their performance on tests of executive function.**

Keywords—video games, children, executive finctions

I. Introduction

The past ten years have seen a revolution in digital technologies with exponential increases in processing power and graphics technology matched by dramatic reductions in cost. This has made the availability of these technologies ubiquitous across a wide range of platforms including tablets and mobile phones. As costs have come down, so children's access to these technologies has increased. This is no truer than for video games. Recent studies in the USA reveal that boys play video games for an average of 16 hours per week and girls for 9 hours per week [1, 2] with 25% of young males reporting playing video games for 4 hours a day or more [3].

A more recent 2-year longitudinal study of school-aged children in Singapore, found more than 80% reported playing video games. The average amount of time played was 20-22 hours per week over the 2-year period [4].

The rising popularity of video games has instigated a debate among parents, researchers, video game producers and policymakers concerning the potential helpful effects of video games on children. Specific information-processing skills (auditory processing, executive functions, mental rotation, motor skills, and visual processing) are crucial to engagement and success in different sorts of video games (e.g., action games, puzzle games, and sports games). Action video games in particular have been demonstrated to improve a range of visual spatial skills in adults [5-7]. Players also exhibit better visual short-term memory [8], and exhibit more flexibility in switching from one task to another [8, 9]. Training studies support a strong causal link between action game experiences and improvements in perceptual, attentional, and cognitive skills [10].

Children who report playing action video games show significantly increased attentional skills as compared to those who do not [11, 12]. This study asks whether children who play video games exhibit similar enhancement of performance across a broad range of executive functions, as has been reported in adults. With the huge increase in the numbers of children playing video games, particularly amongst girls, we aim to look for gender differences. To assess whether there may be a causal relationship between game play and improved executive functions, we look for a dose response effect by examining the relationship between the amounts of time a child reports playing video games and their performance on tests of executive function.

II. Method

A. Subjects

Ethical approval was obtained from the Ethical Committee of the Scientific Research Department at the College of Applied Medical Sciences in King Saud University, Riyadh, Saudi Arabia. The Ministry of Education also gave approval for recruitment of children from within schools in Saudi Arabia. Informed, written consent was obtained from the parents and assent from the children. Children aged 6-12 years of age were recruited randomly from schools in Saudi Arabia. Exclusion criteria were: a past history of a neurological problem, severe visual impairment, an IQ <70, severe behavioral problems.

The children sat at a table in a quiet room directly in front of a computer at a comfortable distance (approximately 30-50cm) to allow them to touch the screen.

B. Tests of Executive Function and Attention

All children undertook assessments of executive function and attention. The Cambridge Neuropsychological Test Automated Battery was used:

- CANTAB, Cambridge Cognition Ltd, Cambridge, UK CB25 9TU (www.cantab.com/cantab/site/home.acds).

This test battery consists of a series of interrelated computerized non-verbal tests of memory, attention, and executive function. It uses touch-screen technology and the tests are language independent and culturally blind. Tests are

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scored automatically and data are exported into spreadsheets. The CANTAB has been used to examine executive function and attention in children previously so it is an appropriate choice in this study [13-15].

The Arabic version of the Wechsler Scale of intelligence was used to obtain a global IQ score.

The criteria of Dye et al., and Li et al., [16, 17] were used to classify video games into Action and Non-Action genres. A questionnaire asked participants to list the games they had played in the preceding 6 months, and to estimate how long they played each game in a typical session along with how many sessions they played per month. The children and their parents each filed in the questionnaire after completing the tests of executive function and IQ.

C. Statistical Analysis

The data were normally distributed. Significance was set at $p<0.05$, with full Bonferroni correction.

T tests for independent samples were undertaken to investigate age and IQ differences between children who played Action Video Games and those who exclusively played Non Action Video Games.

To investigate the effect of Video Game genre on Executive Function test scores, a General Linear Model Analysis of Variance (MANOVA) was used with Greenhouse-Geisser correction if required (SPSS 15, SPSS Inc, Chicago, Illinois, USA). Between subjects, factors of Age Group (completed year of age), Gender (male/female) and Game Genre (Action Video Game, Non Action Video Game) were used. Residuals versus fitted values, normality of the residuals, influential points and outliners were investigated before accepting a model.

To investigate the effect of number of hours of game play in the previous 6 months on Executive Function test scores, univariate analysis was used with the duration of Action or Non Action Video game play and age included as covariates.

III. Results

A. Subjects

156 children were recruited (66 males; mean age 9.2 years range 6.0-12.9 years; Table 1). Only 2 children (one boy and one girl) did not play video games. There was no difference in age (t=1.07, p=0.29) or IQ (t=1.18, p-0.24) between those who played Action Video Games and those who played only Non Action Video Games. Significantly more boys played Action Video Games and more girls only played Non Action Video Games (Chi-squared 7.781, p=0.005).

B. Duration of Game Play

Table 2 summaries the estimated duration of video game play. The total duration of video game play and of action video game play for boys was significantly longer than for girls. Girls played social/strategic video games for significantly longer. There was no main effect for *Age*, nor were there *Age*Gender* interactions (Figure 1; Table 2).

TABLE 1: Subjects' Characteristics

Subjects' Characteristics	Action Video Games	Strategy/Social Games Only	Total
Boys (n)	56	10	**66**
Girls (n)	57	31	**88**
Total (n)	113	41	**154**
IQ mean+ SE	110.4 + 1.38	108.9 + 1.58	
Age (yrs) mean+ SE	9.43 + 0.41	9.18 + 0.43	

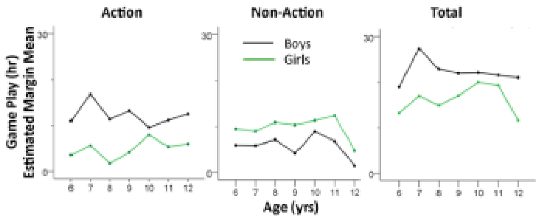

Fig. 1. *Duration of video game play in hours per week comparing boys and girls across the age groups.*

TABLE 2: Duration of Video Game Play in Hours per Week

Game Genre	All Subjects	Boys	Girls	df	F	p
Action mean+SE maximum	7.2+ 0.6	10.9+ 0.8 26.5	4.4+0.7 20.3	1	39.1	<0.001
Social/Strategy mean+SE maximum	7.2+ 0.5	5.2+0.8 31.2	8.6+ 0.3 33.8	1	10.6	<0.001
Mixed Genre mean+SE maximum	1.6+ 0.7	1.4+0.4 14.5	1.7+ 0.8 15.2	1	0.13	0.71
Total Duration mean+SE maximum	16.8+3.2	20.2+3.1 39.6	14.3+ 0.7 33.8	1	27.7	<0.001

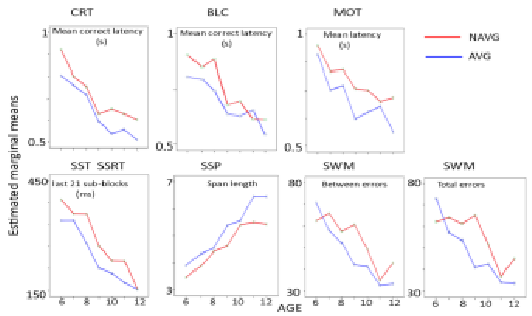

Fig. 2. *Test comparing Action Video Game players (AVG blue line) with Non Action Video Game players (NAVG red line).*

C. Executive Function versus Game Genre

Table 3 and Figure 2 summarise the analysis for the effect of game genre on executive function. For all tests of Executive Function there was a main effect for *Age* but there was no main effect for *Gender*. There were main effects for *Game Genre* for the subtests - SSP (span length), SWM (between errors and

TABLE 3: Tests of Executive Function and Attention; Comparison between Action Video Game and Non Action Video Game players

Test Name	Purpose		All subjects (154)		Girls only (88)	
Visual memory		df	F	p	F	p
Delayed Matching to Sample	Perceptual matching		NS		NS	
Spatial working memory and planning						
Stockings of Cambridge	Spatial planning		NS		NS	
Spatial Span (SSP)	Spatial working memory: Span length	1	9.75	<0.001	8.60	<0.001
Spatial Working Memory (SWM)	Spatial working memory Between errors:	1	7.80	0.006	6.44	0.013
	Total errors:	1	7.87	0.006	5.89	0.018
Attention						
Choice Reaction Time (CRT)	Latency to correct response	1	18.6	<0.001	4.66	0.03
Big / Little Circle (BLC)	Visual discrimination Ability to reverse rules: Latency to correct response	1	11.45	0.001	17.3	<0.001
Response Inhibition						
Stop Signal Task (SST-SSRT)	Response inhibition: SSRT last 21 sub blocks (ms)	1	6.11	0.015	8.63	0.004
Motor tests						
Motor screening (MOT)	Reaction Time	1	9.53	0.002	9.1	0.003

total errors), CRT (mean latency to correct response), BCL (mean latency to correct response), SST–SSRT, and MOT (mean latency to correct response) with Action Video Game players showing superior performance in all these subtests compared to those who only play Non Action Video Games (Figure 2). There were no interactions with *Age* or *Gender*.

Since there were significantly more boys playing Action Video Games, we wished to exclude the possibility that the differences between Action Video Game players and Non Action Video Game players was driven mainly by gender effects but we did not have sufficient power to detect a *Genre*Gender* interaction. We therefore repeated the analysis but only included females. Main effects for *Game Genre* were again demonstrated and revealed the same pattern of significance as observed for the whole group (Table 3).

D. Relationship between duration of Action Video Game play and Executive Function

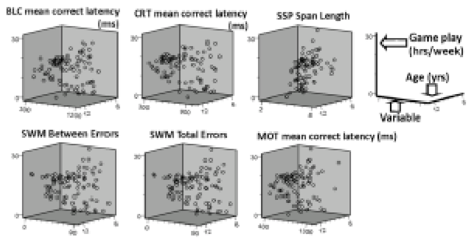

Fig. 3. Relationship between age and duration Action Video Game play and Executive Function test scores

Univariate analysis revealed a significant relationship between the duration of Action Video Game play in the previous 6 months and scores obtained in BLC (mean latency to correct response), SWM (total errors and between errors), CRT (mean latency to correct response) and SSP (span length), MOT (mean latency to correct response). For all variables, increased duration of game play was associated with superior performance (Table 4, Figure 3). There was no relationship

TABLE 4: Relationship between duration of action video-game play and executive function

Test	df	F	p
BCL (mean correct latency)	1	17.6	<0.001
CRT (mean correct latency)	1	15.25	<0.001
SSP span length	1	15.83	<0.001
SWM Between errors	1	9.36	0.003
SWM Total errors	1	9.26	0.003
MOT (mean correct latency)	1	5.3	0.02

between duration of Non Action Video Game play and Executive Function test scores.

IV. Discussion

This study confirms the recent observations of an exponential increase in the numbers of children playing video games [1-3]. It is the first study, however, to report almost universal use of video games by children as young as 6 years of age. Furthermore, this study of children in Saudi Arabia is consistent with reports from the USA and Singapore that children are playing video games for an average for more than 2 hours per day [1-3]. We confirm previous observations that boys play video games for longer than girls (on average for 20 hours per week) but the difference is less than has been reported previously with girls in our study playing video games for more than 14 hours per week on average compared with only approximately 9 hours per week in the previous studies [1-3]. The children also report a very wide range of duration of game play with some boys and girls reporting playing video games regularly for as much as 30 - 40 hours a week.

These findings in children mirror those observed in adult gamers of superior performance, particularly of spatial visual selective attention, for those who play action video games compared to those who play other genres, [5-9]. Importantly, the fact that so many girls in our sample played action video games provided us with the opportunity to exclude a gender difference in visual attention skills as the explanation for the effect of game play, since we could demonstrate the same effect of action video game playing on executive visuospatial functions when we only considered the girls in our study. Furthermore, to support a causal link with game play we demonstrated a dose response, such that at any age the children playing action video games for longest displayed superior performances and there did not appear to be a ceiling effect (Figure 3). These findings support the conclusion that playing action video games accelerates the maturation of these executive functions in children.

The finding of this and other studies of potentially beneficial effects of playing action video games should counterbalance societal concerns that playing action-based games may lead to increased aggressiveness and/or poorer academic performance [18]. Furthermore, if the findings of our present study are supported by an intervention study currently in progress, then action video games may provide an exciting opportunity to improve executive function in groups of children in whom abnormal executive function has been demonstrated.

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