



Exploring the structure and the roles of executive functions in typically developing children and children with autism spectrum disorder

Yunhong Wen

Thesis submitted in candidature for the degree of Doctor of
Philosophy

Newcastle University

Institute of Neuroscience

July 2018

Abstract

Executive functions are a range of goal-directed cognitive abilities. Miyake et al. (2000) suggest that there are 3 correlated but separable executive functions; working memory, inhibition, and shifting. Whilst Fisk and Sharp (2004) add the ability to retrieve information from long-term memory as a fourth. While the developmental trajectories and structures of working memory, inhibition and shifting have been examined widely, there has been less research investigating retrieval from long-term memory. There has also been little research exploring contributions of executive functions to academic achievement in typically developing children, and whilst there is evidence that deficits in executive function are associated with ASD, there is very little research investigating the relationship between EFs and autistic characteristics.

The first study presented in this thesis recruited 187 typically developing children aged 7, 10 and 14 years to investigate the structure of working memory, inhibition, shifting and retrieval from long-term memory (via verbal fluency). The results suggested a four-factor structure was the best fit to the data across all age groups. The second study examined the extent to which the executive functions predicted recent National Curriculum Levels in English and Mathematics. Although the majority of the executive functions were correlated to attainment, there were clear developmental differences in terms of the extent to which executive functions predicted attainment. 30 children with autism and their parents participated in the third study. The results revealed no correlation between laboratory measures of executive functions and parent-ratings of executive functions, and found few significant correlations between executive functions and autism characteristics. Analyses suggested that children with autism can be clustered into 3 groups, according to severity of autism characteristics and executive function difficulties. Further implications for research and practice in executive function in both children with and without autism are explored.

Dedication

I wish to dedicate this work to my parents, Mingxin Wen and Peizhen Cai, and my beloved husband, Dean Joab who have offered unconditional love and support and have always been there for me. Thank you.

Acknowledge

I am extremely grateful to my supervisors Helen St. Clair-Thompson and Jacqui Rodgers for their support, guidance, patience and insight throughout my PhD.

My research would have been impossible without the support of the children and families from Winlaton West Lane Primary School, Harton Academy, Jarrow School, Cardinal Hume Catholic School and the Database of Children with Autism Spectrum Disorder in the North East (Daslne) for their time and enthusiasm to take part in my study. Recruiting participants would not have been possible without the help of Mary Johnson of Daslne and the schools' head teachers and academic staff.

I also would like to acknowledge Trevor James and Robin Beaumont for their help with data acquisition for the statistical analysis undertaken in Chapter 2. Additionally, I would like to thank Amy Ofield for her help as an independent researcher for coding answers in Chapter 6.

Table of Contents

Abstract	iii
Dedication.....	v
Acknowledgements.....	vii
List of Tables and Figures.....	xiii
Chapter 1. General introduction to the structure and contents of executive functions	1
1.1 Executive Functions.....	2
1.1.1 Unity and diversity of execution functions.....	3
1.1.2 Developmental executive functions theories	4
1.2 Working memory.....	6
1.2.1 Definition of working memory	6
1.2.2 Theories of working memory	7
1.2.3 Interaction between executive functions and working memory.....	8
1.2.4 Developmental trends in working memory.....	9
1.2.5 Tasks commonly used for assessing working memory	12
1.3 Inhibition	16
1.3.1 Definition of inhibition	16
1.3.2 Tasks used to assess inhibition.....	17
1.3.3 Developmental trends in inhibition.....	19
1.4 Shifting.....	22
1.4.1 Definition of shifting.....	22
1.4.2 Tasks used to assess shifting.....	23
1.4.3 Developmental trajectory of shifting	24
1.5 Verbal fluency	25
1.5.1 Definition of verbal fluency	25
1.5.2 Tasks used to measure verbal fluency	26
1.5.3 Developmental trends on verbal fluency	28
1.6 Different structures of Executive function in children	28
1.7 How different tasks influence structure of EF.....	40
1.8 Exploratory Factor Analysis and Confirmatory Factor Analysis	41
Chapter 2. Investigating the structure of executive functions in typically developing children	42
2.1 Present Study	42
2.2 Method.....	42
2.2.1 Participants.....	42

2.2.2 Materials	43
2.2.3 Procedure	46
2.2.4 Statistical analysis	47
2.3 Results	47
2.3.1 Data preparation	47
2.3.2 Development of executive function	48
2.3.3 Correlations	50
2.3.4 Confirmatory Factor Analysis	54
2.4 Discussion	59
2.4.1 Developmental trends	59
2.4.2 The structure of executive function	61
2.4.3 Strengths, Limitations and future implications	62
Chapter 3. Literature review on age related differences in the contribution of executive functions to academic achievement in typically developing children ...	65
3.1 Literature Review	65
3.1.1 Working memory and academic achievement	67
3.1.2 Inhibition and academic achievement.....	71
3.1.3 Shifting and academic achievement	72
3.1.4 Verbal fluency and academic achievement	74
3.2 The structure of Executive functions and scholastic attainment	75
3.3 Purpose and predictions.....	76
Chapter 4. Investigating age-related differences in the contribution of executive functions to academic achievement in typically developing Children	77
4.1 Present Study.....	77
4.2 Method	77
4.2.1 Materials	78
4.2.2 Statistics analysis	78
4.3 Results	79
4.3.1 Descriptive statistics	79
4.3.2 Correlational Analyses	79
4.3.3 Regression analyses	80
4.4 Discussion.....	82
4.4.1 Patterns of developmental changes.....	87
4.4.2 Limitations and future studies	89
Chapter 5. Literature review on executive functions in children with Autism	91
5.1 Autism Spectrum Disorder	91
5.1.1 Social communication and social interaction	91

5.1.2 Repetitive behaviours	92
5.2 Explanation of autism.....	92
5.3 Executive dysfunction	93
5.4 Working memory	94
5.4.1 The associations between working memory and ASD characteristics....	95
5.5 Inhibition	96
5.5.1 The associations between inhibition and ASD characteristics.....	97
5.6 Shifting.....	98
5.6.1 The associations between shifting and ASD characteristics	98
5.7 Verbal fluency	100
5.7.1 Association	101
5.8 Assessing executive function including laboratory and parent-rating questionnaires.....	102
5.9 Parental evaluation of autism characteristics in research	104
5.10 Executive function heterogeneity in autism	106
5.11 Hypotheses	107
Chapter 6. Examining the relationship between executive functions and autism characteristics in children with autism spectrum disorder	109
6.1 Present Study	110
6.2 Method.....	110
6.2.1 Participants.....	110
6.2.2 Materials.....	110
6.2.3 Procedure.....	113
6.2.4 Statistics analysis	114
6.3 Results.....	115
6.3.1 Data preparation.....	115
6.3.2 Descriptive statistics	115
6.3.3 Correlations	116
6.3.4 Cluster analysis	118
6.4 Discussion.....	124
6.4.1 Association between executive functions laboratory tasks and ASD characteristics	125
6.4.2 Parent-rating executive scales and ASD characteristics	126
6.4.3 Intra-class correlation	128
6.4.4 Groups of autistic children based on their autistic patterns	129
6.4.5 Strengths, limitations and implications	130
6.5 Conclusion	132
Chapter 7. General Discussion	133

7.1 Overview	133
7.2 Synthesising the evidence: the structure of executive function in typically developing children and children with autism	136
7.3 Synthesising the evidence: the importance of executive function in typically developing children and children with autism	137
7.4 Measurement	139
7.5 Strengths and limitations	143
7.5.1 Strengths	143
7.5.2 Limitations.....	144
7.6 Educational and clinical implications	145
7.7 Future directions.....	146
7.8 Conclusion	147
References	148
Appendices	181

List of Tables and Figures

Table 1.1 A summary of studies concerned with the structure of executive functions during childhood.....	30
Table 2.1 Descriptive statistics showing the number, gender ratio, mean age and standard deviation for whole group and each age group.....	43
Table 2.2 Mean, Standard deviation, Skew, Kurtosis of whole sample.....	48
Table 2.3 One-way ANOVA results with Bonferroni correction, descriptive data for three year groups on different tasks of executive function and significance on group-paired comparison.....	50
Table 2.4 Correlation coefficients between executive function measures for the whole age group.....	51
Table 2.5 7 year old group of correlation coefficients between executive function measures.....	52
Table 2.6 10 year old group of correlation coefficients between executive function measures.....	53
Table 2.7 14 year old group of correlation coefficients between executive function measures.....	53
Table 2.8 Fit indices for CFA models.....	54
Table 4.1 The mean and SD of National Curriculum Levels in three different year groups.....	79
Table 4.2 The Pearson’s correlation between EF tasks and National Curriculum Levels on English and Mathematics in the whole group and three age groups...	80
Table 4.3 Linear regression analyses predicting unique variance in academic achievement	82
Table 6.1 Mean, Standard deviation, Range, Skewness and Kurtosis results for each variable in executive function tasks and parent-rating questionnaires.....	115
Table 6.2 Pearson’s correlations of laboratory tasks variables and parent-rating ASD characteristics.....	116
Table 6.3 Pearson’s correlations of parent-rating executive functions BRIEF and SCI of SRS-2.....	116
Table 6.4 Pearson’s correlations of parent-rating executive functions BRIEF and ASD characteristics.....	117
Table 6.5 Pearson’s correlations between laboratory tasks and parent-rating executive functions, age and FSIQ.....	117
Table 6.6 Mean and standard deviation of ASD characteristics and parent-rated executive functions in each cluster group.....	120
Figure 2.1 Model 1 Measurement model for executive functions.....	55

Figure 2.2 Model 2 Measurement model for executive functions.....	56
Figure 2.3 Model 3 Measurement model for executive functions.....	56
Figure 2.4 Model 4 Measurement model for executive functions.....	57
Figure 2.5 Model 5 Measurement model for executive functions.....	58
Figure 6.1 Dendrogram of hierarchical cluster analysis based on ASD characteristics in the total score of SRS-2, including SCI and RRB.....	118
Figure 6.2 the profile of ASD characteristics in three different clusters.....	121
Figure 6.3 the EF profile of laboratory tasks in three groups.....	121
Figure 6.4 SRS-2 scores in three groups.....	122
Figure 6.5 RBQ scores in three groups.....	122
Figure 6.6 the EF profiles of parent-rating scales BRIEF in three groups.....	123

Chapter 1. General introduction to the structure and contents of executive functions

This thesis focuses on exploring the structure and the roles of executive functions in typically developing children and children with autism spectrum disorder (ASD). Three studies provided the opportunity to examine four different executive functions in order to understand how children develop learning skills and the associations with autistic characteristics in children with ASD.

The past thirty years have seen increasingly rapid advances in understanding the nature of executive functions (also referred to as executive control and cognitive control), especially in cognitive psychology. Executive function is considered to be an umbrella term for a range of cognitive processes, which facilitate goal-directed behaviours (Miller & Cohen, 2001). It is claimed to be responsible for the synthesis of external stimuli and the patterns of thinking and concepts (Luria, 1976). Although a number of researchers have explored executive functions in adulthood, comparatively there is little known about executive functions in typically developing children (Garon, Bryson, & Smith, 2008; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000) and children with Autism Spectrum Disorder (Leung & Zakzanis, 2014; Ozonoff, Pennington, & Rogers, 1991).

Particularly, the structure of executive functions play an important role in addressing the issue of development. The findings regarding whether the structure of executive function is unitary, or whether functions can be fractionated have been mixed (Brydges, Fox, Reid, & Anderson 2014; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). As a result, the studies reported in this thesis aim to explore how these executive functions develop during childhood (Chapter 2) and the association between executive functions and scholastic achievement (Chapter 3), with a focus on the unity and diversity of functions, and also how executive functions relate to autism characteristics to further develop a clear understanding of autism (Chapter 5).

1.1 Executive Functions

Executive function is regarded as a multidimensional and goal-directed concept covering several 'higher-level' cognitive functions, such as working memory, inhibition and shifting (Brydges et al., 2014; Miller & Cohen, 2001). Miyake et al., (2000) suggested that three target executive functions, namely information updating and monitoring ('Updating'), inhibition of prepotent responses ('Inhibition') and mental set shifting ('Shifting') are relatively correlated, but clearly separable. Inhibition is the ability to suppress irrelevant information or impulse. Shifting refers to the ability to switch between two ongoing cognitive processes, multiple tasks or mental sets. Updating requires coding and monitoring incoming information with disengaging the former and irrelevant information. Updating is closely linked to working memory (Jonides & Smith, 1997; Lehto, 1996; Miyake et al., 2000). For example, Lehto (1996) indicated that there are high inter-correlations between memory-updating tasks and working memory span measures. Essentially, the updating function is actively manipulating incoming and relevant information in working memory, instead of passively storing information. In this thesis, the term 'working memory' will be used to discuss this function instead of 'updating'.

In addition to the functions of working memory, inhibition and shifting, the term executive functions may also encompass other functions as well. These include the temporary activation of long-term memory (Baddeley, 2000). It has been suggested that word fluency involves this aspect of executive function, because participants are asked to retrieve as many words as possible from long-term memory subject to a specific defining characteristic (Fisk & Sharp, 2004). In addition, Alloway and Alloway (2010) suggested that as children get older their learning/ attainment may be predicted more by crystallized intelligence than working memory. Verbal fluency is, however, different to other executive functions because it requires crystallized or long-term knowledge. In contrast, some research has indicated a strong relationship between other executive functions e.g. working memory and fluid intelligence (Colom, Rebello, Palacio, Juan-Espinosa, & Kyllonen, 2004).

There is a long history of research into executive functions in patients with frontal lobe impairments (e.g. Damasio, 1994; Shallice & Burgess, 1991), and

research in neuropsychology has provided clear evidence that executive functions are associated with the prefrontal cortex (e.g. Fuster, 1997; Stuss et al., 2000). Alongside behavioural and personality changes, prefrontal cortex lesions influence abstract thinking and planning. In studies of War World I, veterans with prefrontal cortex injuries exhibited difficulties mastering complex tasks but not routine tasks (Goldstein, 1936, 1944). Thereafter, within cognitive psychology, the term executive function started to be used to refer to these complex or controlled processes (e.g. working memory and inhibition).

1.1.1 Unity and diversity of execution functions

A unitary structure or a fragmentary organisation of executive functions has been widely debated for the last thirty years. Theoretically, some researchers approach executive functions in a unitary way. For example, Baddeley (1986) and Norman and Shallice (1986) suggest there is a unitary structure with constituent sub-processes. Developmentally, Duncan, Burgess and Emslie (1995, also see Duncan, Emslie, Williams, Johnson, & Freer, 1996) suggested that general intelligence or Spearman's G was the reflection of executive functions of the frontal lobe because of positive correlations between different ability tests, which indicates a single factor on a conceptual level.

Others hold a more fragmented view of executive function, proposing relatively independent sub-processes in adults and adolescence (Lehto et al., 2003; Miyake et al., 2000). For example, Miyake et al., (2000) examined executive function in 137 undergraduates. They used 9 executive tasks to tap the three executive functions: Shifting, Working Memory and Inhibition. They also used five complex executive tasks to work out whether discrete executive functions contribute to performance on complex executive tasks. By applying confirmatory factor analysis (CFA), the results indicated that the three executive functions are rather independent but correlated structures. When examining which executive functions complex executive tasks really tap, structural equation modeling suggested the Wisconsin Card Sorting Task (WCST) was related to shifting, Tower of Hanoi to inhibition, Random number generation to inhibition

and working memory, and operation span to working memory. The performance on a Dual task was not related to the three executive functions.

In addition, a battery of executive function tasks is widely used in examining executive function, such as the Cambridge Neuropsychological Test Automated Battery (CANTAB) and the Behaviour Rating Inventory of Executive Function (BRIEF). CANTAB (Robbins, James, Owen, Sahakian, McInnes, & Rabbitt, 1994) is a computerised task battery, including executive function tasks, visual memory tasks, attention tasks, etc. However, there are low inter-correlations (usually r equals or is less than .40) among different executive function tasks (Lehto et al., 2003). This has prompted the examination of their fractionation. For example, Lehto et al., (2003) investigated the structure of executive function in 108 children 8-13 years old, using three tasks from CANTAB, namely the spatial span task, spatial working memory task and Tower of London, and another five executive tasks. Both exploratory factor analyses (EFA) and confirmatory factor analyses (CFA) yielded three latent factors instead of a single factor for executive tasks, including working memory, inhibition and shifting.

Gioia, Isquith, Retzlaff and Espy (2002) examined a group of children with mixed clinical diagnoses with the 9-scale BRIEF via CFA, and a three-factor model was proposed. It suggested a Behaviour Regulation factor composed of the inhibit and self-monitor scale, an Emotional Regulation factor consisting of the emotional control and shift scales, and a Metacognition factor composed of the working memory, initiate, plan/organize, organization of materials and task-monitor scales. This finding supports a fractionated view of executive function as measured by the BRIEF.

1.1.2 Developmental executive functions theories

Miyake et al., (2000) proposed a model with three modestly intercorrelated but partly dissociable variables in adulthood; whereas other researchers have looked at the development of executive function across childhood. There are four developmental theories of executive function, which also differ in terms of their approach to unity and diversity. They are offered by Zelazo and Frye (1998),

Munakata (2001), Diamond (2006), and Hongwanishkul, Happaney, Lee and Zelazo (2005), explaining different insights of executive function development.

Zelazo and Frye (1998) considered executive functions in terms of the outcome of problem solving, identifying four phases of executive functions; problem representation, planning, execution, and evaluation. They proposed the Cognitive, Complexity and Control theory (CCC theory) to explain developmental transitions in the extent to which children can reflect on their plans. Their theory assumes a hierarchy of rule representation, in which perseverative errors occur when children cannot integrate two rules. This theory may help to explain the development of the function of shifting, but does not reflect upon the issue of the unity or diversity of executive functions.

Munakata, Snyder and Chatham (2012) proposed a theory for developing cognitive control including three key transitions: a) from perseverating to overcoming habits when directed; b) reactive to proactive control; c) externally driven to self-directed control. Children firstly develop an ability to overcome habits by involving cognitive control when they are directed by a parental or environmental signal; secondly, children shift from reactively to proactively engaging cognitive control in preparation for environment change; thirdly, children become more self-directed to engage cognitive control without relying on environmental signals. This theory explains the development of executive function but does not involve the issue of the structure of executive function.

Diamond (2006) suggested a componential model of EF, which consists of working memory, inhibition, and cognitive flexibility (shifting). She also indicated that these abilities were essential to all forms of cognitive performance. These abilities allow us to hold information in mind to make it possible to remember and plan, to follow instructions and to consider alternatives, to relate one idea to another, and to relate the present to the future and the past. They are important for creativity, for disassembling and recombining elements in a fresh new perspective. Diamond also suggested these three executive functions present different developmental trajectories, with a spurt in development in the last half of the first year and from the age of three to six. Her theory proposed the same

elements for executive functions as Miyake's study. It focused on the development of executive function from early development.

Other theories of executive function suggest that executive functions operate differently in different contexts (Bechara, 2004). One particular theory describes a distinction between two aspects of executive function, a "cool" cognitive aspect of executive function related to dorsolateral regions of the prefrontal cortex and a "hot" affective aspect associated with ventral and medial regions (Zelazo & Müller, 2002). Hongwanishkul et al., (2005) found the evidence that hot and cool executive functions are distinct in 3- to 5-year-old children applying four executive function assessments, including Self-ordered pointing and Dimensional change card sort for cool executive function and Children's gambling task and Delay of Gratification for hot executive function.

There are therefore several approaches to studying the development of executive functions. However, what is particularly of interest in the current thesis is the suggestion of a fractionation between the executive function of working memory, inhibition and shifting. The current studies will explore these three componential executive functions specified by Miyake et al., (2001) with an additional function Verbal fluency (Fisk & Sharp, 2004). Each function will be reviewed with reference to empirical work, including cross-sectional studies.

1.2 Working memory

Working memory is the first component of executive function that will be discussed in this thesis. In this chapter, working memory will be demonstrated in terms of its definition, its relationships with executive functions, the developmental trajectory of working memory, developmental theories about working memory and the tasks that are used to examine working memory.

1.2.1 Definition of working memory

Working memory has been viewed as 'a multicomponent system responsible for active maintenance of information in the face of ongoing processing and/or distraction' (Conway, Kane, Bunting, Hambrick, Wilhelm, &

Engle, 2005, pp. 770). Working memory has also been referred to ‘the temporary storage of information that is being processed in a range of cognitive tasks such as comprehension, learning and reasoning’ (Baddeley, 1986). In children, working memory is considered as the ability to store and manipulate information, and is closely associated with scholastic attainments (Alloway, Gathercole, Willis, & Adams, 2004). For further details, please refer to chapter three.

1.2.2 Theories of working memory

Baddeley and Hitch model

Baddeley and Hitch (1974) proposed a model for working memory, which consists of three components, namely the central executive, the phonological loop, and the visuo-spatial sketchpad. The central executive is the heart of working memory and is closely linked to a mechanism of attention control (Kane & Engle, 2003; Unsworth & Engle, 2007). The phonological loop deals with holding and processing verbal information, and the visuo-spatial sketchpad is responsible for visual and spatial input. In 2000, Baddeley outlined an additional component for this model: the episodic buffer. It provides a limited temporary system for information that comes from the subsidiary components and long-term memory (Baddeley, 2000). However, Baddeley (1996) suggested the central executive component of working memory serves a number of important functions, including temporary activation and manipulation of long-term memory, which has been considered as a fourth function named verbal fluency in the current thesis.

Embedded-Processes Model

Cowan (1999) proposed a model of working memory called the Embedded-Process Model, which consists of three hierarchical parts, including focus of attention, activated memory (short-term store) and long-term memory. The focus of attention is controlled by both voluntary processes, for example, a central executive system; and involuntary processes, including the attentional orienting system. The focus of attention is limited in capacity and the active memory store is time limited. This model is suggested to be more unitary than Baddeley’s (1986) model (Shah & Miyake, 1999). Baddeley’s model has a clearer distinction

between phonological information and visuo-spatial information, whereas different types of information are coded based on the same principle according to Cowan's model.

Controlled Attention Framework

Engle, Kane and Tuholski (1999) proposed the controlled attention framework. This is a domain-free and limited capacity controlled attention model with (a) a long-term memory store active above a threshold, and (b) processes for completing and sustaining activation. Here the working memory capacity refers to controlled attention and it is responsible for maintaining attention when facing distractions. The role of controlled attention is similar to the central executive from Baddeley and Hitch (1974). There are individual differences in controlled processing, and these have been linked to general fluid intelligence. It is also suggested that controlled attention processing requires maintaining short-term targets and blocking distracting or irrelevant events.

Although there are several theories of working memory, the most widely researched model is Baddeley and Hitch's model (Baddeley, 2000; Baddeley & Hitch, 1974). Four components of working memory, namely the phonological loop, visual-spatial sketchpad, episodic buffer and the central executive have been widely tested in a range of ages in typically developing children and children with autism (Alloway, Gathercole, Willis, & Adams, 2004; Williams, Goldstein, Carpenter, & Minshew, 2005; Ozonoff & Strayer, 2001). In this thesis, we have therefore used Baddeley and Hitch's model (1974) in each of the studies.

1.2.3 Interaction between executive functions and working memory

There are three different points of view taken by scholars regarding the interaction between executive functions and working memory. One view is that the central executive from Baddeley and Hitch (1974) performs several functions, which are considered as executive functions. Baddeley (1996) suggested the central executive is responsible for selective attention, the capacity to focus attention on one stream of information, the capacity to switch attention from one source to another, and access and manipulation of information in long-term memory. Other researchers have also attributed these, as well as some

additional functions to the central executive, including shifting between tasks (Baddeley, 1996); retrieval from long-term memory (Baddeley, Lewis, Eldridge, & Thomson, 1984; Morris, Craik, & Gick, 1990), planning (Shallice & Burgess, 1991), the capacity to address and suppress in a particular manner (Baddeley, 1998), and conditional reasoning (Toms, Morris, & Ward, 1993). However, it has been suggested executive functions are separable. Lehto (1996) indicated that there is not a unitary and limited-capacity central executive.

Another view is that executive functions are distinct functions that are loosely related, and that working memory is one of these executive functions. It is indicated that working memory is closely related to the executive function of “Updating” (Jonides & Smith, 1997; Lehto, 1996; Miyake et al., 2000).

The third view is that working memory and executive functions share a common underlying executive attention component (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Research has found that there is a strong correlation between working memory capacity and executive functioning constructs ($r = .97$), but correlations between these constructs and processing speed were relatively lower (i.e., $.77$ for working memory model and $.81$ for executive function model). There is a strong evidence to suggest working memory and executive function tasks measuring a common underlying cognitive construct, however, processing speed tests appeared to measure a different construct because less than two-thirds of the variance in processing speed was shared with working memory or executive functions.

1.2.4 Developmental trends in working memory

In general agreement, working memory improves throughout childhood and adolescence in terms of both visuo-spatial and verbal processing and storage (Gathercole, Pickering, Ambridge, & Wearing, 2004; Hitch, Towse, & Hutton, 2001; Lehto et al., 2003; Siegel, 1994; Wilson, Scott, & Power, 1987). Gathercole et al., (2004) found that children from 4 to 14 years showed a steady linear improvement across nine working memory tasks, such as digit call and word recall, with performance levelling off between 14 and 15 years. It is suggested that the visuo-spatial sketchpad improves rapidly between aged 5 and 11 years

(Wilson, Scott, & Power, 1987). Children achieve adult levels at the age of 11 in a pattern span task assessing the visual storage component of working memory. Alloway, Gathercole and Pickering (2006) found steady improvement on a visuo-spatial sketchpad tasks in children in 4-11 years when using the Automated Working Memory Assessment. However, Lehto (2003) found that from 8 to 13 years old, children did not show significant improvements in the visuo-spatial sketchpad.

In terms of complex working memory span tasks (assessing the central executive), Siegel (1994) suggested that working memory grows gradually from 6 years old to 16 years old and reaches its peak by then. Neuroscience data also supports the view that children develop working memory slowly, indicating that by the age of 9, children can only maintain half the number of the items that adults do in working memory tasks (Kharitonova, Winter, & Sheridan, 2015). Alloway et al., (2006) indicated that children show significant improvement in verbal working memory from 4 to 11 years, and that this is the case for both boys and girls. Prencipe, Kesek, Cohen, Lamm, Lewis and Zelazo (2011) found that there are age-related improvements in verbal working memory in children from 8 to 15 years when using forward and backward digit span. They revealed that children aged 8-9 years performed significantly worse than children aged 10- and 11-years and 14-and 15-years old. Thus, it was suggested that the improvements in verbal working memory appeared between 9 and 10 years old.

Recent research has also explored the development of the episodic buffer, indicating that children improve in their ability to hold temporary bound information from 8 years old to 9 years old and also between childhood and adulthood (Wang, Allen, Lee, & Hsieh, 2015).

However, it is important to note that there may also be developmental changes in terms of the extent to which children use the verbal and visuo-spatial aspects of working memory, which involves tasks requiring storage and operations on the contents of storage (Smith & Jonides, 1999). Hitch, Halliday Hulme, Le Voi, Routh and Conway (1983) suggested that when children are younger than 7 years old, they need the visuo-spatial sketchpad to recall the physical forms of inputs, such as pictures of familiar objects. When they grow

older, they tend to use the phonological loop to record visual stimuli via rehearsal. There is therefore a shift from mainly using the visuo-spatial sketchpad to the phonological loop during the early school years. However, further research is needed to develop a more detailed understanding of the shift of the development of the phonological loop and visuo-spatial sketchpad across childhood. Gathercole et al., (2004) discussed this in the context of the storage capacity of the visuo-spatial sketchpad, which may be related to other developments, such as using strategies and increasingly receiving support by the central executive. Gathercole et al., (2004) indicated that children who are younger than 7 years typically rely on the visuo-spatial sketchpad to support recall of the physical forms of visual stimuli. However, older children tend to use the phonological loop to mediate immediate memory performance where possible, and so recode the visual inputs into a phonological form via rehearsal.

There are further explanations of why children move from the visuo-spatial sketchpad to the phonological loop, based on qualitative and quantitative changes to children's sub-vocal rehearsal at about 7 years old (Gathercole & Hitch, 1993). According to Vygotsky (1963), children will have a developmental process that overt speech can be internalised as an 'inner speech' at age 7. Children then strategically used inner speech to maintain verbal material within the memory system. Before that, the younger ones can't encode a pictorial material in a verbal form, which goes into the visuo-spatial sketchpad.

Neuroscience research also has indicated the developmental change across childhood on working memory. Bathlet, Gathercole, Johnson and Astle (2018) suggested that for younger children, there is a greater involvement of the corpus callosum and posterior temporal white matter for performance associated with the executive part of the working memory system. There was more closely linked with the thickness of the occipitotemporal cortex in older children. These findings suggest that increasing specialisation leads to shifts in the contribution of neural substrates over childhood. The greater importance of large white matter connections in younger children suggests that younger children are relying on a more distributed system. In contrast, the greater importance of cortical thickness in the left posterior temporal lobe demonstrates the importance of this local processing in later stages of working memory development.

Additionally, some studies provide evidence that visual and spatial memory abilities of working memory developed at different rates in childhood (Holmes, Adams, & Hamilton, 2008; Logie & Pearson, 1997). The pattern of development shows that visual working memory showed a relatively rapid development between 5 years old and adulthood, while spatial working memory developed at a slower and steadier increase. It appears that visual and spatial memory task performance follow different developmental trajectories, supporting separate subsystems existed in children (Hamilton, Coates, & Heffernan, 2003).

As well as investigating the development of each component of working memory, researchers have also investigated the separability of the components. Pickering, Gathercole and Peaker (1998) suggested when children are at 5 and 8 years old, there is clear separation between the phonological loop and the visuo-spatial sketchpad. Following this, Gathercole and Pickering (2000) suggested that in 6- and 7-year old children, the central executive and the phonological loop are separable but moderately correlated with each other, consistent with the adult model of working memory. Jarvis and Gathercole (2003) indicated that in 11- and 14-year old children, both verbal and visuo-spatial working memory are independent of one another. It has also been shown that from 6 years old, there is evidence of a model of three distinct but correlated components of the central executive, the phonological loop and the visuo-spatial sketchpad in working memory (Gathercole, et al., 2004).

1.2.5 Tasks commonly used for assessing working memory

There are three commonly used types of tasks to assess working memory, involving the phonological loop, visuo-spatial sketchpad and the central executive, respectively.

Tasks used to assess the phonological loop

The *Forward digit span* requires participants to recall in correct and forward serial order after the presentation of spoken sequences of digits. Typically, the task will start with 2 digits and add one digit at a time if a participant is successful until a maximum of nine digits. The numbers of trials at each level are varied from two (Wechsler Adult Intelligence Scale; WAIS-IV, 2008) up to six (Gathercole,

Pickering, Knight, & Stegmann, 2004). The continuation criterion is varied. In WAIS-IV, participants have to recall one trial correct out of two in order to progress to the next level. However, in the Working Memory Test Battery for Children (Pickering & Gathercole, 2001), a participant is required to answer four correct trials out of six before the next level commences. The score awarded is often the maximum number of digits that can be recalled. The mean test-retest reliability coefficient for this task is varied from 0.53 to 0.81 (Gathercole, Pickering, Ambridge, & Waring, 2004; Gathercole, Pickering, Knight, & Stegmann, 2004).

The *Word list recall* and *non-word list recall* tests are variants of *forward digit span* in which different stimuli are used (words and non-words). In each trial, stimulus items are mono-syllabic words with a consonant-vowel-consonant structure and no stimuli are repeated. Items must be recalled fully accurate (i.e. with all three phonemes correct) and in the correct serial position. The mean test-retest reliability coefficient is .72 for word list recall and .56 for non-word list recall (Gathercole, Pickering, Ambridge, & Waring, 2004)

The *Word list matching* is a task in which participants listen to a spoken sequence of familiar one-syllable words. The same words are presented again after a brief interval. They are presented either in the identical sequence or with the position of two of the words within the sequence reversed. The participant has to judge whether the sequences are the same or different. The number of words in each list increases over successive trials and the participant is required to answer four trials out of six before the next level commences. The test-retest reliability is from .42 to .45 (Gathercole, Pickering, Knight, & Stegmann, 2004).

Tasks used to assess the visuo-spatial sketchpad

In the *Pattern recall task*, the participant views two-dimensional grids consisting of filled (black) squares and unfilled (white) squares, which form a pattern for 3 seconds. The pattern disappears and the participant is asked to repeat the same pattern on the grid. The complexity of the pattern increases by having one additional filled square on each level. Participants progress to the

next level when they get four correct patterns out of six (Gathercole, Pickering, Ambridge, & Waring, 2004).

In the *Block recall* test (sometimes called the Corsi Blocks task), the participant views wooden cubes, which are located randomly on a board. The administrator taps a sequence of blocks and participant repeats the sequence in the same order. The test begins with a single block tap and increases by one additional cube when participant gets four trials correct out of six. The mean test-retest reliability coefficient is .53 (Gathercole, Pickering, Ambridge & Waring, 2004). It is a similar task to *Dot Matrix*, which requires participants to tap the same sequence of red dots that have appeared in a 4 * 4 matrix.

In the *Mazes memory* test, a participant looks at a two-dimensional line maze with a path drawn through the maze. The administrator traces the line with finger in view of the participant. The same maze is shown to the participant without the path, and the participant is required to recall the path by drawing it on the maze. Maze complexity is increased by adding addition walls to the maze. The mean test-retest reliability is .62 (Gathercole, Pickering, Ambridge, & Waring, 2004).

Complex span tasks

The *Backward digit recall* is similar to *Forward digit recall*, the only difference is that the backward digit recall task requires participant to recall the sequence of numbers in reverse order. The test-retest reliability of the test is from .53 to 0.71 (Gathercole, Pickering, Knight, & Stegmann, 2004).

In the *Listening recall test*, the participant listens to a series of short sentences and is asked to judge the veracity of each sentence by responding “yes” or “no”. Then, the participant is required to recall the last word of each sentence in the same order that the sentences were presented. The task begins with one sentence and increases by an additional sentence, following the same pattern as *Forward digit recall*. The mean rest-retest reliability coefficient of this task is .61 (Gathercole, Pickering, Ambridge, & Waring, 2004)

In the *Counting recall task*, the participant views an array of shapes consisting of targets and distracters, for example red circles and blue squares. The participant is asked to count how many red dots are in this picture, and then at the end of a series of arrays they are asked to recall the sequence of count totals. The trial begins with two pictures in one trial and increases the complexity by adding one additional red dot for each level when the participant get four trials correct out of six in one level. Six red dots will be the maximum to present in one trial. The mean rest-retest reliability coefficient of this task is .61 (Gathercole, Pickering, Ambridge, & Waring, 2004).

The *Letter-number sequencing* is a part of Working Memory index of the Wechsler Intelligence Scale for Children-V (WISR-V; Wechsler, 2014). Participants listen to a series of letters and numbers and are required to sort out the letters in alphabetical order and the numbers in ascending order, and state this transformed sequence to the administrator. The total number of correct trials is recorded.

The *Odd-One-Out* is a task that involves the presentation of arrays of three boxes with one shape in each. Two shapes are identical and a participant is asked to select the non-matching shape, remember the location in each array and recall the location of the odd shape when presented with an array of empty boxes at the end of the trial (Engel de Abreu et al., 2014). The test-rest reliability of the original test is .81 (Alloway et al., 2006).

The *N-back paradigm* involves that participants being asked to monitor the identity or location of a series of verbal or nonverbal stimuli and to indicate when the currently presented stimulus is the same as the one presented in N trials previously (Owen, McMillan, Laird, & Bullmore, 2005). In the N-back paradigm, N will be pre-specified as the integer, usually it is 1, 2, or 3. The task requires monitoring and manipulation of remembered previous information during the tasks. Therefore, it assumed to place great demands on a number of key processes within working memory (Owen et al., 2005). Also, in some studies, a 0-back control condition will be tested, which requires participants to respond to which is the pre-specified stimuli that has just been shown. This condition test does not require the manipulation of information within working memory (Ragland

et al., 2002). However, in a recent review, Jaeggi, Buschkuhl, Perrig, & Meier (2010) pointed out that the N-back task is not a useful measure of individual differences in working memory, partly because of its insufficient reliability.

In the *Running span task*, participants are asked to view a running letters or numbers sequences where length of the sequences is $m+n$. Then participants are asked to recall the last n items when the sequences have been displayed. The last n items that are to be recalled are called targets, while m items are non-target letters in the sequences. The $m+n$ items that are displayed are called input sequence. For example, if the last four items were to be reported from an input sequence that was five items long (e.g., T K U I O), a response of "K U I O" would receive 4 points, but a response of "T K U I" would receive 0 points (Broadway & Engle, 2010). They also concluded that the running memory span provides valid measurement of working memory capacity because it is predictive of higher order cognition across a wide range of conditions (Broadway & Engle, 2010).

1.3 Inhibition

The second executive function in this thesis is inhibition, also known as inhibitory control (Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, & Greenberg, 2010). Insights into the nature of inhibition are beginning to develop (Miyake et al., 2000). Barkley (1997) suggested behavioural inhibition is a core function of executive function. In this section, I will discuss the definition of inhibition, the developmental trends in inhibition and the commonly used inhibition tasks.

1.3.1 Definition of inhibition

Definitions of inhibition have been widely discussed in this field (Barkley, 1997; Logan, Schachar, & Tannock, 1997; MacLeod, 2007). For example, MacLeod (2007, p5) suggested that '*Cognitive inhibition is the stopping or overriding of a mental process, in whole or in part, with or without intention.*' MacLeod further explained that inhibition could be considered as either an act of will or an automatic process, which could be a by-product of another cognitive

process. This definition raised the possibility of unintentional suppressing of an ongoing task. However, this thesis focuses on a deliberate and intended suppression of prepotent responses.

Barkley (1997) proposed there are three parts of inhibition, inhibition of prepotent responses, stopping of an ongoing response, and interference control. Furthermore, inhibitory functions were proposed to play an important role for the efficient functioning of other executive functions. For example, people with attention deficient hyperactivity disorder (ADHD) experience poor inhibition, which leads to secondary deficits in executive functions (Klenberg, Korkman, & Lahti-Nuutila, 2001).

In this thesis, the definition of inhibition is narrowed to the first two parts of Barkley's theory, inhibition of prepotent responses and stopping of an ongoing response. It can be explained as the ability to stop planned or ongoing actions or thoughts (Logan, 1994). It also requires people to override the tendency and focus on a more dominant response (Miyake et al., 2000). Like other aspects of executive functions, it has been linked to the frontal lobes (e.g., Jahanshahi, Profice, Brown, Ridding, Dirnberger, & Rothwell, 1998; Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998).

1.3.2 Tasks used to assess inhibition

Several tasks have been used to assess the executive function of inhibition. With young children, researchers sometimes use the Statue task. The Statue task is a motor inhibition task from NEPSY, which requires children to stand in a statue pose for 75 seconds. The examiner attempts to distract children, such as by coughing or dropping a pencil. Each 5-second epoch is recorded for children's eye and body movement and talking (Wiebe et al., 2008).

The *Tower of Hanoi* (ToH; Simon, 1975; Welsh, Pennington, & Groisser, 1991) is a task with several variants, which is considered to measure inhibition by getting to the final state with fewest moves. For example, in Miller et al., (2012)'s study, children were instructed to move three monkeys from the leftmost tree to the rightmost tree and there were two rules that needed to be followed: a) Only one monkey can be moved at one time; b) the smaller monkey can be placed on

top of bigger monkeys, but bigger monkeys cannot be on top of the smaller monkeys. The aim is to reach the goal state in as few moves as possible, without violating the rules.

Similarly, the Tower of London (ToL; Shallice, 1982) is a task requiring children to move objects to achieve the goals given by examiner. It is important to note that these tasks were originally considered as a test of planning and problem solving, however, empirical evidence has supported the view that they are instead inhibition tasks (Lehto et al., 2003). Task reliability of the Tower of London was explored in 1036 4-13-year-old children and the Cronbach's alpha was .46 (Fancello, Vio, & Cianchetti, 2006).

The *Go/No-Go* paradigm (Durstun, Thomas, Yang, Uluğ, Zimmerman, & Casey, 2002) has been extensively used in children to assess inhibition and has acceptable test-retest reliability .58 (Willoughby & Blair, 2011). The *Go/No-Go* paradigm requires children to press the button every time they see a 'go' signal, such as an animal. However, children have to withhold pressing the button when they see a 'no-go' signal, a particular animal such as a pig. Different studies include different proportions of go and no-go signals, for example Brydges, Reid, Fox and Anderson's study (2012) has 75% of go signals in the task. The correct responses and reaction times to go signals to no-go signals are usually recorded (Howard, Okely & Ellis, 2015; Brydges et al., 2014). The reliability is .91 in the study conducted by Xu, Han, Sabbagh, Wang, Ren, & Li (2013).

The *Stroop* task (Stroop, 1935) can be administered in a paper version or a computerised version. There are three conditions, often termed neutral, congruent, and incongruent conditions. In the neutral condition children are asked to name the colour of strings of asterisks as quickly as possible. In the congruent condition, the stimuli are words and the meaning of the word and the ink colour of the word are the same, for example, 'BLUE' is presented in blue ink. In the incongruent condition, children are asked to state the ink colour of incongruent words (for example, the word 'RED' presented in blue ink). Researchers commonly use a score of the difference in time taken to complete the neutral condition and incongruous condition (Brydges et al., 2012, 2014; Xu et al., 2013).

The *Stop-signal* is an inhibition task with several variants. For example, a Stop-signal task adapted from Van Boxtel, Van Der Molen, Jennings, & Brunia (2001), in which children are asked to respond as quickly as possible to a left or right pointing arrow by a left or right button press. The colour of the arrow changes from green to red on 20% of the trials, indicating children should suppress their responses. The correct rate for inhibiting the stop signals is recorded (Huizinga, Dolan, & Van Der Molen 2006).

In the *Eriksen Flankers* task (modified from Ridderinkhof & Molen, 1995), children are presented with five arrows with a target arrow in the middle. The target arrow is flanked by four arrows pointing in the same direction (i.e., $\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow$ or $\leftarrow\leftarrow\leftarrow\leftarrow\leftarrow$; congruent condition) or by four arrows pointing to the different direction (i.e., $\leftarrow\leftarrow\rightarrow\rightarrow\leftarrow\leftarrow$ or $\rightarrow\rightarrow\leftarrow\leftarrow\rightarrow\rightarrow$; incongruent condition). Children are required to identify the direction of the target arrow on both conditions as quickly and accurately as possible. The reaction time and accuracy on both conditions are recorded (Engel de Abreu et al., 2014; Huizinga et al., 2006; Lee, Ng, Pe, Ang, Hasshim, & Bull 2012).

In the *Simon task* (modified from Simon & Berbaum, 1990), children are presented with either a red rectangle or a green rectangle. Red or green rectangles appear randomly on the left or right side of the screen. Children are asked to press a button on the left when they see a red rectangle or press a button on the right when they see a green rectangle no matter where the rectangles are. The congruent condition is a red rectangle on the left side of the screen and green rectangle on the right side of the screen. The incongruent condition is a red rectangle on the right side and green rectangle on the left side, as they are opposite to the keyboard positions that children have to press to make their response (Engel de Abreu et al., 2014; Lee, Ng, Pe, Ang, Hasshim, & Bull, 2012; Van Der Ven, Kroesbergen, Boom, & Leseman, 2013).

1.3.3 Developmental trends in inhibition

Aged-related improvements in inhibition have been found during childhood and adolescence (Bedard, Nichols, Barbosa, Schachar, Logan, & Tannock, 2002; Klenberg, Korkman & Lahti-Nuutila, 2001; Narra & Mathew, 2012; Williams,

Ponessa, Schachar, Logan, & Tannock, 1999). Klenberg, Korkman & Lahti-Nuutila (2001)'s study included 400 healthy Finnish children aged from 3 years old to 12 years old who completed two tasks of inhibition, Statue and Knock and Tap. The results suggested that the development of inhibition begins at a fairly early age. Developmental improvements were evident from 3 to 5 years old. In the Statue task, children could reach a 12-year-old level when they were 6 years old, and in the Knock and Tap task, children reached a 12-year-old level when they were at the age of 7 years. Other work, however, has suggested that developmental improvements still arise beyond this age. Bedard et al., (2002) identified that children aged from 6-12 years old performed significantly less accurately than adolescents (13-17 years old group) on inhibitory stop-signal tasks. Results also indicated that the stop-signal reaction time of inhibition got faster with age throughout childhood. However, reaction time alone cannot explain the development of inhibition.

The developmental trends of inhibition are also varied in different inhibition tasks and maturity is reached at different ages depending on the particular task (Dempster, 1992; Nigg, 2000). In Go/No-Go task, Howard et al., (2015) found that 4-year-old children outperformed 3-year-olds among 281 participants. Xu et al., (2013) found that in a sample of 457 children of 7-15 years old, children 13-15 years old were better than those 10-12 years old, and those 10-12 years old were better than those aged 7-9 years old. Brydges et al., (2014) found a similar result in a sample of 135 of children. Significant improvement in Go/No-Go was found in 10-year-old children compared to 8 year old children. However, in the earlier studies, Brydges et al., (2012) did not find the improvement in 215 children from 7- to 9-years old. Becker, Isaac and Hynd (1987) suggested that children aged 8 years old can perform Go/No-go tasks as well as those aged 10-12 years old.

In the Stop-signal task, the reaction times to both stop and go signals improves throughout childhood, from 6 years old to 17 years old (Williams et al., 1999). Age-related differences also have been found from 7-year-old to 15-years old, however, there may be no significant difference between 15-year-old and 21-year-olds (Huizinga et al., 2006).

Several studies have demonstrated developmental improvements on the Stroop task, for example, Huizinga, Dolan, & Van Der Molen (2006) demonstrated improvements from aged 7 to aged 21, and Wu et al., (2011) found that Stroop performance improved significantly from aged 7 to aged 14, and Brydges et al., (2014) pointed out that performance significantly improved from 8-years-old to 10-years-old.

Developmental improvements on the other tasks have also been found. Huizinga et al., (2006) found that there is a significant improvement across 7-to 15-year old children but not from 15- to 21-years old in the Eriksen Flankers task. Furthermore, in an 18-month longitudinal study, it has been found that children who are aged 8 were significantly better than when they were 6.5 years old on the Simon task, regarding both accuracy and speed (Van Der Ven et al., 2013).

The age at which maximum performance is achieved on tasks of inhibition varies across different tasks. A Go/No-Go task, Stop-signal task, Stroop task, Eriksen Flankers task and Simon task are commonly used measures. Previous studies have showed that Go/No-Go task, Stop-signal task and Eriksen Flankers task reach their age plateaus at age 15 (Huizinga et al., 2006; Williams et al., 1999; Xu et al., 2013), while Stroop task seems to continue developing into adulthood (Huizinga et al., 2006). The Simon task has been applied to a younger age due to the simple rules, therefore, there are no age thresholds being indicated in the literature.

The reason why different tasks may appear to have different age thresholds may be due to the different types of inhibition. One explanation for it is that greater inhibition is required when responding according to a harder rule than an easier rule (Davidson, Amso, Anderson, & Diamond, 2006). Another major model which explains developmental inhibition is susceptibility to interference (Dempster, 1993). This model suggests that developmental change in ability to suppress the distraction is related to the maturation of the frontal lobes. During ontogenetic development, the frontal lobes increase in size and myelinisation is not complete until young adulthood. Increased cortical fistulation will allow more refined control of behaviours, such as selection, regulation and verification. These behaviours are necessary to form the ability to resist interference.

Dempster (1993) has explained that the child is particularly sensitive to motoric forms of interference at the beginning. This is followed by a period of increased sensitivity in perceptual forms of interference accompanied by a decline in the sensitivity to motoric interference. Eventually, children show increased sensitivity to linguistic interference associated with reduced sensitivity to perceptual interference. Therefore, different tasks involve a variety of information and interference forms, which leads to age thresholds being presented different in tasks.

1.4 Shifting

1.4.1 Definition of shifting

Shifting is the third executive function investigated in this thesis. It is also known as 'flexibility', 'switching', 'attention switching' and 'task switching' (Miyake, et al., 2000). In this thesis, 'shifting' is used to represent this function, which involves switching backwards and forwards between multiple tasks, operations or mental sets (Monsell, 1996).

According to one definition, shifting refers to switching from one mental set to another one, which involves two stages (Huizinga, Dolan, & Van Der Molen, 2006). The first stage requires participants to form a mental set, which is an association between a particular stimulus and a response. Participants need to focus on relevant stimuli and disregard the irrelevant information. The second stage involves switching to a new mental set, which conflicts to the former association.

The nature of shifting has been broadly discussed in two ways, namely attention shifting and response shifting (Dias, Robbin, & Roberts, 1996; Nagahama, Fukuyama, & Shibasaki, 2002). The type of shifting is distinguished by whether the conflicts happen in the perceptual or response stage. If a shift requires attention to be redirected to a different aspect of a stimulus this is labelled attention shifting. For example, in the dimensional change card sort (DCCS; Frye, Zelazo & Palfai, 1995), participants are required to sort cards on two dimensions (e.g. shape and colour). In phase one, participants have to sort

the cards out by colour, but in the next phase they need to be sorted by shape, thus attention is shifted from focussing on colour to focussing on shape.

When shifting does not require attention to be redirected to different aspects of a stimulus, but rather requires changes in the way that responses are selected, it is labelled response shifting or task shifting (Rushworth, Passingham, & Nobre, 2005). For instance, in the Hand Game (Hughes, 1998; Luria 1959), children are required to replicate the experimenter's hand posture, like fist or pointed finger in the first stage. However, children need to switch to an alternative posture in the second stage. Furthermore, a response shifting task requires a stimulus-reaction (S-R) association, which is learned during the task instead of an already established prepotent response.

1.4.2 Tasks used to assess shifting

One frequently used task of shifting is the Trail Making Task (McLean & Hitch, 1999; Reitan & Wolfson, 2004). It usually has two parts: Part A requires participants to connect a set of irregularly located numbers (i.e., from 1 to 50), and part B requires participants to connect numbers (i.e., from 1 to 25) and letters (i.e., from A to Y). Participants need to connect 1 and A, then continue to 2 and B, and so on. Sometimes, a third part (Part C) will be included as part of the control or baseline, in which children are asked to connect a series of letters in alphabetic order. The scores awarded can be correct connections within a given time (Van Der Sluis, De Jong, & Van Der Leij, 2007); completion time for each part (Lehto et al., 2003); or difference in the time taken to complete Part A and Part B (Rose, Feldman & Jankowski, 2011).

The *Wisconsin Card sorting test* (WCST) involves sorting cards according to one of three dimensions: colour, shape, or number (When children take part in the task, they need to sort cards out to match one of four key cards. The children are not told how to choose each dimension, i.e. whether to match for colour, shape or number, but they receive feedback regarding whether or not each card was correctly sorted. The dimensions change after ten consecutive trials, after which a child needs to work out the new dimension that they should be matching for. The measurement is the number of perseverative errors, in which a child

does not change his categorisation strategy even though the feedback indicates that their response it is not correct (Brydges et al., 2012; 2014); or the numbers of completed categories, which is the number of runs of ten correct responses (Arán-Filippetti, 2013).

A task similar to the WCST is the *Dimensional change card sort* (DCCS; Zelazo, 2006), which has been widely used with pre-school aged children (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Viterbori, Usai, Traverso, & De Franchis, 2015). Children are asked to sort two different types of cards out (i.e., rabbit and boat) based on either colour or shape. The administrator presents and clarifies both dimensions for the children and chooses one dimension (i.e., colour) as the sorting rule for the pre-switch phase. After six pre-switch trials, post-switch trials are administered (i.e., shape). The administrator repeats the rule for each trial but does not provide feedback, and never presents the same type of card on more than two consecutive trials. The score for this task is the number of correctly sorted cards for all trials.

1.4.3 *Developmental trajectory of shifting*

Some studies show that in the Wisconsin card sorting test, the ability of shifting improves from 6 years old to 20 years old, and the largest improvement occurs from 6 years old to 10 years old (Heaton, 1993). Brydges et al., (2012) found that children 7 – 9 years old improved in WCST performance, and Brydges (2014) found that children improved across 8-10 years old in a 2-year longitudinal study (Brydges et al., 2014).

Other research has also suggested that shifting abilities start to develop relatively early on in childhood. In a DCCS task, older 4-year-old children outperformed younger 4-year-old children and younger 4-year-old children outperformed 3-year-old children in a sample of 281 pre-schoolers (Howard et al., 2015). Zelazo (2006) suggested that most healthy 3-year-old children fail the post-switch tasks of DCCS, however the majority of 4- and 5-year olds pass this phase.

In the trail making task, Lehto et al., (2003) found that children who are aged from 8 to 13 show non-significant improvement in Part A and Part C. However, in

Part C of the trail making task, which required children to connect all the letters in alphabetic order, children showed significant improvement across 8 to 13 years old. Furthermore, Van Der Ven et al., (2013) found that in a sample of 211 children who were aged 6 from a longitudinal study, children performed significantly faster in the tasks after 18 months.

1.5 Verbal fluency

1.5.1 Definition of verbal fluency

Verbal fluency is the fourth function considered in this thesis, which includes retrieving information from long-term memory. Although not covered in the work by Miyake et al. (2000), verbal fluency has been considered an important executive function in research work. Verbal fluency can be assessed in two different ways, phonemic verbal fluency and semantic verbal fluency (Thurstone, 1938). Siegel (1994) indicated that a temporary storage of resources, which processes incoming information and retrieves information from long-term memory at the same time, was an important component of the development of reading skills. Baddeley (1996) also suggested that temporary activation of long-term memory was one of the key functions of the central executive. Unsworth, Spillers and Brewer (2010) indicated that in verbal fluency, an individual has a two-stage cyclical search process, which first searches for higher-order categories and is followed by a search for specific items within these categories.

Anderson (2002) proposed a developmental model of four discrete but inter-related executive domains, including information processing. In Anderson's model, information processing has been considered as measuring fluency, efficiency and speed of processing, which taps on the function of verbal fluency. Cassidy (2016) was the first one to identify verbal fluency as a distinct latent construct along with working memory, shifting, internalising and externalising factors in a sample of 353 children who were from 7 years old to 18 years old.

Another issue about verbal fluency is the relationship between verbal fluency and language proficiency; whether verbal fluency is driven by the verbal knowledge. Luo, Luk, & Bialystok (2010) examined fluency in three groups: two groups of bilinguals: a high-vocabulary group and a low-vocabulary group, and a

group of monolingual adults. The bilingual groups and the monolingual group performed equivalently in category fluency (semantic verbal fluency), but the high-vocabulary bilingual group outperformed both monolinguals and low-vocabulary bilinguals in letter fluency (phonemic verbal fluency). Luo et al., (2010) have indicated that on phonemic word verbal fluency task, vocabulary size had an impact from the initiation of the trail. Also, a novel word-search strategy is considered to reflect executive control on monitoring and retrieving new items. This therefore suggested that phonemic fluency relies more upon vocabulary size than semantic fluency. Jacobsen et al., (2017) also conducted verbal fluency tasks on children who were aged 6- to 12-year old. The results showed effects of age and school type, verbal fluency scores increased with age and were higher among private school students. Jacobsen et al., (2017) suggested that the impact of type of school on verbal fluency performance may be explained by the greater availability of cognitive stimulation (semantic knowledge), provided by private schools and families with better socioeconomic levels.

In the neuroscience research, most of neuroimaging studies of verbal fluency have demonstrated a left-lateralisation of the activation in the prefrontal cortex, involving Broca's language area and surrounding cortex (Bookheimer, 2002). Weiss et al., (2003) suggested that the role of these regions is still debated and may be related to verbal working memory, attentional, and executive functions which are essential features of actual verbal fluency.

The nature of verbal fluency as an executive function remains vague. It is not really known whether verbal fluency shares variance with the other executive function components, including working memory, inhibition and shifting, or whether it is a separate yet correlated additional factor.

1.5.2 Tasks used to measure verbal fluency

In this thesis, word fluency is a task used to measure verbal fluency. The word fluency task was first introduced by Thurstone (1938) as a written test of verbal fluency, which was called the Chicago Word Fluency Test (CWFT). It was the first standardised test for the psychometric assessment of word fluency. The oral fluency was developed about 30 years after WFT. The two types of word

fluency tasks are phonemic and semantic. Phonemic verbal fluency task requires participants to generate as many words as possible within a limited time beginning with a specific letter (i.e., letter 'S' or 'F'). Semantic verbal fluency task requires participant to say as many words as possible within a certain category (i.e., animals). The indicator is the total number of correct words generated for each condition.

Verbal fluency is used by 50% of neuropsychologists (Butler, Retzlaff, & Vanderploeg, 1991) and in general, persons with frontal lobe damage present a deficient in phonemic fluency while their semantic fluency remains intact (Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998). Some previous neuroimaging and lesion studies have suggested that semantic verbal fluency (category-based word retrieval) is mediated primarily by temporal cortex, while phonemic verbal fluency (letter-based word retrieval) is mediated primarily by frontal cortex (Gourovitch et al., 2000; Mummery, Patterson, Hodges, & Wise, 1996). Baldo, Schwartz, Wilkins, & Dronkers (2006) suggested that phonemic verbal fluency is dependent on frontal cortex because of its role in strategic retrieval of word forms. In the meantime, semantic verbal fluency is dependent on temporal cortex because of its role in accessing lexical-semantic networks.

Based on the previous literature and the neuroimaging research, verbal fluency is worth considering as an executive function task, especially as it has been categorised as a distinct executive function in previous literature. The verbal fluency tasks are also activating the prefrontal cortex and the temporal cortex. However, it is acknowledged that working memory, shifting and inhibition are measuring fluid ability, while verbal fluency partly relies on crystallised ability, such as vocabulary knowledge.

It is also important to note that the verbal fluency task has also been considered as measuring the shifting function (Arán-Filippetti, 2013; Brydges et al., 2012; 2014). Shifting from generating as many words as possible beginning with a specific letter to generating words from a specific category, is considered as switching mental sets. Arán-Filippetti (2013) failed to identify verbal fluency as a distinct function in a sample of 248 Spanish-speaking children aged from 8 to 12 years old. Arán-Filippetti (2013) has categorised verbal fluency within the

cognitive flexibility (shifting) factor. The task impurity issue can be shown in this way. Moreover, it has also been found that verbal fluency is dependent on working memory capacity, with a working memory factor receiving a small positive loading from a fluency task (Rosen & Engle, 1997). However, the task in this thesis was expected to measure the efficiency of verbal fluency.

1.5.3 Developmental trends on verbal fluency

Brydges and colleagues (2012) found that children who are aged 9 performed significantly better in the verbal fluency task when compared to those 7 years old. In 2014, Brydges and colleagues also found that 10-year-old children performed significantly better than 8-year-old children in verbal fluency tasks (Brydges, 2014).

In a sample of 160 Italian children who were aged from 5-to 11-year-old, there were significant age-related improvements on semantic and phonetic tasks (Riva, Nichelli, & Devoti, 2000). Sauzéon, Lestage, Raboutet, N'Kaoua, & Claverie (2004) have suggested that children who are 7-8 years old and 9-10 years old performed better in a semantic task than in a phonemic task. The development of the phonemic task only occurred after the age of 13-14 years. This could be explained by later development of the ability to use a search strategy, with information retrieval by letter requiring more effort than retrieval by a given category.

1.6 Different structures of Executive function in children

A range of cross-sectional research has been conducted to investigate the structure of executive functions. The three-factor model of executive functions found by Miyake et al. (2000) has also been found in children aged 7 years old to 14 years old (Duan, Wei, Wang, & Shi, 2010; Lehto et al., 2003; Rose, Feldman, & Jankowski, 2001; Wu, Chan, Leung, Liu, Leung, & Ng, 2011). Other studies, however, have identified a unitary structure in children aged 2 years old to 8 years old (Fuhs & Day, 2011; Hughes, Ensor, Wilson, & Graham, 2009; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Wiebe, Espy, & Charak, 2008;

Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011; Willoughby, Blair, Wirth, & Greenberg, 2010).

Other studies have shown a two-factor structure of executive functions in children. Most of these studies have indicated that working memory is one of the functions in the two-factor structure of EF. Van Der Ven, Kroesbergen, Boom and Leseman (2013) maintained that there is a two-factor structure including updating and a combined inhibition and shifting factor, which appeared amongst children aged 6 and 8. A working memory factor and an inhibition factor also have been found in children who are 3- 5 years old (Lerner & Lonigan, 2014) and 11-12 years old (St Clair-Thompson & Gathercole, 2006). A two-factor fractionation including working memory and shifting, has been identified in children aged between 9- and 12-years old (Van Der Sluis, De Jong, & Van Der Leij, 2007) and a 7-21 years old group (Huizinga, Dolan, & Van Der Molan, 2006). Usai, Viterbori, Traverso and De Franchis (2014) argued that there is a two-factor structure including an inhibition factor and a combined working memory and shifting factor in children between 5 and 6 years old.

Research has also suggested that the structure of EF can shift as children develop towards adulthood (Brydges et al., 2014). A longitudinal latent-variable analysis showed that the fractionation of EF significantly differed from 8 years old to 10 years old and the structure changed from a unitary model to a two-factor model including working memory and a combined inhibition and shifting factor. This study also provided evidence of the development and differentiation of EF.

Due to the growing literature on the structure of executive functions in children, and the different patterns of findings that have emerged, the key findings from published literature on this topic have been summarised in table 1.1.

Table 1.1: A summary of studies concerned with the structure of executive functions during childhood

No	Study	N	Age (year)	Design	Factors and tasks	Applied Statistics	Findings
01	Wiebe et al. (2008)	243	2.25-6	Cross-sectional	<u>Working memory:</u> Delayed Alternation task, Six boxes, Digit span task <u>Inhibitory control:</u> Delayed response task, Whisper task, Statue, Visual attention, Shape school, Tower of Hanoi, Continuous performance test	CFA	<u>Single factor</u>
02	Willoughby et al. (2010)	112 3	3	Longitudinal	<u>Working memory:</u> Working memory span <u>Attention shifting:</u> Item selection <u>Inhibitory control:</u> Spatial conflict, Silly sounds stroop, Animal Go No-Go	CFA	<u>Single factor</u>
03	Wiebe et al. (2011)	228	3	Cross-sectional	<u>Working memory:</u> Nine boxes, Nebraska Barnyard, Delayed alternation <u>Inhibitory control:</u> Big-little stroop, Go/No-go, Snack, Shape school, Delay	CFA	<u>Single factor</u>
04	Fuhs and Day (2011)	132	3-5	Longitudinal	<u>Response inhibition:</u> Head/Feet game, Day/Night game, BRIEF-P (inhibition)	CFA	<u>Single factor</u>

					<u>Attention shifting</u> : Flexible item selection task, spatial reversal, BRIEF-P (shifting)		
05	Brydges et al. (2012)	215	7-9	Cross-sectional	<u>Inhibition</u> : Stroop, Go/no-Go, Compatibility reaction time <u>Working memory</u> : Letter-number sequencing, Backward digit span, Sentence repetition <u>Shifting</u> : Wisconsin Card Sorting Task (WCST), Verbal Fluency, Letter monitoring	CFA and SEM	<u>Single factor</u>
06	Hughes et al. (2009)	191	4,6	Longitudinal	<u>Working memory</u> : Beads <u>Inhibitory control</u> : Day/Night stroop <u>Planning</u> : Tower of London	CFA	<u>Single factor</u>
07	Willoughby et al. (2012)	103 6	5	Longitudinal	<u>Working memory</u> : Working memory span, Pick the picture <u>Attention shifting</u> : Something's the same <u>Inhibitory control</u> : Spatial conflict arrows, Silly sounds stroop, Animal Go No-Go	CFA	<u>Single factor</u>
08	Brydges et al. (2014)	135	8,10	Longitudinal	<u>Working memory</u> : Letter-number sequencing task, Backward digit span, Sentence Repetition test <u>Shifting</u> : WCST, Verbal Fluency test, Letter Monitoring task <u>Inhibition</u> : Stroop, Go/No-Go task, Compatibility reaction time task	CFA and SEM	<u>One factor (younger); Two factors (older):</u> working memory and an

							inhibition/shifting combined factor
09	Howard et al. (2015)	281	3-4	Cross- sessional	<u>Working memory:</u> Backward word span <u>Shifting:</u> Dimensional change card sort <u>Inhibition:</u> Go/No Go	HMR*	<u>One factor</u> (younger), <u>Discrete yet</u> <u>related</u> (older)
10	Shing et al. (2010)	263	4-7, 7- 9.5, 9.5- 14.5	Cross- sessional	<u>Memory maintenance:</u> Abstract shapes, Dots-mixed <u>Inhibitory control:</u> Dots-mixed, Dots-incongruent, Pictures, Arrows	SEM	<u>One factor (4- 7,7-7.5), Two</u> <u>factors (9.5- 14.5):</u> Memory maintenance, inhibitory control
11	Xu et al. (2013)	457	7-9 10- 12 13- 15	Cross- sessional	<u>Updating working memory:</u> N-back task, Running memory task <u>Shifting:</u> Number-pinyin task, Dots-triangle task <u>Inhibition:</u> Go/No-Go task, Colour-word stroop	CFA	<u>One factor (7- 9,10-12), Three</u> <u>factors (13-15):</u> Updating working memory, Shifting, Inhibition

12	Lerner & Lonigan (2014)	285	3-5	Cross-sessional	<u>Working Memory:</u> Word span reversed, Size ordering, Object span, Listening span <u>Inhibitory Control:</u> Bird and dragon, Luria's hand game, Picture imitation, Block sorting, Day-Night, Knock-tap	CFA	<u>Two factors:</u> Working memory, Inhibitory control
13	Miller et al., (2012)	129	3-5	Cross-sessional	<u>Working memory:</u> Backward digit and backward word spans, Boxes task, Preschool continuous performance test (P-CPT) <u>Shifting:</u> Go/No Go, Border version Of the Dimensional Change Card Sort <u>Inhibition:</u> P-CPT, Boy-girl stroop, Tower of Hanoi, Go/No-Go	CFA	<u>Two factors:</u> Working memory and Inhibition
14	Lonigan et al., 2016	241	38-69 months (3-5 yrs)	Cross-sessional	<u>Working memory:</u> Size ordering task, Word span reversed task, Listening span task, Animal span task <u>Inhibitory control:</u> Knock-Tap task, Picture Imitation task, Day-Night Stroop task	CFA	<u>Two factors:</u> Working memory, Inhibitory control
15	Viterbori et al., (2015)	175	5	Longitudinal	<u>Working memory:</u> Backward digit span, Dual request selective task <u>Flexibility:</u> Semantic fluency, Dimensional change card sort	CFA and SEM	<u>Two factors:</u> Inhibition, working

					<u>Inhibition:</u> Circle drawing task, Tower of London		memory/flexibility
16	Usai et al., (2014)	565	5, 6	Longitudinal	<u>Working memory:</u> Backward digit span, Dual request selective task <u>Shifting:</u> Semantic fluency, Dimensional change card sort <u>Inhibition:</u> Circle drawing task, Tower of London	CFA	<u>Two factors:</u> Inhibition, working memory/shifting
17	Lee et al., (2012)	163	6	Cross-sectional	<u>Updating:</u> Listening recall task, Mister X task, Pictorial updating task <u>Inhibitory:</u> Flanker task, Simon task <u>Switching:</u> Flanker task, Simon task, Picture-symbol task	CFA and SEM	<u>Two factors:</u> Updating, Inhibition/switch factor
18	Monette et al., (2015)	272	68.4 2 months, longitudinal study)	Cross-sectional (draw from longitudinal study)	<u>Working memory:</u> Backward word span, Backward block span <u>Flexibility:</u> Trails-P, Card sort, Verbal fluency shift, Face sort <u>Inhibition:</u> Fruit Stroop, Day-night test, Hand Stroop	CFA	<u>Two factors:</u> Working memory-flexibility, Inhibition
19	Van Der Ven et al. (2013)	211	6, 7.5	Longitudinal	<u>Updating:</u> Digit span backwards, Odd one out, Keep track <u>Shifting:</u> Animal shifting, Trail making test in colours, Sorting task <u>Inhibition:</u> Animal stroop, Local global, Simon task	CFA	<u>Two factors:</u> Updating, Inhibition/shifting factor

20	Van Der Sluis et al. (2007)	172	9-12	Cross-sessional	<u>Inhibition</u> : Quantity inhibition, Object inhibition, Stroop, Numerical size inhibition <u>Shifting</u> : Objects shifting, Symbol shifting, Place shifting, Making trails task <u>Updating</u> : Keep track, Letter memory, Digit memory,	CFA	<u>Two factors</u> : Shifting, Updating
21	Huizinga et al. (2006)	384	7, 11, 15, 21	Cross-sessional	<u>Working Memory</u> : Tic tac toe, Mental Counters, Running Memory <u>Shifting</u> : Local-Global, Dots-Triangles, Smiling Faces <u>Inhibition</u> : Stop-signal, Eriksen Flankers, Stroop	CFA	<u>Two factors</u> : Working memory and Shifting
22	Lee et al. (2013)	688	6-15	Longitudinal	<u>Updating</u> : Listening recall task, Mister X task, Pictorial updating task <u>Inhibition</u> : Flanker task, Simon task, Mickey task <u>Switch</u> : Flanker task, Simon task, Picture-symbol task	CFA	<u>Two factors (5-13 yrs)</u> : Updating, Inhibition/Switch; <u>Three factors (12-14 yrs)</u> : Updating, Inhibition, Switch
23	Ropovik (2014)	96	9-10	Cross-sessional	<u>Inhibition</u> : Stroop <u>Selective attention</u> : Toulouse-Pieron test	SEM	<u>Three factors</u> : Inhibition, Selective

								attention, Working memory
24	Rose et al. (2011)	134	11	Longitudinal	<u>Working memory:</u> Spatial working memory, Listening span <u>Shifting:</u> Trail making, Intra/Extra-dimensional shift <u>Inhibition:</u> Go/No-Go, Rapid visual information processing	CFA		<u>Three factors:</u> Working memory, Shifting, Inhibition
25	Arán-Filippetti (2013)	248	8-12	Cross-sectional	<u>Cognitive flexibility (Shifting):</u> WCST, Matching familiar figures test <u>Inhibition:</u> Stroop Color-Word Test <u>Working Memory:</u> Digit Span, Letter-Number Sequencing <u>Verbal fluency:</u> Semantic Verbal Fluency Test, Phonological Verbal Fluency <u>Planning:</u> Porteus Maze Test	CFA and MGCF A		<u>Three factors:</u> Working memory, Cognitive flexibility (Shifting), Inhibition
26	Lehto et al. (2003)	108	8-13	Cross-sectional	<u>Shifting:</u> Word Fluency test, Trail Making Test <u>Working memory:</u> Auditory attention and response set, Spatial span task, Spatial working memory task, Mazes <u>Inhibition:</u> Tower of London, Matching familiar figures	EFA and CFA		<u>Three factors:</u> Shifting, Working memory, Inhibition
27	Wu et al. (2011)	185	7-14	Cross-sectional	<u>Shifting:</u> Creature Counting, Opposite World, Naming Test <u>Working Memory:</u> Code transmission	SEM		<u>Three factors:</u> Shifting, Working

					<u>Inhibition</u> : Sky search, Stroop, Tower of London		memory/Updating, Inhibition
28	McAuley & White, 2011	147	6-24	Cross-sectional	<u>Processing speed</u> : Simple reaction time task, Go/No-Go, Stimulus-response compatibility task <u>Response inhibition</u> : Go/No-Go, Stimulus-response compatibility task <u>Working memory</u> : Two-back task, Recognition span task, Digit span task	CFA	<u>Three factors</u> : Processing speed, Inhibition, Working memory
29	Engel de Abreu et al., (2014)	106	6-8	Cross-sectional	<u>Working memory</u> : Digit recall, Counting recall, Dot matrix, Odd-One-Out <u>Cognitive flexibility</u> : Duck task, Opposite World <u>Inhibition</u> : O Mestre Mandou, Go/No Go, Simon task, Flanker task <u>Selective attention</u> : Map mission, Sky Search	PCA***	<u>Four factors</u> : Working memory/cognitive flexibility, Interference suppression, Selective attention, Response inhibition

30	Klenberg et al. (2001)	400	3-12	Cross-sectional	<u>3-4 yrs:</u> Statue, Visual search, Semantic Fluency <u>5-6 yrs:</u> Above and Knock and Tap, Auditory Attention, Auditory response set, visual attention, Tower, Design fluency test <u>7-12 yrs:</u> Above and Phonemic fluency test	EFA	<u>Four factors:</u> Inhibition, Auditory attention, Visual attention and Fluency
31	Agostino et al., (2010)	155	8-13	Cross-sectional	<u>Mental-attentional capacity (M-capacity):</u> Mental-Attention Memory task, Direction Following task <u>Inhibition:</u> Antisaccade task, Number Stroop task, Colour Stroop task <u>Updating:</u> Letter-Memory task, Visual n-back task <u>Shifting:</u> Contingency Naming task, Trail Making Test (TMT)	SEM	<u>Four factors:</u> M-capacity, Inhibition, Updating, Shifting
32	Garcia-Barrera et al., (2011)	216 5	6-11	Cross-sectional	<u>Behavioural control:</u> Behavioural assessment of executive functions (BASC) <u>Emotional control:</u> (BASC) <u>Attentional control:</u> (BASC) <u>Problem solving:</u> (BASC)	CFA	<u>Four factors:</u> Behavioral control, Emotional control, Attentional

33	Cassidy (2016)	352	7-18	Cross-sessional	<u>Working memory</u> : Spatial Span, Spatial working memory, Digit span, BRIEF <u>Shifting</u> : BRIEF <u>Verbal Fluency</u> : Verbal fluency tasks <u>Externalizing</u> : Child Behavior Checklist <u>Internalizing</u> : Child Behavior Checklist	CFA	control, Problem solving <u>Five factors</u> : Working memory, shifting, verbal fluency, Externalizing, Internalizing
34	Fisk & Sharp (2004)**	95	20-81	Cross-sessional	<u>Updating</u> : Reading span, Computation span, Brooks spatial sequences, Random generation, Consonant updating <u>Shifting</u> : WCST <u>Inhibition</u> : Random generation <u>Accessing long-term memory</u> : Chicago word fluency test	PCA	<u>Four factors</u> : Updating, Shifting, Inhibition, Long term memory access

* HMR: Two-step hierarchical multiple regression

**MGCFA: Multi-group confirmatory factor analysis

***PCA: Principal component analysis

****No.34 Fisk and Sharp's paper is drawn from an adult sample study, however, it is a key paper which includes assessing long-term memory function that this thesis want to look at

1.7 How different tasks influence structure of EF

Whether executive functions are dissociable or not, there is a problem when researchers tend to investigate the structure of EF by using executive tasks. Miyake et al., (2000) argued that it is difficult to examine components of EF purely, because executive functions manifest themselves in tasks not aimed at assessing that specific executive function. This is the so-called task impurity problem. For example, the WCST is primarily used to test the shifting function of executive processes, but other researchers (Wang, Kakigi, & Hoshiyama, 2001) also maintain that WCST involves inhibition and working memory. When a category switch occurs, participants have to suppress or inhibit the former response. Also, working memory has to be updated every time the categories change in the task. The Word Fluency test is viewed as a measurement of shifting in a study by Lehto et al., (2003), but considered as tapping on accessing long-term memory by Fisk and Sharp (2004). The Tower of London has been employed for inhibition by Lehto et al., (2003), but has also been viewed as a measure of problem-solving and planning (Klenberg et al., 2001), and working memory and attention (Sikora, Haley, Edwards, & Butler, 2002).

Moreover, low test-retest reliability in complex executive tasks may result in low correlations with other executive tasks. Therefore, multiple separable factors may be the reflection of low reliability rather than the reflection of independent EF targeted by individual tasks.

The method for dealing with executive task impurity problems is to use control tasks (Scheres et al., 2004; Sergeant, Geurts, & Oosterlaan, 2002). In this design, participants perform executive tasks and control tasks, and the only difference between them is an additional component related to a particular executive function. Therefore, researchers can focus on the difference in the performance on the executive tasks and control tasks, such as difference scores or on the variance in the executive tasks that cannot be explained by the control task, for example a regression residual (Van De Sluis, De Jong, & Van Der Leji, 2007). It is also important to note that research examining the structure of executive functions has also used different methods of analysis, such as an exploratory factor analysis and confirmatory factor analysis.

1.8 Exploratory Factor Analysis and Confirmatory Factor Analysis

Exploratory factor analysis, such as Principal Factoring Analysis (PCA), is used to obtain general dimensions of executive functions. It allows researchers to explore the potential structure of a large set of variables and look for the underlying relationships between measured variables (Lehto et al., 2003).

Confirmatory factor analysis is also a useful approach to examine EF models, and it is being used by an increasing number of studies (e.g. Huizinga, Dolan, & Van Der Molen, 2006; Lehto, et al., 2003; Miyake, et al., 2000). For example, Miyake et al., (2000) suggested shifting, working memory, and inhibition are relatively correlated, but clearly separable by using CFA. There are two advantages when using this approach to study the organisation and roles of EF (Miyake et al., 2000). One is that CFA is driven by theories, which helps researchers to test their models against competing and existed models effectively and explicitly. The other is that CFA extracts latent variance from different tests. CFA is using different executive tasks in one executive domain to extract common variance and the consequence is that latent variables are considered as a purer measure of the EF organisation. In addition, Miyake et al., (2000) proposed that the results of structural equation modelling suggested that three mentioned executive functions contribute to performance on complex executive tasks differentially.

In conclusion, Chapter one has explored executive functions, including working memory, inhibition and shifting. Verbal fluency has also been considered as an additional executive function. Chapter one has also illustrated two different points of view on the unity or diversity structures in executive functions during childhood. A range of studies have been conducted to investigate the structure of executive functions, which is summarised in a table. An empirical study in Chapter two is going to examine whether verbal fluency is a fourth executive function in typically developing children and to look for an underlying structure of these executive functions.

Chapter 2. Investigating the structure of executive functions in typically developing children

In this chapter, a cross-sectional investigation of the fractionation of executive functions in typically developing children who are from 7 years old to 14 years old is reported. As noted in Chapter 1, this research thesis will investigate working memory, inhibition, shifting and verbal fluency as four separate but correlated executive functions, alongside the developmental trajectories of these executive functions, and look for the underlying structure of these functions using confirmatory factor analysis.

2.1 Present Study

The aims of this research were to: 1) examine age-related differences in each executive function from childhood to early adolescence; 2) investigate the fractionation of executive functions in children aged between 7 and 14 years old.

2.2 Method

2.2.1 Participants

187 typically developing children who were aged from 7 years old to 14 years old participated in this study and they were from three different year groups (i.e. year 3, year 6 and year 9). Two of them were removed because of absence for the second part of testing, 185 participants remained in the data analysis. There were 98 girls and 87 boys in the whole sample. The mean age and standard deviation of whole sample and different age groups are presented in table 2.1. Children were recruited from mainstream schools in the North East of England. At the time of recruitment, schools indicated that none of the participants had been identified with special education needs. Assent was obtained from each child and consent was additionally obtained from their parents/guardians. Prior to the study, a favourable ethical opinion was provided by the Newcastle University Ethics Committee.

Table 2.1. Descriptive statistics showing the number, gender ratio, mean age and standard deviation for whole group and each age group

	N (girls : boys)	Mean (years old)	sd
whole group	185 (98:87)	10.93	2.74
Year 3 7 year old group	60 (33:27)	7.74	.57
Year 6 10 year old group	63 (28:35)	10.66	.79
Year 9 14 year old group	62 (37:25)	14.31	.25

2.2.2 Materials

Nine executive function tasks were used in the study.

Working memory was assessed using Lucid Recall Working Memory tests (St. Clair-Thompson, Stevens, Hunt, & Bolder, 2010), administered on a computer. This included three tasks that assess the phonological loop, the visuo-spatial sketchpad and the central executive. In the word recall test (WR), which was assessing the phonological loop, participants were required to listen to some words and click on the words on the screen in the same order as they were presented, using the computer mouse to select target words from within a 3 * 3 matrix of nine words. The test began with a demonstration with two words in the practise trial. During practise trials, children received audio feedback as to whether they were correct or not. There were then a series of trials beginning with two words to remember, increasing up to six words to remember. One more word would be added if participants answered 4 out of 6 trials correctly at the same list length. The test would stop when participants failed three or more trials at any level. Test-retest reliability was reported to be .71 at 7-9 years and .68 at 13 years (St Clair-Thompson, 2015). The score is the number of correct words at the maximum level that has been recalled by participant.

In the pattern recall test (PR), which was assessing the visuo-spatial sketchpad, participants were required to remember a number of patterns. A pattern within a 4 * 4 matrix was shown on the screen for two seconds, and children were then required to click on the squares in an unfilled matrix on the screen to copy the

pattern. The test began with a practise trial and children were given feedback. The test began with four squares and it would increase by two more squares as children correctly answered four trials at the same level. Each matrix size is regarded as a level. The test would stop when participants failed three or more trials at any level. The test-retest reliability was reported as .69 at the age of 7-9 and .77 at the age of 13 (St Clair-Thompson, 2015). The score awarded reflected the number of squares in the largest pattern that participants correctly recalled.

In the counting recall test (CR), which was assessing the central executive, children were required to count the red circles in an array of shapes on the screen and click on the right total at the bottom of the screen. After the presentation of several sets of shapes, they needed to recall each count total in the same order as they were presented. The test started with a demonstration and practise trials of two 2-count arrays and two 3-count arrays. Feedback was given. The task began with two numbers to remember and increased to a maximum of six numbers to remember. The number of counting arrays increased one count over subsequent trials, and the test stopped when a child failed three or more out of six trials at the same level. Test-retest reliability was reported to be .49 at the age of 7-9 and .76 at the age of 13 (St Clair-Thompson, 2015). The counting recall task was constructed in levels, each level representing an increase in the number of items that had to be held in working memory. The score is based on the total number of trials on which the count totals were recalled correctly (St Clair-Thompson, 2015)

Inhibition was assessed using the Simon Task (ST) and the Go/ No Go task (GNG). The Simon Task (Engel de Abreu et al., 2014) was administered using E-Prime 2.0 (Schneider & Zuccoloto, 2007). It included forty trials where a red block and a green block were presented on the screen separately. When participants saw the red block on the screen, they needed to click the left hand side shift key on the keyboard as soon as possible. When participants saw the green block on the screen, they needed to press the right hand side shift key on the keyboard as soon as they could. This was regardless of the blocks actual position on the screen (as left or right). Half the trials were incongruent, such that a left key press was required when a stimulus was presented on the right, or vice versa. The cut-off time was 1500ms, which means a maximum reaction time of 1500ms. The score awarded

was the proportion of correct responses across the entire task (Van Der Ven et al., 2013).

In the Go/No Go task, administered using E-Prime 2.0 (Schneider & Zuccoloto, 2007), adapted from Cragg and Nation (2008), there were two blocks and each block had 80 trials. In the first block, participants were asked to press on space bar as soon as possible to respond when they heard a 1000Hz tone and not to press any keys when they heard a 1500Hz tone. On the second block, participants were required to respond to the 1500Hz tone as soon as possible and not to respond to the 1000Hz tone. The cut-off time was 1500ms, which means a maximum reaction time of this length. The first block set up a baseline for response speed, and the second block was assessing inhibition ability when the rule was reversed. Therefore, the score awarded for the Go/No go test was the correct rate for the second block (i.e., Brydges et al., 2012).

Shifting was measured using the trail making task (TMT; Van Der Sluis, De Jong, & Van Der Leij, 2007) and Wisconsin card sorting task (WCST; Heaton 1993). In the trail making task, participants needed to complete the standard pencil-and-paper version of this task, including two parts (Part A and Part B; Reitan & Wolfson, 2004). Part A required participants to connect a set of numbers (1 to 50), which were located irregularly on a piece of paper. Part B required participants to switch between a set of numbers (1 to 25) and letters (A to Y). For example, participants needed to connect 1 and A, then continue to 2 and B, and so on. A practise trial was presented before the formal task. The score awarded was the number of correct connections made within a given time of 50 seconds. Part A built a baseline response and the process of part B involved shifting ability. Correct answers on part B were recorded. Test-retest reliability is .75 for part A; .85 for part B in an adult sample of 287 (Giovagnoli, Del Pesce, Mascheroni, Simoncelli, Laiacona, & Capitani, 1996).

WCST requires participants to sort cards according to one of three dimensions: colour, shape, or number (Heaton, 1993). It was programmed with PsyToolkit in a Linux system (Stoet, 2010). The rules are not explicitly conveyed to children and change at various points in the task. Feedback regarding whether or not the card was correctly sorted was conveyed to children. There were 60 trials in

this task, 10 trials for sorting cards according to colour, 10 trials for shapes, and 10 trials for number, and the later 30 trials were the same rule order as the former 30 trials. Correct items, perseveration errors and non-perseveration errors were recorded. Perseverative error is when a child does not change their categorisation strategy even though the feedback indicates that the response is not correct, and this variable assessed shifting ability. Non-perseverative errors are when a child has made a mistake, which did not follow the previous categorisation strategy or click the answers incorrectly to follow any rules (Brydges et al., 2012; 2014). WCST revised perseverative error was the total items minus perseverative error items, which was applied in the analysis. The higher the WCST revised perseverative error score is, the better shifting ability that participant has.

Verbal fluency was measured with the phonemic word fluency task and semantic word fluency task. The tasks were chosen from the NEPSY-II battery (Brooks, Sherman, & Strauss, 2009). In the phonemic word verbal fluency task (PWVF), within two minutes, participants were required to generate and write down as many words as possible, beginning with the letter 'S'. In the semantic word verbal fluency task (SWVF), participants needed to write down as many animals as possible in two minutes. The scores corresponded to the number of words generated. The test-retest reliability for verbal fluency tasks is .74 (Tombaugh, Kozak, & Rees, 1999).

2.2.3 Procedure

Children were seen in one group session and one individual session based in schools, each of which was about 30 minutes in length. The first session was a group session and was carried out in a computer room. 6-8 children were grouped together to complete tasks in order: trail making task part one, trail making task part two, semantic word verbal fluency task, phonemic word verbal fluency task, lucid recall working memory words recall task, pattern recall task and counting recall. The second part was an individual session, which was carried out in a small quiet room in school, including WCST, Simon Task and the Go/No-Go task.

2.2.4 Statistical analysis

From previous studies, effect sizes were considered as medium effect size at 0.5 (e.g. Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). One-way ANOVA in this study recommends that statistic power is 0.95, and the probability of type I error is 0.05. According to the number present above, a sample size of 33 is necessary, which is calculated by G*Power 3.1.9.2. In this study, we recruited 186 participants to take part.

All data were analysed using SPSS (Version 23). One-way ANOVA was applied to test differences in performance according to age in each test. *Post hoc* tests with *Bonferroni* equal variance assumed were applied to identify differences between age groups (Field, 2013). Bivariate Pearson's correlation tests were carried out to examine the relationship between variables in the whole group and in each age group. The alpha significance level was at .05. SPSS Amos was used to conduct confirmatory factor analysis (CFA; Blunch, 2012). In CFA, several fit indices were used to evaluate the model fit to the data. The Chi-square (χ^2), the Bentler's comparative fit index (CFI), the root-mean-square error of approximation (RMSEA) and akaike information criterion (AIC) were used (Hu and Bentler, 1998). The criteria for excellent model fit based on these indices: $\chi^2 / df < 3$ (Wheaton, Muthen, Alwin, & Summers, 1977), CFI \geq .95 and RMSEA $<$.05 (Hu & Bentler, 1998). Lower values of AIC indicate a better fit and so the model with the lowest AIC is the best fitting model (Kenny & McCoach, 2003).

2.3 Results

2.3.1 Data preparation

All data were screened initially for missing data and outliers in SPSS (Version 23). Data were examined for univariate outliers by applying standardised values (z-scores). Z-scores which are larger than absolute value of 3.29 were identified (Field, 2013). Z-scores of 3 participants in ST and 5 participants in GNG were smaller than -3.29. Outliers were replaced by the second highest or lowest value in the group (Ghosh & Vogt, 2012). Missing data were found in WR (1%), PR (1%), CR (1%), ST (1%) and GNG (2%). Skewness and kurtosis were calculated for each variable. The values for asymmetry between -2 and +2 and kurtosis values

between -7 and +7 are considered acceptable in order to prove normal univariate distribution (George & Mallery, 2010). Skew and kurtosis for all of tests met criteria for multivariate normality. These results are shown in table 2.2.

Table 2.2. Mean, Standard deviation, Skew, Kurtosis of whole sample

	Mean	SD	Range	Skew(SE)	Kurtosis(SE)
Words recall	4.16	1.20	0-6	-.70 (.18)	1.63(.36)
Pattern recall	7.13	2.08	0-12	-.28 (.18)	1.28 (.36)
Counting recall	4.03	1.35	0-6	-.09 (.18)	-.55 (.36)
Simon task	.94	.07	.68-1.00	-1.94 (.18)	3.98 (.36)
Go/No Go	.89	.12	.49-1.00	-1.95 (.18)	3.47 (.36)
WCST	48.36	4.14	34-56	-.78 (.18)	.73 (.36)
TMT	15.46	1-50	8.43	.75 (.18)	.83 (.36)
Semantic	17.05	6.27	2-36	.39 (.18)	.42 (.36)
Word Fluency task					
Phonemic	13.25	6.82	1-33	.62 (.18)	-.01 (.36)
Word Fluency task					

2.3.2 Development of executive function

Age-related differences were explored using one-way ANOVA and are presented in table 2.3.

For the results of all three working memory tasks, significant age differences were identified (words recall test, $F(2, 183) = 55.43, p < .001, \eta^2 = .380$; pattern recall test, $F(2, 183) = 72.56, p < .001, \eta^2 = .445$; counting recall test, $F(2, 182) = 40.07, p < .001, \eta^2 = .308$). The three tasks showed medium to large effect sizes (Cohen, 1992). The results of post hoc tests showed significant age differences across all the three age groups (between the 7-year-old group and 10-year-old group, between the 10-year-old group and 14-year-old group and 7-year-old group and 14-year-old group, $p < .001$). The only exception was that the p-value of counting recall between the 10-year-old group and 14-year-old group was .009 ($p < .001$).

For the Simon Task, there was a main effect of age, $F(2, 183) = 21.61, p < .001, \eta^2 = .193$, with a small effect size. Pairwise comparisons revealed significant age differences in correct rates between children aged 7 and 10 and between the 7-year-old group and 14-year-old group ($p < .001$), but not between the 10-year-old

group and 14-year-old group ($p = .060$). For the Go/No Go task, there was a main effect of age, $F(2, 179) = 15.29, p < .001, \eta^2 = .147$. A small effect size was shown in the Go/No Go task. In pairwise comparisons, the 10-year-old group was not significantly better than 7-year-old group ($p = .095$), the 14-year-old group was significantly better than 7-year-old group and the 10-year-old group ($p < .001$).

For shifting, in the trail making task, a main effect of age was shown in part two, $F(2, 184) = 49.97, p < .001, \eta^2 = .354$. A medium effect size was found in the trail making task. In pairwise comparisons, significant differences were found between 7-year-old group and 10-year-old group ($p = .020$), 10-year-old and 14-year-old group and 7-year-old group and 14-year-old group ($p < .001$). In WCST, there were no significant age differences between groups in preservative errors, $F(2, 184) = 2.81, p = .063, \eta^2 = .030$.

In both the semantic and phonemic word fluency tasks, a main effect of age was shown. In the semantic task, $F(2, 184) = 40.48, p < .001, \eta^2 = .308$, a medium effect size was found. Pairwise comparisons revealed significant age differences between 7-year-old group and 10-year-old group ($p = .001$), between the 10-year-old group and 14-year-old group and 7-year-old group and 14-year-old group ($p < .001$). In the phonemic task, $F(2, 184) = 51.40, p < .001, \eta^2 = .361$, again a medium effect size was found. In pairwise comparisons, there were differences between the 7-year-old group and 14-year-old group and between 10-year-old group and 14-year-old group ($p < .001$) but not between the 7-year-old group and 10-year-old group ($p = .317$).

Table 2.3. One-way ANOVA results with Bonferroni correction, descriptive data for three year groups on different tasks of executive function and significance on group-paired comparison.

Measures	7 yrs		10 yrs		14 yrs		F	p
	Mean	sd	Mean	sd	Mean	sd		
Words recall	3.34	1.06	3.98	0.96	5.13	0.82	55.43	.000 ¹
Pattern recall	5.54	1.90	6.86	1.24	8.92	1.49	72.56	.000 ¹
Counting recall	3.21	1.17	3.83	1.12	5.02	1.11	40.07	.000 ¹
Simon task	0.90	0.09	0.95	0.05	0.98	0.04	21.61	.000 ³
Go/No Go	0.84	0.14	0.88	0.12	0.95	0.07	15.29	.000 ²
WCST	47.48	4.01	48.33	3.31	49.24	4.83	2.81	.063 ⁴
Trail making task	10.32	5.18	13.70	6.40	22.24	8.42	49.97	.000 ¹
Semantic Word Fluency Task	13.03	4.15	16.48	5.08	21.52	6.25	40.48	.000 ¹
Phonemic Word Fluency Task:	9.57	4.75	11.17	5.15	18.94	6.39	51.40	.000 ²

¹ Pairwise comparisons between 7yrs group and 10yrs group, 10yrs group and 14yrs group, 7yrs and 14yrs are significant.

² Pairwise comparison between 7yrs group and 10yrs group is non-significant, but comparison between 10yrs group and 14yrs group is significant.

³ Pairwise comparison between 7yrs group and 10yrs group is significant, but comparison between 10yrs group and 14yrs group is non-significant.

⁴ Pairwise comparisons between 7yrs group and 10yrs group, 10yrs group and 14yrs group are non-significant.

2.3.3 Correlations

The Pearson's correlations for the executive measures as a whole group are presented in table 2.4. The correlations for each age group are presented below. Bonferroni correction has been applied to the correlations to minimise the risk of a type 1 error.

For the whole sample, executive tasks were significantly correlated with each other except the WCST and Simon Task, indicating convergent validity. For each expected domain, all three tasks of working memory were significantly correlated with one another ($p < .001$). For inhibition, the Simon task and Go/No-go task were significantly correlated with one another ($p < .001$). For shifting, trail making task and WCST were significantly correlated with one another ($p < .001$). For verbal

fluency, the word fluency tasks were significantly correlated with one another ($p < .001$). The Bonferroni adjusted P value was $p=.001$ and therefore these correlations were significant after the Bonferroni adjustment.

Table 2.4. Correlation coefficients between executive function measures for the whole age group

	WR	PR	CR	ST	GNG	WCST	TMT	SWVF	PWVF
WR	-								
PR	.579**	-							
CR	.528**	.559**	-						
ST	.343**	.391**	.348**	-					
GNG	.415**	.388**	.342**	.322**	-				
WCST	.283**	.216**	.240**	.172	.324**	-			
TMT	.499**	.563**	.480**	.313*	.319**	.298**	-		
SWVF	.536**	.462**	.457**	.339**	.358**	.292**	.554**	-	
PWVF	.520**	.460**	.493**	.341**	.403**	.314**	.522**	.720**	-

Note: WR is working memory words recall task, PR is pattern recall task, CR is counting recall task, ST is Simon task correct rate, GNG is Go/ No Go part 2 correct rate, WCST is WCST revised preservative errors, SWVF is semantic word verbal fluency task, PWVF is phonemic word verbal fluency task.

Note 2: * $p < 0.05$, ** $p < 0.001$.

Table 2.5 displays the Pearson's correlations for each of the executive tasks in the 7-year-old group. Bonferroni correction has been applied to the correlations to minimise the risk of type 1 error. Most of the variables were not significantly correlated with each other. A significant correlation was found between working memory words recall and pattern recall ($r = .413$, $p < .001$). Also, phonemic word verbal fluency was found to have significant correlations with Simon task ($r = .459$, $p < .001$), Go/No Go task ($r = .443$, $p < .001$) and Semantic word verbal fluency task ($r = .604$, $p < .001$). The Bonferroni adjusted P value was $p=.001$ and therefore these correlations were significant after Bonferroni adjustment.

Table 2.5 7-year-old group of correlation coefficients between executive function measures

	WR	PR	CR	ST	GNG	WCST	TMT	SWVF	PWVF
WR	-								
PR	.413**	-							
CR	.213	.330	-						
ST	.207	.097	.332	-					
GNG	.294	.322	.142	.302	-				
WCST	.264	.121	.036	.183	.132	-			
TMT	.295	.293	-.094	.159	.138	.319	-		
SWVF	.298	.368	.219	.311	.169	.205	.285	-	
PWVF	.183	.177	.275	.459**	.443**	.149	.154	.604**	-

Note: WR is working memory words recall task, PR is pattern recall task, CR is counting recall task, ST is Simon task correct rate, GNG is Go/ No Go part 2 correct rate, WCST is WCST revised preservative errors, SWVF is semantic word verbal fluency task, PWVF is phonemic word verbal fluency task.

Note 2: * $p < 0.05$, ** $p < 0.001$.

Table 2.6 displays the Pearson's correlations for each of the executive tasks in the 10-year-old group. Bonferroni correction has been applied to the correlations to minimise the risk of type 1 error. Most of the variables were not significantly correlated with each other. A significant correlation was found between working memory counting recall and Simon task ($r = .414, p < .001$). Also, WCST and Go/No Go task were significant correlated ($r = .484, p < .001$). Semantic words verbal fluency task was found to be significantly correlated with TMT ($r = .437, p < .001$) and phonemic words verbal fluency ($r = .502, p < .001$). The Bonferroni adjusted P value was $p = .001$ and therefore these correlations were significant after Bonferroni adjustment.

Table 2.6 10-year-old group of correlation coefficients between executive function measures

	WR	PR	CR	ST	GNG	WCST	TMT	SWVF	PWVF
WR	-								
PR	.161	-							
CR	.148	.319	-						
ST	-.016	.414**	-.029	-					
GNG	.257	.015	.159	.039	-				
WCST	.251	.051	.138	.123	.484**	-			
TMT	.197	.234	.307	.023	.078	.042	-		
SWVF	.339	.019	.086	-.036	.272	.081	.437**	-	
PWVF	.285	.110	.185	-.013	.276	.358	.186	.502**	-

Note: WR is working memory words recall task, PR is pattern recall task, CR is counting recall task, ST is Simon task correct rate, GNG is Go/ No Go part 2 correct rate, WCST is WCST revised preservative errors, SWVF is semantic word verbal fluency task, PWVF is phonemic word verbal fluency task.

Note 2: * $p < 0.05$, ** $p < 0.001$.

Table 2.7 displays the Pearson's correlations for each of the executive tasks in the 14-year-old group. Bonferroni correction has been applied to the correlations to minimise the risk of a type 1 error. None of the variables were significantly correlated with each other except for words recall and pattern recall ($r = .539$, $p < .001$), and semantic words verbal fluency and phonemic words verbal fluency ($r = .660$, $p < .001$). The Bonferroni adjusted P value was $p = .001$ and therefore these correlations were significant after the Bonferroni adjustment.

Table 2.7 14-year-old group of correlation coefficients between executive function measures

	WR	PR	CR	ST	GNG	WCST	TMT	SWVF	PWVF
WR	-								
PR	.224	-							
CR	.539**	.270	-						
ST	.141	.125	.101	-					
GNG	.146	.198	.269	.196	-				
WCST	.203	.224	.336	-.003	.360	-			
TMT	.193	.348	.369	.163	.229	.332	-		
SWVF	.284	.077	.332	.150	.172	.353	.300	-	
PWVF	.299	.082	.282	-.103	.006	.305	.354	.660**	-

Note: WR is working memory words recall task, PR is pattern recall task, CR is counting recall task, ST is Simon task correct rate, GNG is Go/ No Go part 2 correct rate, WCST is WCST revised preservative errors, SWVF is semantic word verbal fluency task, PWVF is phonemic word verbal fluency task.

Note 2: * $p < 0.05$, ** $p < 0.001$.

2.3.4 Confirmatory Factor Analysis

A confirmatory factor analysis was employed to test the structure of executive functions for the whole group. A four-factor executive function model, with factors for working memory, inhibition, shifting, and verbal fluency, were tested. The model fitted the data well: $\chi^2(21) = 17.682$, $p = .669$, $\chi^2 / df = .842$; CFI = 1.000; RMSEA = .000; AIC is 83.690. All loadings and correlations among the latent variables were significant. The χ^2 fit was significant, but this test is considered overly strict, unrealistic, sensitive to both sample size and data normality, and dichotomous in nature (Bentler, 2007). χ^2 / df is considered a fairer test of model fit as it is somewhat less susceptible to these issues, with an ideal value being < 2 ; thus the current model demonstrated a good fit (Hu & Bentler, 1999). Likewise, CFI is considered to have good fit at $\geq .95$ and RMSEA is at $\leq .06$. In order to guarantee the power of 0.8 in the CFA analysis, the sample size requirement for the CFA model was 175 (Muthén & Muthén, 2002). CFA was therefore not applied to examine factor structure separately in each of three age groups due to sample size.

Table 2.8 Fit indices for CFA models

Model	<i>df</i>	χ^2	χ^2 / df	<i>p</i>	<i>AIC</i> ^a	<i>RMSEA</i> ^b	<i>CFI</i> ^c
1. Full four-factor	21	17.682	.842	.669	83.690	.000	1
2. One-factor	27	58.454	2.165	.000	112.454	.080	.946
3. Two-factor (EF and VF)	13	14.333	1.103	.351	58.333	.024	.997
4. Three-factor (combined Shifting and Inhibition)	11	8.790	.799	.641	56.790	.000	1
5. Three-factor (combined WM and VF)	24	55.635	2.318	.000	115.635	.085	.946

^a Low value stand for better degree of parsimony.

^b RMSEA $\leq .06$ indicates a good fit to the data.

^c CFI $\geq .95$ indicates a good fit.

Note. N = 185. Accepted model is in bold.

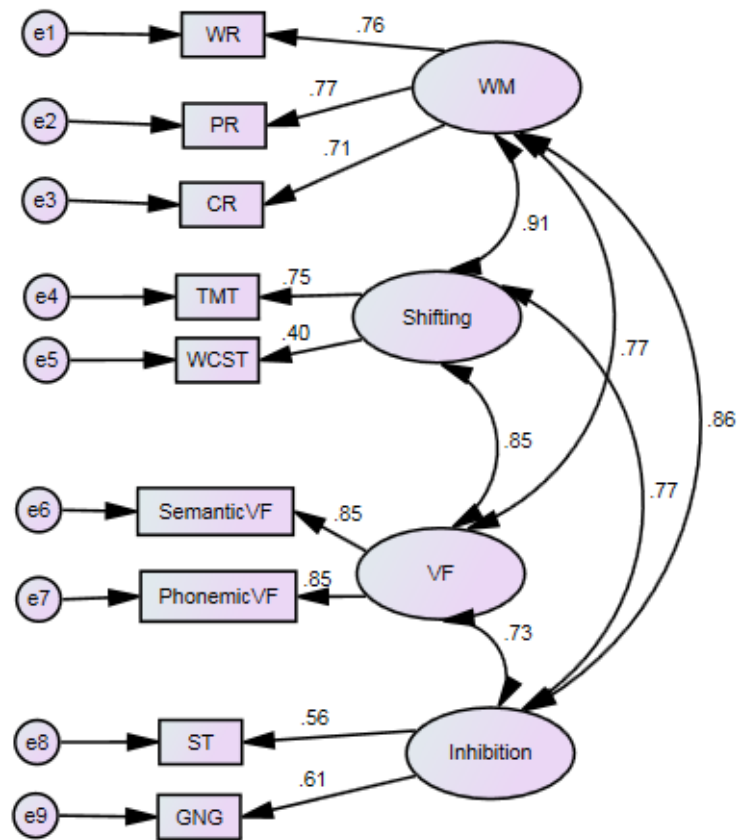


Figure 2.1 Model 1 Measurement model for executive functions.

Model 1 presented a full four-factor model, nine executive tasks were loaded on four relatively separate latent factors, namely working memory, inhibition, shifting and verbal fluency. The model fit indicates it is the best model we had proposed.

Based on previous literature, one-factor model has been tested. However, CFI of this one-factor model was .946, which was lower than the criteria. This model has not been selected.

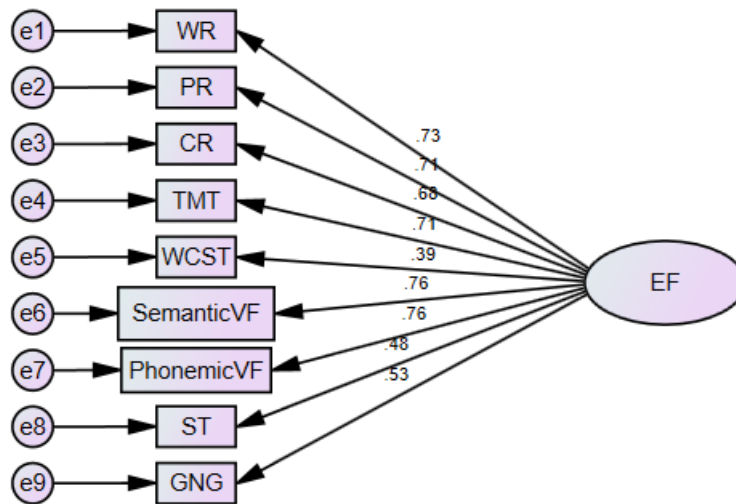


Figure 2.2 Model 2 Measurement model for executive functions.

Figure 2.3 has presented model 3. Wisconsin cart sorting task and Simon task have displayed with low correlations in the last model. We also would like to identify whether verbal fluency was the additional factor. We conducted a two-factor model. Compared to the model 1, the model fit of model 3 was not as good as the four-factor one.

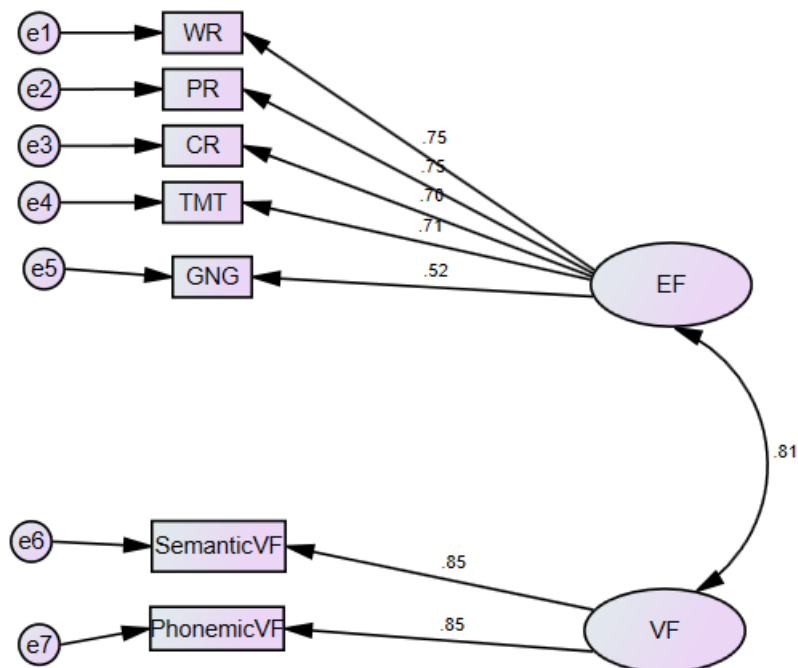


Figure 2.3 Model 3 Measurement model for executive functions

Model 4 has tested the model as a three-factor model with working memory, verbal fluency and a combined inhibition and shifting factor. The indices of this analysis appeared to be a good model fit as CFI was 1.000 and RMSEA was .000. However, the correlations between latent factor working memory and latent factor inhibition/shifting was in excess of 1. Therefore, this model has not been selected.

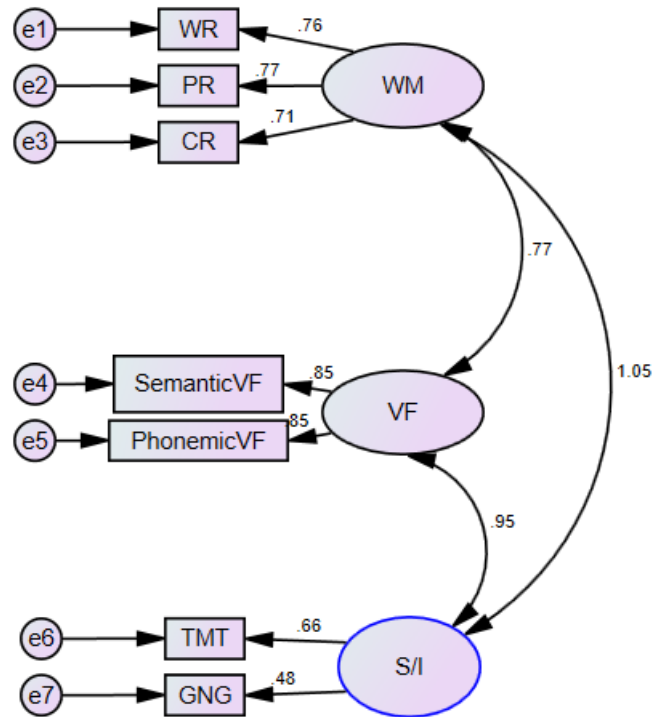


Figure 2.4 Model 4 Measurement model for executive functions.

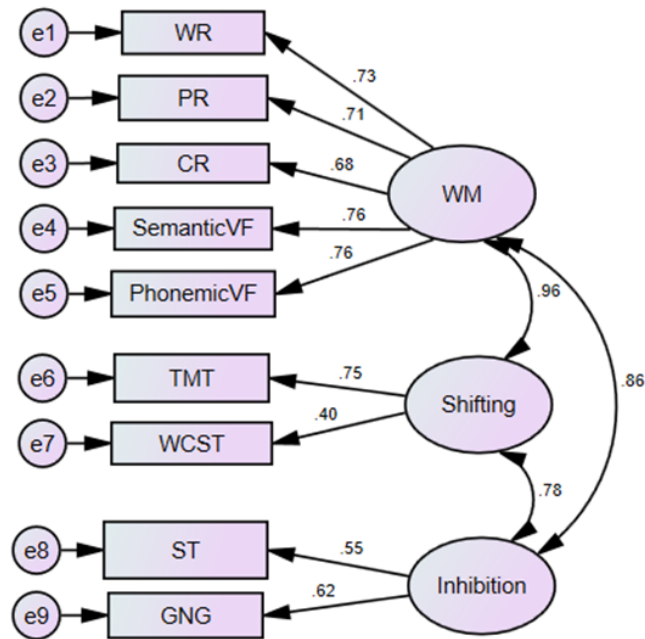


Figure 2.5 Model 5 Measurement model for executive functions.

Figure 2.5 presented a three-factor model with a combined working memory and verbal fluency factor, a shifting factor and an inhibition factor. The model fit was not as good as the model 1, so it has not been selected.

It is worthy to note that there is ceiling effect in Simon task, as all of the three groups achieved at least 90% correct rate. Also, there was no significant difference between the WCST results across three age groups. However, both the Simon task and WCST task were accounted in the CFA model because it is suitable in the CFA based on its normality requirement. We can observe that WCST and Simon task had the least factor loading from the latent variables to the observed variables. Therefore, caution needs to be taken when using these two tasks to interpret the model of executive functions.

2.4 Discussion

The aims of the present study were to investigate age-related differences in executive function in children from 6 to 15 years old, and to explore the structure of executive functions for children from childhood to early adolescence.

2.4.1 Developmental trends

The current study revealed that children showed significant differences in working memory between the 7-year-old group, 10-year-old group and 14-year-old group. Similar improvements were found on all three working memory tasks. This suggests that children continue developing their working memory function until at least 14 years old. This finding is consistent with previous literature (Gathercole et al., 2004; Lee, Bull, & Ho, 2013). For example, Lee et al., (2013) suggested that both the phonological loop and the visuo-spatial sketchpad showed a significant year-on-year improvement in a longitudinal study with children aged from 6- to 15-year-old.

The present study also found significant age-related differences in inhibition. However, the patterns of findings varied between the different sets of executive tasks that were used. Developmental differences in performance on the Simon task were identified in the younger age groups, while the performance among the older group was not significantly different. It is worthy to note that there is a ceiling effect in Simon task, three age groups achieved high correct rates. It is considered that Simon task was relatively easy for children who are aged from 7 to 14 years old in the current study. It is suggested that Simon task might not be suitable for a wide age range of children. For the Go/No Go task, results indicated that there was no significant developmental difference between 7 and 10 years old, but that there were improvements between 10 and 14-year-old. These findings are consistent with those of previous literature in which different aspects of inhibition mature at different ages, depending on the specific task administered (Brydges et al., 2012, 2014; Howard et al., 2015)

Similarly, there were different developmental trends in shifting tasks, depending on the task. The trail making task demonstrated significant age-related differences across three age groups. This suggests shifting ability continues

improving at least until 14 years old. However, the Wisconsin card sorting task did not show any clear age-related difference across the three age groups. This finding is not consistent with previous findings that WCST improves from 6 to 20 years old (Heaton, 1993; Brydges et al., 2012; Brydges et al., 2014). The potential reason for this is that the WCST is not sensitive enough for assessing shifting, with the three year groups achieving high scores on the non-preserved answers. It is worth noting that in the current study, shifting was the main focus in the research. Therefore, preserved answers were the key concept that in the study. In order to gain the same scoring direction with other tasks, we have used the scores as the total scores minus preserved answers, which is actual correct scores and the non-preserved scores. This reduced the sensitivity of WCST for assessing shifting ability in this study.

The current study also examined verbal fluency. It found significant age-related differences across the three age groups. Only a few previous studies have focused on developmental trends of verbal fluency (Brydges et al., 2012; Brydges et al., 2014, Riva, Nichelli, & Devoti, 2000), and the present study has further explored the age-related differences until 14 years old and on both semantic and phonemic verbal fluency tasks. Developmental differences in performance on the semantic verbal fluency task were identified between all three age groups, whilst significant differences in phonetic verbal fluency task were only shown between the 10 year group and 14 year old groups. Children presented more answers in semantic tasks than in phonemic tasks in all of the three age groups. The findings are consistent with Sauz on et al., (2004) that the development of phonemic verbal fluency is later than semantic verbal fluency. These results could be explained when children retrieve information from a given category, it is dependent on their long-term memory and spelling knowledge. When it was phonetic verbal fluency, it required children to rely on a strategic retrieval process.

In addition to the age-related differences in each executive function, we have found a few significant associations between verbal fluency tasks and other executive tasks in both the 7-year-old group and the 10-year-old group, but not in the 14-year-old group. In the 7-year-old group, the phonemic verbal fluency task was significantly associated with both the inhibition tasks while in the 10-year-old group, only the semantic verbal fluency task was significantly related to the trail

making task within shifting. This suggests that verbal fluency might rely more on inhibition in early childhood, with children needing to inhibit items they have already retrieved. As children get older they may then use a different strategy which relies more upon shifting, involving for example shifting attention between related items whilst generating a response (Sauzéon et al., 2004).

It shows that verbal fluency tends to involve inhibition during childhood but move on to shifting in early adolescence. It indicates that at 7-years-old, children selectively inhibit their mental ability in order to continue retrieving information on the cognitive tasks. They will need to prevent moving their attention onto distracting activities. When they reach early adolescence, shifting ability is more important in cognitive tasks by switching between different mental sets to navigate their attention on the task they are concentrating on while they may have different strategies for retrieving information in verbal fluency tasks.

The developmental trends in executive functions displayed at different speed, working memory showed significant age-related differences across three age groups. The other executive functions either displayed significant difference between 7-year-old and 10-year-old or between 10-year-old and 14-year-old. Only WCST did not show significant age-related differences due to the potential reason of sensitivity with assessing shifting ability. Thus, the present investigation contributes to the existing literature by documenting that children and adolescents' developments on executive functions varied.

2.4.2 The structure of executive function

The CFA suggested that performance on the nine executive tasks was best accounted for by four relatively separate factors: working memory, inhibition, shifting and verbal fluency, while significant correlations among these executive functions can be found in this sample of 7- to 14-year-old children. This finding supports those of previous studies that indicated three latent executive function factors (i.e. working memory, inhibition and shifting; Aran-Filippetti, 2013; Lehto et al., 2003; Rose et al., 2011; Wu et al., 2011). In addition, verbal fluency has been identified as the fourth distinct latent variable in the current model, which further supports the previous literature (Cassidy, 2016; Klenberg et al., 2001).

The theoretical interpretation has been proposed for this structure observed in children who are aged 7 to 14 years old: a four-factor structure with a focus on verbal fluency as an additional latent factor. A one-factor model and a three-factor model provided poor model fits to the data. The three-factor model has considered both working memory tasks and verbal fluency tasks loaded on one latent factor, however it did not achieve an acceptable model fit. This indicates that verbal fluency which is accessing long-term memory has been important in the executive process. It was clearly separated but yet related to the other three executive functions. In addition, previous studies have focused on crystallised verbal abilities whilst overlooking more executive aspects of language functioning, such as verbal fluency.

Furthermore, in the current study, the four executive functions were closely related to one another, which suggested there may be some unity as well as diversity of EFs. Both unity and diversity are reflected in current models of EF. For example, Friedman and Miyake (2017) have proposed a new bi-factor model. In this bi-factor model, unity is captured by a common executive function factor and diversity is captured by one working memory-specific factor and one shifting-specific factor. Also, there is no inhibition-specific factor captured in this model because the common executive function factor has already explained all of the correlations among the inhibition tasks. However, in the current study, although inhibition showed task-specific differences across three age groups, inhibition has been captured by Simon task and Go/No Go task and correlated with each of the other factors.

2.4.3 Strengths, Limitations and future implications

A particularly important contribution of the current study was the finding of verbal fluency being a fourth distinct latent construct. Verbal fluency was first investigated in Fisk and Sharp's (2004) study in an adult sample. Compared to other research into the other executive functions, working memory, inhibition and shifting, there is a sparsity of research into verbal fluency in some research domains and verbal fluency was found as a distinct latent variable. It has been suggested that verbal fluency tasks demand an activation and retrieval from long-

term memory and use of a strategy, which is linked to scholastic attainment (Klenberg et al., 2001). Further research may therefore be helpful to explore verbal fluency across childhood and the potential relationships with other outcomes, such as educational attainment (see Chapter 3 & 4).

A strength of the current study was that each factor was assessed using at least two different tasks rather than only a single task. This approach allows for common variance to be examined. In addition, the current study included three working memory tasks, in order to measure Baddeley and Hitch's model, namely the phonological loop, the visuo-spatial sketchpad and the central executive. Scores on these tasks were significantly inter-correlated with each other and they loaded on the same executive factor.

A number of limitations need to be acknowledged. Firstly, the study did not include an assessment of intellectual ability. Accumulating studies indicate that executive functions are related to intelligence (Duncan, Emslie, Williams, Johnson, & Freer, 1996). Friedman, Miyake, Corley, Young, DeFries and Hewitt (2006) directly examined three executive functions (i.e. working memory, inhibition and shifting) with fluid and crystallised intelligence in young adults. They suggested that these three executive functions are to some extent associated to both fluid and crystallised intelligence. Therefore, future research should consider statistically controlling for intelligence to gain a more effective and accurate picture of the structure of executive function.

The current study is also limited by sample size and its cross-sectional design. Due to the sample size in each age group, we could not apply confirmatory factor analysis in each age group to capture the development of the structure of executive functions. Lee et al., (2013) suggested a process of differentiation from a two-factor structure in early childhood to a three-factor structure in adolescence in a 10-year period longitudinal study. They also suggested a moderate correlation between factors in younger children and reduced correlations between factors in adolescents. Future research would benefit from a longitudinal study with a larger sample size which provides evidence for the developmental changes in children and adolescents.

In conclusion, the current study examined the development of executive functions, and revealed that different executive functions showed different developmental trends. It also explored the structure of executive functions, and identified a four factor structure in children aged 7- to 14-years-old.

Chapter 3. Literature review on age related differences in the contribution of executive functions to academic achievement in typically developing children

Previous chapters have focused on the structure and the development of executive functions. Over recent years, executive functions have increasingly been studied within an educational setting. A substantial number of studies have examined the relationships between young children's executive functions and Early Years and Lower Key Stage 1 results. For example, inhibition, shifting and metacognitive planning at age 4 have been found to account for substantial variability in children's mathematical achievement in school at age 6 (Clark, Pritchard, & Woodward, 2010). This current study will be focusing on the contribution of executive function to scholastic attainment in school-aged children and adolescents.

The previous chapter suggested that during childhood, there is a four-factor structure of executive functions, namely working memory, inhibition, shifting and verbal fluency. While working memory, inhibition and shifting have been widely investigated in relation to learning, there has been little research into the contribution of all four functions, especially verbal fluency to academic achievement.

In this chapter, a literature review on the relationships between executive functions, age and academic achievement will be presented. The next chapter will report the results of an investigation into the contribution of age and executive functions to academic achievement in typically developing children in childhood to early adolescence.

3.1 Literature Review

Recent studies on scholastic attainments have highlighted the importance of executive functions in school-age children. Studies have proposed that scholastic attainments, such as reading, writing and mathematics are predicted by executive functions (Bull & Scerif, 2001, Engel de Abreu et al., 2014, St Clair-Thompson &

Gathercole, 2006). Working memory has gained the most attention in the scholastic attainment literature (see review Raghubar, Barnes, & Hecht, 2010). Less research has explored the relationship between other executive functions such as shifting, inhibition and verbal fluency, and school achievements at different developmental stages (Bull & Scerif, 2001; Davis, Finch, Drapeau, Nogin, Moss, & Moore, 2016; Zorza, Mariano, & Mesas, 2016).

One way of assessing children's scholastic achievement in the UK is to use national curriculum levels. Children of compulsory school age in the UK must be taught the national curriculum. At regular intervals, a teacher must assess each child's performance according to expected levels (Department for Education, 2013). Children who are aged 4 to 5 will attend the reception class, aged 5 to 7 will attend Key Stage 1 classes and aged 7 to 11 will attend Key Stage 2. Adolescents who are aged 11 to 14 will attend Key Stage 3 (Department for Education, 2013).

The National Curriculum includes a set of eight levels of scholastic achievements, set by the Government, and is used to measure a child's progress compared to other pupils of the same year across the country. By the time children leave primary school, they are expected to have achieved at least level 4 in English and Mathematics (National Curriculum Expectations, 2011). In 2014, schools started changing to a new grading system which removed 'level descriptors' (e.g. Level 3a, 2b), and recorded students' achievements as 'working with the expected level of attainment for his/her age', etc.

The aim of this literature review is to explore the evidence for age-related differences in the associations between executive functions and academic achievement. Two databases, PsycINFO (1987-2018) and Web of Science, were searched. The key search terms were executive function, working memory, inhibition, shifting or switching, verbal fluency or fluency, academic achievement or scholastic attainment, children. After removing duplicate records, narrative descriptions of the relevant identified studies have been included in this literature review.

Using a large sample size to examine the relationship between executive function and academic achievement, Best, Miller, & Naglieri, (2011) report on a sample of 1395 students aged from 5 to 17 years old and demonstrate the

developmental pattern of associations between complex executive function and attainment, measured by the Cognitive Assessment System (CAS; Das, Naglieri, & Kirby, 1994) and Woodcock-Johnson Tests of Achievement-Revised (WJ-R; Woodcock & Johnson, 1989). Similar strengths of associations between executive functions and reading, and between executive functions and mathematics are reported by Best et al., (2011). Associations between scholastic attainment and executive tasks differed across development. For example, a working memory task of matching numbers (e.g. holding information and matching to the same number) and a task of shifting ability, similar to the trail making task, had similar developmental trends with a spike in the strength of the association with English and maths at age 6, a second spike at age 8-9 followed by a weaker and fairly consistent correlation thereafter until 15 years old (Altemeier, Jones, Abbott, & Berninger, 2006). The finding suggests that executive functions are important in early schooling. When children get older, children will become more practiced at their work, and in this case automatic processing may become more important when dealing with academic tasks.

3.1.1 Working memory and academic achievement

Working memory has been used to refer to a mental workplace. In order to support ongoing complex cognitive activities information can be temporarily stored and manipulated in working memory (Gathercole & Pickering, 2000). Baddeley and Hitch's model (1974) of WM is composed of three main components: the central executive, the phonological loop and the visuo-spatial sketchpad (see Chapter 1). The working memory system has been found to play an essential role in the typical school classroom in both English and maths. There are many classroom activities that impose simultaneous processing and storage demands. For example, children will be asked to listen whilst trying to take notes, to follow step by step instructions, to decode unfamiliar words and to do mental arithmetic (St Clair-Thompson, 2013).

Working memory and English

Several studies have found that working memory contributes significantly to English achievement throughout childhood, at aged 6-8 years (Engel de Abreu et

al., 2014); 5-10 years (Alloway & Alloway, 2010); 11- to 12-years (St Clair-Thompson & Gathercole, 2006) and 9- to 15 years (Aran-Filippetti & Lopez, 2016).

Some studies have suggested that the relationships between working memory and English may change across development. Similar to earlier findings, working memory is closely related to aspects of attainment in the early school years and Key Stage 1 but the strength of the relationship reduces in later years. Gathercole, Pickering, Knight and Stegmann (2004) found that children's levels of attainment in English were significantly related with working memory scores, particularly on complex span tasks, at aged 7 years. However, at age 14, there was no strong association between English and working memory skills. They have suggested that at the younger age, working memory capacity was linked with acquisition in literacy. However, at the older age, skills of comprehension and analysis of English literature were independent of working memory.

Jarvis and Gathercole (2003) revealed that verbal constructs (phonological loop and verbal central executive) were significantly related to National Curriculum English levels at aged 11 and 14 years. As for specific working memory tasks and attainment, complex span tasks that are associated with the central executive were most closely related to English at 14 years old. In the same study, a structural equation model (SEM) indicated that both verbal working memory (digit recall, word recall, backwards digit recall and listening recall) and non-verbal working memory (visual patterns recall, dynamic matrices and spatial span) predicted English ability in both 11 and 14 year old children. So here, there was less evidence for developmental changes in the contribution of working memory to English. As previously stated, the strength of associations between working memory and English has been reported to reduce over the course of development in correlational and regression analyses based studies, however, Jarvis and Gathercole's (2003) SEM model supported that verbal and non-verbal working memory strongly predicted attainment in both 11 and 14 year olds. This inconsistency may be due to different types of analysis and Jarvis and Gathercole's study did not include a Key Stage 1 sample. Also, in Jarvis and Gathercole's model, only 55 participants were involved in the Key Stage 2 model and 73 children were involved in the Key Stage 3 model. These results therefore need to be interpreted with caution due to the small sample size for an SEM analysis.

Working memory and Mathematics

Working memory has also been reported to contribute significantly to mathematics throughout childhood, in children aged 4-7 years (Bull, Espy, & Wiebe, 2008); 6-7 years (De Smedt, Janssen, Bouwens, Verschaffel, Boets, & Ghesquière, 2009); 5-10 years (Alloway & Alloway, 2010); 11- to 12-years (St Clair-Thompson & Gathercole, 2006); and 11 and 15 years (Visu-Petra, Cheie, Benga, & Miclea, 2011).

Some research has suggested that there are developmental changes in the relationship between working memory and maths. Swanson & Beebe-Frankenberger (2004) suggested younger children performed poorer on working memory as well as measures of maths calculation than older children (Swanson & Beebe-Frankenberger, 2004). Compared with the developmental trend of associations between working memory and English, the association between working memory and maths is consistently strong across age. For example, Gathercole et al., (2004) found that at both age 7 and 14, working memory was strongly associated with mathematics performance. Similarly, Jarvis and Gathercole's model (2003) showed verbal and non-verbal working memory predicted maths level at both 11 years old and 14 years old. The findings suggested that working memory, including verbal and non-verbal working memory contributed significantly to maths throughout childhood and early adolescence.

Research has also examined specific working memory components in relation to maths. Holmes and Adams (2006) focused on components of working memory and suggested there is a shift in the components that are most related to maths from 7-8 year old to 9-10 year old. They found that composite visuo-spatial sketchpad scores predicted 10% of a total maths score in 7- to 8-year-olds, but only 3% of a total maths score in 9- to 10-year-olds, which implies that the overall contribution of the visuo-spatial sketchpad to maths decreases with age. The phonological loop did not predict maths in the younger group but accounted for 2% variance of maths in the older group, and the central executive predicted maths in both age groups. The results indicated that younger children appear more dependent on the visuo-spatial sketchpad to support their mathematics and early numeracy development while older children are beginning to rely on the

phonological loop to solve difficult maths problems by using direct retrieval strategies.

Furthermore, Holmes, Adams and Hamilton (2008) focused on the visuo-spatial sketchpad and suggested there is a different pattern for visual working memory ability and spatial working memory ability from 7-8 year old to 9-10 year olds. The spatial subcomponent of the visuo-spatial sketchpad predicted younger children's maths, while visual working memory predicted maths in the older group. The results indicate younger children may use spatial ability as a workspace for storing and manipulating problem information, while older children employ a visual strategy to process the problem information (Holmes et al., 2008).

However, Meyer, Salimpoor, Wu, Geary, & Menon (2010) did not find the visuo-spatial sketchpad to predict maths at age 7-8, but at age 8-9 years the visuo-spatial sketchpad was the only working memory measure that significantly predicted mathematical abilities, including numerical operations and maths reasoning. Both the phonological loop and the central executive predicted maths reasoning in the younger group instead of the older group. The inconsistent findings indicate that different components of working memory are experiencing developmental changes across 7- to 10-years-old. These inconsistent findings may also be due to different focuses of mathematics tests (i.e., numeracy in Holmes et al., (2006) and numeracy and reasoning in Meyer et al., (2010). In general, the visuo-spatial sketchpad is important in numeracy at 7-8 year old, while the phonological loop and the central executive are more associated with problem-solving maths reasoning in the later stage of mathematics, which includes applying mature strategies.

The phonological loop and the central executive have also been investigated in Andersson (2008), who suggests that both are important during arithmetical performance, such as monitoring and coordinating multiple processes and accessing arithmetical knowledge from long-term memory. The phonological loop and the central executive significantly predicted written arithmetical performance in 9-to 10-year old children (Andersson, 2008). It is worthy of note that Andersson's study (2008) included the trail making task and semantic verbal fluency to measure the ability of the central executive. This is different to the current study where the

trail making task was used to assess shifting and the semantic verbal fluency task was used to measure verbal fluency. Task impurity is discussed in Chapter 1 and Chapter 7.

Research has also examined the role of working memory in specific maths abilities. Holmes and Adam (2006) examined four mathematics skills, namely number and algebra; shape, space, and measures; handling data and mental arithmetic and found that there was little difference between working memory contributions to each mathematical skill for 7-8 year olds and 9-10 year olds. They also suggested that that the different mathematical skills recruited the same working memory abilities may be due to these four mathematical skills sharing common processes for their solution.

3.1.2 Inhibition and academic achievement

Several studies have reported that inhibition contributes to academic achievement in preschool children (Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004) and school-aged children (Bull & Scerif, 2001; Swanson and Beebe-Frankenberger, 2004). Inhibition was associated significantly with English and maths in children aged 11-12 years old (St Clair-Thompson & Gathercole, 2006). However, the magnitude of the associations between working memory and attainments in English and maths were higher than the associations between inhibition and attainments (St Clair-Thompson & Gathercole, 2006).

In terms of age-related differences, no clear explanations of the relationship between inhibition and English were found, while previous studies have found inhibition predicts mathematics results across different ages. For example, Bull and Scerif (2001) found that children aged 6-8 years with poor mathematics performance showed difficulties on the ability to inhibit pre-potent information (i.e. Stroop task) and inhibition predicted unique variance in mathematics performance after controlling for reading proficiency and intelligence scores. In an adolescent sample (11-16 years), Litzman, Elkovitch, Young, & Clark (2010) found inhibition significantly predicted mathematics, including problem-solving.

Some longitudinal studies also report that inhibition contributes to children's mathematics ability in the early years (Chung & McBride-Chang, 2011; Clark,

Pritchard, & Woodward, 2010). For example, Clark et al., (2010) examined the relationships between inhibition at age 4 and subsequent mathematics achievement at age 6, suggesting that inhibition was associated with mathematics performance in a 2 year longitudinal study. Chung and McBride-Chang (2011) found a similar pattern in Hong Kong Chinese children aged 4 to 5 years old.

To date there has been little agreement on the association between inhibition and English. St. Clair-Thompson and Gathercole (2006) suggest that inhibition is significantly related with English and other curricular areas, which indicates that inhibition supports general academic learning instead of specific domains of skills and knowledge. Borella, Carretti, & Pelegrina (2010) found that poor reading comprehension was related to inhibition problems in children aged 10 to 11, whereas, Engel de Abreu et al., (2014) and Latzman et al., (2010) failed to find a significant association between inhibition and reading in both a 6-8 year old group and a 11-16 year old group.

In terms of the relationship between inhibition and maths, inconsistent results were found. Some research has found that inhibition predicts maths (Latzman et al., 2010), while Van Der Ven and colleagues (2012) using factor analytic techniques reported that inhibition and shifting do not predict mathematics performance at 7-8 years old, with no satisfactory model fit for the model. Task impurity was also discussed in the study. Van Der Ven (2012) argued that both inhibition and shifting require working memory skills. In this case, a possible explanation is that processes of inhibition involved in attainments were probably captured by all other tasks, such as working memory, which results in eliminating the significant associations between inhibition and maths (Andersson, 2008).

3.1.3 Shifting and academic achievement

Studies have also examined the relationship between shifting and academic achievement. Shifting may be important for reading comprehension which requires skills in decoding and linguistic comprehension at a simultaneous level (Cartwright, 2002).

Developmental changes have not been reported in either cross-sectional or longitudinal studies to our best knowledge. Some studies report associations

between shifting and English ability (Engel de Abreu et al., 2014; Latzman, 2010; Van Der Sluis, 2007) and between shifting and maths (Andersson, 2008; Bull & Scerif, 2001; Clark et al., 2010; Mayes, Calhoun, Bixler, & Zimmerman, 2009). In contrast, other studies show no link between the two (English: Maye et al., 2009; maths: Espy et al., 2004; Mayes et al., 2009; Monette, Bigras, & Guay, 2011; Van Der Ven, et al., 2012).

In terms of the association between shifting and English, Van Der Sluis et al., (2007) have found shifting is mainly related to reading in 9 to 12 year olds, Engel De Abreu et al., (2014) have found similar in age 6- to 8-year olds. In addition, Latzman (2010) reported that shifting predicts reading comprehension skills at age 11-16 years. In this context, it was suggested that children were required to shift between different mental sets, from initiating problem-solving behaviours to formulating the presentation of new information and concepts. However, Mayes et al., (2009) reported that shifting did not predict reading after controlling for intelligence, and intelligence was the best predictor of achievement in a 6- to 12-year-old group. Inconsistent findings suggest controlling for intelligence in the studies may affect the results. A meta-analysis also indicates the importance of taking intelligence into account when exploring the contribution of shifting to academic performance (Yeniad, Malda, Mesman, Van Ijzendoorn, & Piper, 2013).

Shifting has been suggested to be important for alternation between different aspects of mathematical problems or arithmetical strategies (Yeniad et al., 2013). Therefore, the relationship between shifting and mathematics has been investigated. For example, Bull and Scerif (2001) found that children with poorer mathematics ability had lower WCST results, indicating that children of poorer mathematical ability had also problems switching to a new strategy, supporting earlier work (Shallice & Burgess, 1996).

However, other studies have failed to find a connection between shifting and mathematical achievements. Espy et al., (2004) have suggested that shifting does not predict maths in children between 2 to 5 years old, because flexibility would contribute to maths more for older children, given the necessity for older children to flexibly apply different mathematical procedures (i.e. borrowing, carrying numbers in arithmetical test) while younger ones were only involved in counting and simple

regrouping numbers. Latzman (2010) did not find a relationship between shifting and mathematics ability in an adolescent sample (11-16 years old), suggesting developmental changes in the associations between shifting and maths.

Furthermore, Yeniad et al., (2013) have suggested that task demands may be important in relation to this association. They assert that whether or not the switching rule is explicit may moderate the relationship between shifting performance and academic achievements. Two types of shifting tasks are involved in the current study, including rules have been explicitly explained to children (i.e. trail making task) and rules have not been explicitly presented in most of cards sorting tasks (i.e. Wisconsin card sorting task). Andersson (2008), using the trail making task with explicit rules report a significant association with reading and math scores after controlling for age. Bull and Scerif (2001) also suggested shifting tasks with implicit rules can predict mathematic ability. In order to address this contradiction in the literature two types of shifting tasks are included in the current study, the trail making test in which the rules will be explicitly explained to children and the WCST where the rules have not been explicitly presented.

3.1.4 Verbal fluency and academic achievement

Verbal fluency has been evaluated in Chapters 1 and 2, including phonemic verbal fluency and semantic verbal fluency. Verbal fluency may be important in attainment because the acquisition of reading skills requires children to manage and process both phonemic and semantic information (Cartwright, 2002). In an adult study, path analysis indicated that only phonemic fluency was statistically significantly related to reading and the relationship was weak in adult participants ($r = .05$; Davis et al., 2016).

So what are the associations between verbal fluency and academic achievement in children? Altemeier, Jones, Abbott and Berninger (2006) reported that verbal fluency predicted the results of a reading comprehension task and written expression task, in both 3rd graders and 5th graders'. Aran-Filippetti & Richaud (2015) found that only working memory (WM) and verbal fluency significantly accounted for variance in the production of a writing task (i.e., writing a narrative text) in 8- to 15-year old children. This is supported by Aran-Filippetti &

Lopez (2016) who reported that only working memory (i.e., the central executive component) and semantic verbal fluency explained a unique percentage of variance in reading comprehension in a group of 9- to 15 years old children (Aran-Filippetti & Lopez, 2016).

Other studies have not found the significant associations between verbal fluency and scholastic attainment (Mayes et al., 2009; Zorza, Marino, & Mesas, 2016). Particularly, verbal fluency has been considered to be related to retrieval of task-relevant information rather than scholastic attainment. For example, in a regression analysis, Andersson (2008)'s semantic verbal fluency task did not capture variance in arithmetical performance but accounted for a 3% unique variance in arithmetical fact retrieval.

Age related differences have not been found in the association between verbal fluency and scholastic attainment to our best knowledge. The current study is going to investigate the difference of relationship between verbal fluency and English and mathematics across three different age groups.

3.2 The structure of Executive functions and scholastic attainment

In the previous literature, it has been proposed that there is a change in developmental fractionations of executive functions. However, it still remains unclear how the changes of structure of executive functions contribute to school attainment. The existing research has put emphasis on the structure of executive function and explored to what extent each of factors contribute to the attainment. There is rare literature on the topic of what the link is between the developmental changes on structure and scholastic achievement. A unity structure of executive functions in children's early years has been proposed (e.g. Wiebe et al., 2008). It is more difficult to differentiate in a younger group as executive measures has been better characterised by a unity executive construct. There was less evidence for contributions of any specific measure of executive function to achievement and for predicting later achievement, specifically in mathematics (Clark Pritchard, & Woodward, 2010). Furthermore, with developmental changes in the executive functions, they appear to be more fractionated. For example, Van Der Sluis et al., (2007) have identified a working memory factor and a shifting factor, but not an

inhibition factor in their confirmatory factor analysis in the children aged 9 to 12. The working memory has explained 6.1% and 2.1% of variance on reading and arithmetic, respectively. However, shifting only explained 2.7% variance in reading. Therefore, the results indicate different executive functions have contributed to different areas of attainment.

Also, the strengths of the correlations between executive functions and scholastic attainment have been suggested to be reduced over the time. Some research found that executive function is more closely related to academic achievement in early schooling (Altemeier et al., 2006). In detail, Best et al., (2011) found that the correlation strength between complex executive function and academic attainment increased substantially from 5 years old to 6 years old and decreased slightly but remained moderate through adolescence on a large and representative national sample.

Furthermore, due to previous studies using cross-sectional studies and different tasks being used for both executive functions and attainment across different studies and age groups, the current study has applied the same executive tasks in different age groups to focus on the four different executive functions and scholastic attainment.

3.3 Purpose and predictions

This study provides new insights into the relationship between four executive functions and scholastic achievement, exploring the contribution of working memory, inhibition, shifting and verbal fluency to children's English and mathematics results, and age related differences in these contributions.

The major prediction of this study is that all of executive tasks will contribute to children's scholastic achievement. As children grow older, the strength of the associations between executive functions and academic achievement are predicted to reduce.

Chapter 4. Investigating age-related differences in the contribution of executive functions to academic achievement in typically developing Children

In this chapter, a correlational study of the relationship between executive functions and national curriculum levels in typically developing children who are from 6 years old to 15 years old is reported. As noted in Chapter 3, the relationship between executive function and scholastic attainment has been investigated in school-aged children but still remains equivocal in several areas (e.g. shifting and verbal fluency). A correlation analysis examines the relationship between executive functions and scholastic attainments in different age groups and a Linear Regression model is used to investigate to what extent different tasks contribute to scholastic attainments in different age groups.

4.1 Present Study

In chapter 2, developmental trends and the fractionation of executive functions were presented. The current study continued the design of the first study, looking at a 7-year-old group, 10-year-old group and a 14-year-old group. In terms of academic progress, the 7-year-old group has just had their SATs at the end of Year 2. The 10-year-old group was preparing for their SATs in year 6 while the 14-year-old group was in Key Stage 3. The three-year groups have covered a wide range of academic length, which covered Key Stage academic assessments.

In addition to the previous study, this research aims to a) investigate the association between executive functions and their academic achievement throughout childhood; b) clarify the extent to which EF task contributes to English and mathematics skills in school-aged children.

4.2 Method

We have continued the study from Chapter 2 and they are the same sample for both of the studies. The current study is looking at the school-aged students,

based on the four-factor model that has been found in the same age range. Three age groups are designed to test the cross-sectional difference on the correlation between four executive functions and scholastic attainment. Also, the age groups have been chosen to reflect the Key Stages of the National Curriculum in England which is in line with our aim to observe scholastic achievement in schools. The materials and procedure for the measures of executive function were reported in Chapter 2.

4.2.1 Materials

In addition to the executive tasks, the most recent National Curriculum Results (2015/2016) were collected for these analyses, including English and mathematics results. Teachers recorded each child's progress according to the national curriculum, measured by tests conducted within schools. Different schools followed different systems of rating the National Curriculum Levels (i.e., some schools assessed students English in reading and writing domains, some schools only used one result representing English ability). In order to keep consistency across schools the results for reading and writing were averaged in order to produce a level for English where appropriate (i.e., if a child's reading level was 2a, it was coded as 2. If a child's writing level was 3c, it was coded as 3. If a child's reading level was 3a but writing level was 2b, their English level was coded 2.5).

4.2.2 Statistics analysis

From previous studies, effect sizes were considered as medium effect size at 0.5 (e.g. Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Pearson correlation analysis in this study recommends that statistic power is 0.8, effect size (correlation coefficient) is 0.5, and the probability of type I error is 0.05. According the number present above, a sample size of 26 is necessary, which is calculated by G*Power 3.1.9.2. In this study, we recruited 186 participants to take part.

Pearson correlation was applied to examine the relationships between each measures of executive function, age, English and mathematics. Simple linear regression analysis was conducted to examine the extent to which executive functions predicted English and mathematics attainment.

4.3 Results

4.3.1 Descriptive statistics

There were significant differences in both English and mathematics across the three age groups. Descriptive statistics are presented in table 4.1. As noted in Chapter 2, EF tasks, namely the word recall working memory task, pattern recall working memory task, counting recall working memory task, trail making task, semantic word fluency task and phonemic word fluency task scores also differed significantly across the three age groups, showing a similar pattern as academic achievement.

Table 4.1 The mean and SD of National Curriculum Levels in three different year groups

	7 yrs		10yrs		14 yrs		F	p
	Mean	SD	Mean	SD	Mean	SD		
English	2.28	.54	3.50	.88	5.07	.66	230.97	.000 ¹
Mathematics	2.31	.57	3.66	.92	5.16	.86	188.31	.000 ¹

¹ Pairwise comparisons between values between 7 yrs group and 10 yrs group, 10 yrs group and 14 yrs group, 7yrs group and 14yrs group are significant.

4.3.2 Correlational Analyses

Pearson's correlations for the executive measures, age and scholastic attainment are presented in table 4.2. Bonferroni correction was applied to the correlations to minimise the risk of type 1 error (all $p < .001$ were considered as significant).

For the whole sample, all of the EF tasks were significantly correlated with English and mathematics except WCST (English: $r = .203$, $p = .006$; math: $r = .176$, $p = .018$).

7-year-old children's attainment in English was significantly associated with performance on the word recall task, Go/No go task, semantic word fluency task and phonemic word fluency task (all $r > .406$, $p < .002$) after Bonferroni correction. Mathematics was significant associated with word recall task, Go/No Go task, trail making task and semantic word fluency task performance (all $r > .388$, $p < .002$)

after Bonferroni correction. The pattern recall task, counting recall task, Simon task and WCST were not significantly related to English and math attainment.

Similarly, 10-year-old children showed significant correlations between performance on the pattern recall task, trail making task, semantic word verbal fluency task, phonemic word verbal fluency task and English attainment (all $r > .375$, $p < .002$) after Bonferroni correction. The pattern recall task, trail making task and semantic word verbal fluency task were significantly associated with mathematics (all $r > .368$, $p < .002$) after Bonferroni correction.

However, in the 14-year-old group, none of the executive tasks were significantly correlated with English or maths.

Table 4.2 The Pearson's correlation between EF tasks and National Curriculum Levels on English and Mathematics in the whole group and three age groups.¹

	All (N = 185)		7 year old (n = 60)		10 year old (n = 63)		14 year old (n = 62)	
	English	Maths	English	Maths	English	Maths	English	Maths
WR	.643**	.602**	.439**	.388**	.324	.178	.107	.157
PR	.626**	.643**	.197	.233	.375**	.368**	-.149	.112
CR	.568**	.541**	.248	.081	.262	.184	.160	.262
ST	.406**	.411**	.310	.319	-.030	-.048	-.013	.139
GNG	.435**	.407**	.406**	.393**	.169	.101	.132	.144
WCST	.203	.176	.335	.322	.166	.125	-.076	-.115
TMT	.615**	.642**	.311	.407**	.483**	.571**	.072	.179
SWVF	.639**	.580**	.483**	.480**	.539**	.393**	.185	.066
PWVF	.601**	.532**	.435**	.330	.427**	.257	.020	-.033

Note: WR is working memory words recall task, PR is pattern recall task, CR is counting recall task, ST is Simon task correct rate, GNG is Go/ No Go part 2 correct rate, WCST is WCST revised preservative errors, SWVF is semantic word verbal fluency task, PWVF is phonemic word verbal fluency task.

¹ Full Pearson's correlation table between each executive task can be found in Chapter 2. English is National Curriculum results in English. Maths is National Curriculum results in Mathematics.

Note 2: **correlation is significant at the .01 level (2-tailed).

4.3.3 Regression analyses

Specific relationships between predictor variables and academic attainment were further tested in a simple linear regression analyses to assess the amount of variance in academic achievement (English and maths, respectively) accounted for by each of the significantly related measures of executive function. The data were checked for multicollinearity and there was no evidence of highly correlated

independent variables, which could impact the regression analysis. The outcomes are presented in table 4.3. Based on the correlation results, it has been applied in the regression analyses with those significant correlations. For example, only word recall working memory task, Go/No Go, semantic word verbal fluency and phonemic word verbal fluency tasks were significantly associated with English in the 7-year-old group. Therefore, only these four tasks have been taken into account in the regression analyses. None of the significant correlations were shown in the 14-year-old group, so no regression analysis was conducted on this year group.

Results revealed that for the 7-year-old group, measures of executive function contributed approximately 40% of the variance to English and 36% of the variance to maths. The word recall task contributed significant variance to English, while Go/No go task and semantic word verbal fluency task predicted unique variance in 7-year-old's mathematics results.

For the 10-year-old group, the measures accounted for 45% of the variance in English and 39% of the variance in maths. The pattern recall task and trail making task contributed significant variance to both the English and maths models, while semantic verbal fluency contributed unique variance to English.

Table 4.3. Linear regression analyses predicting unique variance in academic achievement (n = 60 for 7-year-old group; n = 63 for 10-year-old group)

	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>
7 year old group					
<i>English</i>					
Constant	.611	.395		1.548	.128
WR	.158	.056	.330	2.823	.007
GNG	.707	.480	.186	1.474	.147
SWVF	.032	.018	.254	1.790	.080
PWVF	.018	.016	.168	1.109	.273
<i>Maths</i>					
Constant	.546	.380		1.439	.157
WR	.111	.059	.233	1.899	.063
GNG	.944	.440	.248	2.144	.037
TMT	.023	.012	.231	1.955	.056
SWVF	.032	.015	.251	2.104	.041
10 year old group					
<i>English</i>					
Constant	.360	.538		.669	.506
PR	.206	.070	.295	2.941	.005
TMT	.031	.015	.226	2.036	.046
SWVF	.059	.021	.345	2.798	.007
PWVF	.030	.019	.178	1.584	.119
<i>Maths</i>					
Constant	.886	.592		1.496	.140
PR	.195	.076	.265	2.557	.013
TMT	.060	.017	.418	3.623	.001
SWVF	.037	.020	.204	1.823	.074

Note. For 7 year old group English model, $R^2 = .395$, $F(4, 49) = 9.657$, $p < .001$; For 7 year old group Maths model, $R^2 = .356$, $F(4, 49) = 8.313$, $p < .001$; For 10 year old group English model, $R^2 = .445$, $F(4, 56) = 13.007$, $p < .001$; For 10 year old group Maths model, $R^2 = .386$, $F(3, 58) = 11.493$, $p < .001$;

4.4 Discussion

The current study explored age-related differences in the contribution of four different executive functions to academic achievement in English and mathematics, with two main aims. The first aim was to investigate the age-related differences in the associations between executive functions and attainment. The second aim was to examine the extent to which different executive function tasks contributed to English and mathematics skills.

All of the executive tasks were significantly correlated with English and maths in the whole sample, except the Wisconsin card sorting task. Further analyses showed that the word recall task, the Go/No go task and the semantic word verbal fluency task were significantly associated with English and mathematics at 7 years old. The phonemic word verbal fluency task was significantly related to English while the trail making task was significantly associated with maths at 7 years old. At the 10-year-old group, the pattern recall task, the trail making task and the semantic word verbal fluency task were significantly related to both English and maths, while phonemic word verbal fluency task was significantly related to English. None of executive tasks was significantly associated with attainment. The executive functions assessed in the current study appear to be less involved in learning in typically developing children in middle and late childhood, which is consistent with previous studies (Altemeier et al., 2006; Gathercole et al., 2004). Also, the pattern of executive functions appears to be shifted, for example from word recall task assessing the phonological loops to pattern recall assessing the visuo-sketchpad. It might be due to the nature of attainment, which is assessed using different methods in students across three age groups. The discussion below will explore in more details the relationship between executive functions and school attainment.

The second question in the current study was to explore the extent of the contribution of EF to academic achievement. The current findings show that executive tasks contribute significantly to scholastic attainment in both the 7 and 10-year-old groups. Executive tasks contributed 40% of variance to English and 36% of variance to mathematics in the 7-year-old group, and 45% of variance to English and 39% of variance to maths in the 10-year-old group. Due to none of the executive tasks being significantly associated with English or maths in the 14-year-old group, no further regression analysis was applied. The pattern has been found that the contribution of executive functions to learning diminishes with age.

In working memory, regression analyses revealed that the phonological loop (measured by word recall task; WR) significantly predicted English attainment at 7 years old but not at 10 years old, which suggests that the phonological loop, for holding verbal information is essential in acquisition of literacy skills during the early school years. This finding is in line with that of Gathercole et al., (2004), Jarvis and

Gathercole (2003) and St Clair-Thompson and Gathercole (2006), adding to the evidence that the contribution of the phonological loop to English in young children.

The current study did not however find that the phonological loop continued to contribute to English after 10 years old, in contrast to previous studies. Possible explanations for this inconsistency might be: a) studies by Jarvis & Gathercole and St Clair-Thompson & Gathercole did not cover early year students in their samples; b) the contributions depend on the extent to which the English test requires holding and processing verbal information rather than reading comprehension and interpretation of the literature.

This study was unable to demonstrate that the visuo-spatial sketchpad showed a significant correlation with English and mathematics in the 7-year-old group, however, the visuo-spatial sketchpad significantly predicted English and mathematics at 10 years old. Previous research has focused on the associations between the visuo-sketchpad and mathematical skills. The current results found that in the youngest group and the oldest group, the visuo-spatial sketchpad did not predict mathematical skills, which is different from previous studies that suggested that visuo-spatial sketchpad is consistently associated with maths (Gathercole et al., 2004; Jarvis & Gathercole, 2003). This outcome is also contrary to that of Holmes and Adams (2006) who found the visuo-spatial sketchpad predicted more variance in a 7-8 years old group than a 9-10 years old group. However, the current study used the pattern recall task to measure the visuo-spatial sketchpad, which should be counted as a measure of the visual subcomponent of the visuo-spatial sketchpad. It is in line with Holmes et al., (2008) that the visual subcomponent predicted maths in the 9-10 year old group. This result may be explained by the fact that visual subcomponent of visuo-spatial sketchpad provides essential visual cues when children process maths problems at around 10 years old. When children are younger, they tend to use the spatial subcomponent as the mental workplace for storing information (Holmes et al., 2008), and when children are older, they are more likely to use mature strategies in mathematics solutions.

Surprisingly, the visuo-spatial sketchpad displayed significant association with English in 10 year olds, which is consistent with Jarvis and Gathercole's (2003) research using an SEM model. This result has not been widely explored in previous

studies, but in the current study, it indicates that the visual subcomponent of the visuo-spatial sketchpad may provide visual cues that play an important role in literacy. Another unanticipated finding was that the central executive did not predict English and maths in the three age groups. This suggests that children employ visual strategies rather than numerical-verbal strategies (counting span) in their academic study in early schooling. However, Andersson (2008) has argued that the central executive, which was assessed by semantic verbal fluency task, trail making task, colour stroop task, counting-span task and visual-matrix span task was the most important cognitive process in arithmetic development. This was attributed to the central executive coordinating and monitoring information and developing a mixture of solution strategies (i.e. verbal and visual strategies), which is useful in solving arithmetical problems. It is worthy of note that these cognitive tasks were used for assessing different functions than those in the current study. For example, in Andersson's study, semantic verbal fluency task was assessing the central executive and trail making task was assessing inhibition, but the current study has applied semantic verbal fluency tasks for assessing verbal fluency function and the trail making task for assessing shifting function (also can see Chapter 7.4). The same task has been applied to assess different executive function, which can cause confusion in interpretation. It is essential to figure out the actual construct that tasks are assessing. At the same time, confirmatory factor analysis is loading tasks onto factors for each cognitive ability. In the current thesis, the central executive is considered as the attention control system of working memory. However, Baddeley (1996) suggested the central executive is also responsible for the temporary activation and manipulation of long-term memory. This function of the central executive has been assessed here using verbal fluency and considered as a fourth function.

In terms of inhibition, only the Go/No go task contributed to mathematics attainment in 7-year-old group. This finding is consistent with previous longitudinal studies that inhibition contributes children's mathematics ability in the early years (Chung & McBride-Chang, 2011; Clark et al., 2010). It suggests that the abilities to suppress prepotent behaviours and stay focused are important in early mathematics learning.

However, inhibition did not play an important role in English and mathematics learning in late childhood in the current study. This finding is consistent with previous studies that inhibition is not a predictor of reading achievement at around 10 years old (Engel de Abreu et al., 2014; Litzman et al., 2010) or mathematics attainment in school (Van Der Ven, 2012). There are several possible explanations why inhibition does not predict scholastic achievement. Firstly, Altemeier et al., (2006) has found that inhibition only contributed to a read-take notes task rather than a writing report task in English, which suggests that inhibition only plays an essential role in the process of taking notes but not in writing tasks. English tests within the National Curriculum focus on the latter option by requiring the generation novel English stories, which might be the reason why the current study did not find that inhibition predicted unique variance in the regression model. Another possible explanation that why inhibition is not significantly associated with attainment is because inhibition is a very fundamental process in working memory and shifting. The associations between inhibition and attainments were captured by working memory tasks and shifting tasks (Andersson, 2008). Task impurity may have an impact on the analysis, which will be further discussed in Chapter 7.

Another important finding is that shifting contributed significantly to English and mathematics in the 10-year-old group. The findings are consistent with previous studies on English (Litzman et al., 2010; Van Der Sluis et al., 2007) and mathematics (Andersson, 2008). It suggests that shifting is playing an important role in English and mathematics at around middle childhood. Initiating behaviours for solving problems, switching mental sets and forming new rules and concepts are essential in English exams for writing novel answers and solving maths problems by figuring out new schemes (Litzman et al., 2010).

In addition, the trail making task, which is a shifting task with explicit rules, contributed unique variance to English and maths in the 10-year-old group. The result suggests that shifting is related to English and mathematics learning. However, the shifting task with implicit rules (i.e. WCST) did not contribute to English and maths in the current study. Yeniad and colleagues have argued that shifting tasks with implicit rules are involved in more cognitive processes than purely shifting, such as language and intelligence (Yeniad et al., 2014). Therefore,

WCST may not have been as sensitive as the trail making task in the current study for assessing the contribution of shifting to academic achievement.

Semantic verbal fluency was significantly associated with both English and maths in the 7-year-old group and 10-year-old group and associations were attenuated in the older sample. Most importantly, semantic verbal fluency contributed significantly to mathematics in 7-year-old group and English in the 10-year-old group. This finding is in line with previous studies that verbal fluency remains important for English and maths learning in childhood (Altemeier et al., 2006; Aran-Filippetti & Richaud, 2015). Loehr, Miller, DeCaro and Rittle-Johnson (2013) suggested that verbal fluency, which is the ability to strategically search and retrieve information, is important for students to better process and apply conceptual instructions in English and mathematics learning. Therefore, verbal fluency has been more important for the 10-year-old group than the 7-year-old group, who mainly learn basic knowledge of English and mathematics and 14 year old group who have acquired higher-level of conceptual knowledge in English and mathematics.

Finally, an interesting result of this study was that semantic verbal fluency was a significant predictor of English in the 10-year-old group, however, phonemic verbal fluency was not. Most of the previous studies either considered one of the verbal fluency tasks in their studies or considered the combination of scores from both verbal fluency tasks. There have been few studies that show different patterns across verbal fluency tasks, suggesting content-related retrieval ability is more important in English schooling than phonemic-lead retrieval.

4.4.1 Patterns of developmental changes

It has been shown that the strength of contributions between executive functions to academic achievement reduced over the time and there are no significant associations between executive functions and achievement on 14-year-old group. The finding indicates that it is consistent with previous studies, which shows similar developmental changes across childhood and adolescence (Best et al., 2011).

It is worthy to draw our attention that whether executive function still predict academic achievement into adulthood. In the previous literature, Georgiou and Das (2018) have found that only shifting predicted directly reading comprehension in university students. Miller, Nevado-Montenegro and Hinshaw (2012) have found that working memory and global executive function were the predictors of academic achievement in a 10-years longitudinal study on young female adults. Arguably, executive functions include manipulating information to achieve a goal, to learning and to reasoning (Baddeley, 1992). The daily learning activities requires people to be able to continue applying executive functions, particularly the ability to plan and organize thoughts and actions (Miller et al., 2012)

The reasons why executive functions could contribute to adult achievement but we found no significant associations at a middle adolescent group were: 1) Executive function studies have been guided by the principles about frontal-lobe function in adults, the current study has selected the executive tasks which can be used in children and adolescents. It may be that executive skills are important in young childhood and adulthood, but not in adolescence. For example, a number of studies have found that a strong relationship between EF and mathematics in early childhood and adulthood due to the recruitment of frontal brain areas in numerical processing with age (Cragg & Gilmore, 2014); 2) in the current study, it has looked at basic EF while adult research considers more complex EF, such as planning. Planning has been suggested to make the largest gains in later adolescence and adulthood (Best, Miller, & Jones, 2009); 3) the way that learning and attainment are measured differently across groups. We can use maths as an example. In this thesis, we looked at national curriculum levels which encompass a range of things, mainly basic arithmetic at a younger age which relies on EF, whereas at an older age, it involves arithmetic but also heavily involves reasoning, applying mathematics principles and considering shape, space and measures. In adulthood, these mathematic skills become more natural after regular practice. Additionally, administrators likely applied basic arithmetic test for assessing mathematics skills in adult participants (Miller et al., 2012). Therefore, the contribution of executive functions to mathematical processing will differ for children who are at different stages of learning mathematics (Cragg & Gilmore, 2014).

4.4.2 Limitations and future studies

As with any study, it is critical to consider limitations of this study. First of all, the curriculum tests to measure both English and math did not allow a detailed analysis of specific subcomponents of English and maths. National Curriculum levels, which were used in the current study, were provided by teachers. However, teachers presented English and mathematics levels as a whole, we were not able to analyses on the relationship between executive functions and each component of English skill and mathematics skill. Examining such relationships may have allowed us to further understand why executive functions are important for children's attainment.

Language, IQ and processing speed were three variables that could have been taken into account in the research, but unfortunately, we did not have this data. Some studies indicate that the role of working memory in mathematics is impacted by literacy ability (Lee, Ng, Ng, & Lim, 2004). It was suggested that the contribution of working memory to mathematics was reduced when the effect of language was partialled out. Using a path analysis, Lee et al., (2004) found that although there were moderate to strong correlations between working memory measures and algebraic performance, neither the phonological loop nor the visual-sketchpad contributed to algebraic word problem solving directly in a group of 10-year-olds. Literacy provided a greater contribution than working memory did. It was suggested that literacy was important for processing word problems.

IQ has also been found to be important in the area of executive functions. A previous study found that intelligence was a stronger contributor to scholastic performance than shifting, and shifting was substantially associated with intelligence (Yeniad et al., 2013). However, Aran-Filippetti and Richaud (2015) found that working memory, inhibition, shifting and verbal fluency accounted for a unique percentage of variance in writing expository texts, over and above the contributions of age and verbal IQ. Alloway and Alloway (2010) also suggested that working memory is a more powerful predictor than IQ of academic success.

Last but not least, Van Der Sluis et al., (2007) found that a non-executive factor was strongly related to reading and arithmetic performance. The non-executive factor included verbal ability, motor speed and other processes. Berg

(2008) also found that processing speed was a significant contributor of arithmetic calculation. The current study would have been improved by the inclusion of a non-executive factor such as processing speed, in order to provide the full conceptual model for executive functions.

The strengths of this study are that we considered a wide range of executive functions and their associations with National Curriculum tests. In a cross-sectional study, we can see the developmental differences across 7-14 years old.

This study has important implications for educational settings. The present results suggest that all of the four executive functions are important for children's skill development in scholastic attainment. Especially in early schooling, working memory, shifting and verbal fluency contributed significantly to academic performance. In older children attainment may be more dependent on higher levels skills, such as comprehension, interpretation and evaluation.

In summary, the four executive functions, working memory, inhibition, shifting and verbal fluency contributed differently to children's English and mathematics development at different ages. Word recall task of working memory significantly predicted 7-year-old's English, pattern recall of working memory, trail making task of shifting and semantic verbal fluency task of verbal fluency predicted unique variance in 10-year-old's English, and pattern recall task and trail making task significantly predicted 10-year-old's mathematics.

Chapter 5. Literature review on executive functions in children with Autism

Executive function underpin activities in everyday life. Executive functions are potentially able to explain some of the phenomena of autism (Russell, 1998). It has been considered that executive dysfunction is associated with autistic children's daily lives, for example, executive impairment is proposed to explain the repetitive and restricted behaviour in autism. Also, deficits in shifting appear to be characteristic of autism. In this chapter, we have the chance to investigate the relationship between executive functions and the characteristics in autism spectrum disorder. Clarifying cognitive processes of autistic behaviours is important for identify neurocognitive mechanisms linked with ASD, which potentially could inform new educational strategies in order to improve quality of life for children with ASD.

5.1 Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a neurodevelopmental disorder with lifelong impacts (Lyll et al., 2017). ASD is characterised by communicative difficulties, impairment in social interaction and the presence of restricted, repetitive and stereotyped behaviours in DSM-V (American Psychiatric Association, 2013). Recently the prevalence of ASD was reported to be 1 in 68 children in the population according to centres for disease control and prevention autism and developmental disabilities monitoring network. It is about 4.5 times more common in boys than among girls. It has also been reported that ASD may occur in all racial, ethnic and socioeconomic groups (Christense et al., 2016). ASD is defined using behavioural criteria, because there is the absence of specific biological markers (Hill, 2004).

5.1.1 Social communication and social interaction

According to DSM-V (American Psychiatric Association, 2013), children who are on the autism spectrum show two main types of difficulties, including persistent deficits in social communication and social interaction across a variety of contexts,

currently or by history. Children may demonstrate difficulties in social-emotional reciprocity, for example they fail to maintain normal back and forth conversation or to initiate or respond to social interactions (Bauminger, 2002). Also, children find it is difficult to share interests, affect and emotions with other people (Quill, 2002). Furthermore, children with autism have fewer eye contacts and nonverbal communication, abnormalities in body language and difficulties in understanding and using body gestures (Quill, 2002). Children find it difficult to share imaginative play, make friends and adjust behaviours to suit multiple social contexts (Wolfberg & Schuler, 1999). Therefore, it is hard to develop, maintain and develop relationships between autistic children and other people.

5.1.2 Repetitive behaviours

The second of the diagnostic criteria is that children show they have restricted, repetitive patterns of behaviours, interests or activities (RRBI), including stereotyped motor movements. It has been considered as a core feature of autism (Asperger, 1944). Children may demonstrate behaviours such as lining up objects, flipping hands, and repeating other people's speech (Richler, Bishop, Kleinke, & Lord, 2007). In addition, children insist on sameness of routine and/or environment and they would feel extreme distress at small changes (Leekam, Prior, & Uljarevic, 2011). Children also may display hyperreactivity or hyporeactivity to the input of sensory or unusual interests in sensory aspects of environment, for example children have excessive smelling or touching of objects (Ritvo & Freeman, 1977). Furthermore, Szatmari et al., (2006) find that the structure of the repetitive behaviours and interests domain in children with autism consists two distinct factors: insistence on sameness (IS) and repetitive sensory and motor behaviours (RSMB). The IS factor seems to be associated with autistic characteristics in the ADI-R communication domain, while the RSMB factor is negatively related with level of adapting functioning (Szatmari et al., 2006).

5.2 Explanation of autism

A range of cognitive theories have been proposed to explain autism, including the theory of mind deficit (Happé, 1994), central coherence (Frith, 1989; Happé &

Frith, 2006) and executive dysfunction (Teunisse, Cools, Van Spaendonck, Aerts, & Berger, 2001).

The first theory is the ‘theory of mind’ and it has been the most extensively researched theory in cognitive explanations of autism. Theory of mind suggests children with ASD are impaired at communication, socialisation and imagination, because they fail to provide context-appropriate mental states and fail to make appearance-reality distinctions (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). For example, autistic children will find it difficult to accept an object is a candle because it is shaped as an apple. Scholars believe lack of theory of mind affects children with autism, who are unable to represent and attribute mental states to other people, such as thoughts and beliefs, in order to predict or explain the people’s actions (Frith, 1989; Leslie, 1987). However, theory of mind has been unable to explain characteristics cohesively, such as restricted and repetitive behaviours and interests (Turner, 1997).

The second cognitive theory is central coherence. Frith (1989) introduced the term weak central coherence to describe an internal drive that everyone tends to integrate information into a whole and understand the meaning from it. Children with ASD experience a weak drive to derive meanings from a whole and display a failure in processing information in context. When children with ASD process information, instead of understanding it as a meaningful whole, they process it as fragmented and meaningless pieces (Frith and Happé, 1994). However, no correlations have been found between central coherence tasks and ASD characteristics (Teunisse et al., 2001; White and Saldana, 2011).

5.3 Executive dysfunction

Executive function is an umbrella term used to describe a wide range of everyday abilities considered to be necessary for day to day living, including working memory, inhibition, shifting and verbal fluency (see Chapter 1). The fractionation of executive function has been investigated in Chapter 1. In this Chapter, we draw upon the results from Chapter 4 and continue investigating the relationships between each executive function and ASD characteristics.

The executive dysfunction theory of ASD has been widely explored, it suggests that executive dysfunction is an impairment of individuals with ASD. For example, Robinson and colleagues examined 54 children with ASD and found significant impairments in an inhibition task (Stroop) and preserved performance for shifting (WCST) and verbal fluency (verbal fluency task) in children with ASD when compared to an age, gender and IQ matched control group of typically developing children (Robinson, Goddard, Dritschel, Whisley, & Howlin, 2009).

While deficits in executive function have been identified compared to controls, associations between executive function and both of the autism characteristics (social communication/ interaction and restricted, repetitive and stereotyped behaviours) remain unclear (e.g. Dichter, Lam, Turner-Brown, Holtzclaw, & Bodfish, 2009; Teunisse et al., 2001; Turner, 1997). For example, in repetitive behaviours, two hypotheses of executive dysfunction have been proposed (Turner, 1997). The first hypothesis is that inhibition is impaired, which may lead to repetition because children may be unable to control attention and action in such manner, which shows a 'locked' pattern in behaviours. The second hypothesis is that the inability to generate novel behaviours and lack of prompts may lead to the repetition of behaviours.

Such executive dysfunction may also result in trouble concentrating on chores and schoolwork or getting used to new situations. Among the cognitive theories mentioned above, executive dysfunction theories can explain many aspects of autism characteristics and acknowledge both cognitive and motor aspects of ASD (Rajendran & Mitchell, 2007).

5.4 Working memory

Working memory has been defined as a process of storing and processing information mentally and it includes phonological loop, visuo-spatial sketchpad and the central executive (Baddeley, 1996). More details about definitions and commonly used tasks of working memory have been described in Chapter one.

It is stated that the majority of children with poor working memory are slow to learn reading and mathematics across both primary and secondary educational

settings (Gathercole, Alloway, Krikwood, Elliott, Holmes, & Hilton, 2008). It has also been proposed that these students have difficulties in following instructions. When these learning activities require both storage and processing, they tend to have difficulties on place-keeping, short attention span and they are easily distracted.

There has been inconsistent and inconclusive evidence about whether children with ASD have working memory deficits (see for reviews Kercood, Grskovic, Banda, & Begeske, 2014). A few studies suggest children with ASD have intact working memory abilities (Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Strayer, 2001). Ozonoff and Strayer (2001) examined working memory in adolescents in a high functioning autistic group, a Tourette syndrome group and a control group, and found no significant group differences. However, a recent meta-analysis review found a significant working memory impairment in autism, with the visuo-spatial sketchpad more severely impaired than the phonological loop (Wang et al., 2017). Despite the fact that working memory impairments have been widely acknowledged, the link between working memory and ASD characteristics remains unclear. Therefore, this highlights the importance of future research in this area.

5.4.1 The associations between working memory and ASD characteristics

ASD characteristics have been acknowledged in DSM-V as two main domains, including communicative difficulties, impairment in social interaction and the presence of restricted, repetitive and stereotyped behaviours. However, research which was conducted before DSM-V, investigated three different domains: communication characteristics, social interaction characteristics and restricted and repetitive behaviours. In this case, we have grouped communication and social interaction into one characteristic to present in this thesis, therefore, two domains will be discussed in this chapter.

Inconsistent results have been found in the relationship between working memory and ASD characteristics. Kenworthy and colleagues (2009) used Score DT task from Test of Everyday Attention for Children (TEA-CH; Manly, Robertson, Anderson, & Nimmo-Smith, 1999) to assess divided attention and working memory in a sample of 89 children with average age of 9.6 years old. Score DT requires the participants to listen for an animal name during an audio-taped news report. After

each of the 10 trials, the child must report the number of targeted tones counted and the name of the animal. It was found that there was a significant correlation between Score DT and communication characteristics and reciprocal social interaction characteristics, but not with restricted and repetitive symptoms. However, Score DT did not predict communication characteristics, but did predict social characteristics in the multiple regression model.

Lopez and colleagues (2005) examined the association between cognitive processes and the restricted, repetitive behaviours in 17 adults with Autistic Disorder (AD) and 17 healthy controls with letter-number sequencing from WAIS-III (Wechsler, 1997). Working memory was highly related to the restricted and repetitive behaviours.

In conclusion, working memory has been found to be related to communication and social interaction characteristics in children and related to repetitive behaviours in adults. More studies need to be undertaken to investigate the broader age range and the relationship between specific components of working memory and ASD characteristics.

5.5 Inhibition

Inhibition is the ability to suppress prepotent responses, which are irrelevant and non-dominant. Children with autism may experience difficulties in their daily lives as they may have a lack of the inhibition ability. For example, one of the difficulties children with autism have in social communication and interaction is autistic children tend to interpret language in the most literal meaning. This is associated with an inability to suppress the most frequently used meanings of words. Additionally, repetitive behaviours are associated with an inability to inhibit the behaviours despite other people's persuasion. Therefore, inhibition is associated with most atypical behaviours in children with ASD (Geurts, Van Den Bergh, & Ruzzano, 2014).

Inconsistent results of whether inhibition is deficient have emerged in various studies of ASD. Christ, Holt, White and Green (2007) examined 6-12 year old children with ASD and their siblings and other typically developing children, and

found that children with ASD illustrated impaired performance on inhibition tasks: Flanker task and Go/no-go task. However, Kilincaslan, Mukaddes, Kucukyazici and Gurvit (2010) suggested that children with ASD have similar results to controls on the Stroop task. In 2014, there was a meta-analyses review on inhibition among children with ASD, Geurts et al., (2014) suggested that inhibition problems were observed in children with ASD, but they also found a large variation between studies.

5.5.1 The associations between inhibition and ASD characteristics

It has been found that inhibition deficits are not specific to autism in children (Bishop and Norbury, 2005b). Contrasting results have been found between inhibition and repetitive behaviours. Some studies have applied verbal and non-verbal inhibition tasks which have shown that there were no significant correlations between poor inhibition and repetitive behaviours (Manly et al., 1999).

However, Kenworthy and colleagues (2009) have used walk-don't walk for measuring inhibition of prepotent responses in autistic children who were 6 to 17 years. They found inhibition of prepotent response was significantly related to restricted and repetitive behaviours. Some other studies, for example, Mostert-Kerckhoffs and colleagues (2015) also found the correlation between inhibition and repetitive and restricted trait with two semi-structured autism diagnostic assessments: autism diagnostic interview-revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) and autism diagnostic observation scale (ADOS; Lord et al., 2000).

In terms of the aspects of repetitive behaviours, two types of behaviours were insistence on sameness (IS) and repetitive sensory and motor behaviours (RSMB). Mosconi et al., (2009) investigated 18 individuals with ASD aged 8-54 years old and found individuals with a failure to inhibit prepotent responses were significant associated with insistence on sameness (IS) rather than repetitive sensory and motor behaviours (RSMB). This indicates that individuals with ASD experiencing IS and RSMB are also experiencing inhibition deficit.

Previous literature has found few studies on the association between inhibition and the social interaction trait of ASD characteristics in children. The possible reason was that inhibition difficulties may clearly appear on repetitive behaviours

rather than on social and communication behaviours. It requires additional study to investigate the underlying process of how inhibition interacts with social interaction and communication (Kenworthy et al., 2009).

5.6 Shifting

Shifting, also known as 'cognitive flexibility', is the ability to switch between two ongoing cognitive process, multiple tasks or mental sets (Miyake et al., 2001, see Chapter 1). Previous studies have suggested that individuals with ASD showed reduced shifting compared to typically developing children (Van Eylen, Boets, Steyaert, Evers, Wagemans, & Noens, 2011). Miller and colleagues (2015) found that children with ASD were able to initiate shifting sets, but they showed difficulties maintaining new mental sets. Reduced shifting may also lead to children who try the same way to approach a problem even when it does not work and feel upset by a change in plans.

5.6.1 The associations between shifting and ASD characteristics

Studies have revealed inconsistent findings regarding the relationship between shifting and social communication and interaction. A handful of studies have indicated that shifting is neither correlated with social communication in children with ASD (Yerys, Wallace, Harrusin, Caelano, Giedd, & Kenworthy, 2009) nor with adolescents and young adults with ASD (Teunisse et al., 2001). Yerys et al., (2009) indicated that there is no significant correlation between shifting and social communication in a group of 35 high-functioning children aged 6- and 13-year-old by using Intradimensional /Extradimensional (ID/ED) shift test. In another study, Reed, Watts and Truzoli (2013) did not find a significant correlation between shifting and social communication and communication difficulties in a group of 15 low-functioning autistic children whose mean age was 8 years old and mean nonverbal IQ was 71. Similarly, Teunisse et al., (2001) suggested that shifting is not correlated with social competence in a sample of 35 high-functioning people who are aged from 16 to 24 years old, by using several laboratory tasks including a Wisconsin card sorting task.

However, Berger, Aerts, Spaendonck, Cools, & Teunisse (2003) suggested that shifting was a prognostic marker on social functioning including symptom severity, social intelligence and social competence after a 3-year period pre-test and post-test.

In terms of repetitive behaviours and interests, several studies have suggested links between shifting and repetitive behaviours. Brunsdon and Happé (2014) suggested that shifting deficits underlie restricted and repetitive behaviours and interests (RRBI) in ASD because of the failure to shift mental sets. Turner (1997) hypothesised that difficulties in shifting between two ongoing tasks underpin the RRBI seen in ASD. Yerys et al., (2009) reported shifting ability has a significant and positive correlation with RRB in 35 children with autism aged 6 to 13 years old using ED reversal shifting score in ID/ED task but not during ED shifting stage. Similarly, South, Ozonoff and McMahon (2007) found that perseverative errors on Wisconsin card sorting task of shifting was significantly correlated with repetitive behaviour in a sample of 19 adolescents with high-functioning autism aged 10 to 19 years. These studies suggested that laboratory shifting task underlying repetitive behaviours and interests in ASD. Also, D'Cruz, Ragozzino, Mosconi, Shrestha, Cook and Sweeney (2013) examined 41 adolescents with ASD aged 15 years old using a probabilistic reversal learning task. This required the participants to choose the picture which was in the correct location by following the criterion. After the first stage, participants had to adapt to a new reversal criterion and immediate feedback was provided. The regressive errors which were assessing how well participants could maintain the new criterion, were found to be significantly correlated with RRBI (Repetitive Behaviours Scale-Revised, (RBS-R; Bodfish, Symons, Parker, & Lewis, 2000).

The association between shifting and increased severity of RRBI has been found by Miller et al., (2015) using ADOS and ADI-R. Shifting was assessed by a card-sorting paradigm test, Penn Conditional Exclusion test (PCEF; Kurtz, Ragland, Moberg, & Gur, 2004). Total error rates were found to be significantly related to RRB in a group of 60 adolescents with ASD aged 15 years.

The relationship between shifting and RRBI has also been supported in further research extended to a low-functioning autism group (Reed, Watts, & Truzoli, 2011)

and to an adult autism group (Lopez, Lincoln, Ozonoff, & Lai, 2005). Reed et al., (2011) have examined children aged 8 with conditioning materials, which was assessing shifting ability. Significant correlations were found between several perseverative errors within shifting task and stereotyped behaviours. Lopez et al., (2005) have found that in adults with autism spectrum disorder, there was a positive relationship between shifting and restricted and repetitive behaviours. In the further examination of a multiple regression model, shifting was the sole executive deficit to predict restrictive and repetitive symptoms. However, when shifting, working memory and inhibition were entered into the same regression model, none of the cognitive abilities predict the restricted and repetitive behaviours.

There have therefore been several studies which have suggested that shifting is associated with RRBI in all of the participants' samples, including high-functioning autistic children, low-functioning autistic children and adults.

5.7 Verbal fluency

Verbal fluency is the ability to generate a series of novel responses (see Chapter 1), which requires successful information retrieval from memory. In this Chapter, two types of fluency, word fluency and ideational fluency will be examined.

There are a few studies indicating that verbal fluency is significantly poorer in ASD groups than typically developing control groups. Pastor-Cerezuela, Fernández-Andrés, Feo-Álvarez and González-Sala (2016) found that in a sample of 5- to 8-year-old children with and without ASD, children with ASD scored lower in semantic word fluency task than those without ASD. Chronological age is the predictor of semantic word fluency ability in children without ASD, verbal IQ is the best predictor in the ASD group, which indicates that better linguistic competence would contribute to verbal fluency ability.

Inokuchi and Kamio (2013) suggested that in their qualitative analyses, children with high-function autism had fewer correct responses on verbal fluency when compared to age-, gender- and IQ-matched control group. Also, Turner (1999) found that for both word fluency and ideation fluency tasks, an autistic group

generated significantly fewer responses compared to a control group. In addition, word fluency was found to be correlated with verbal IQ and ideational fluency.

5.7.1 Association

To date, there are a handful of studies that have assessed the correlation between verbal fluency and autism characteristics. For example, Bishop and Norbury (2005) found there was a significant correlation between the composite of verbal fluency and communication characteristics in a sample of autistic children aged 6 -10 years. The composite of verbal fluency included the overall correct response rates of the uses of objects and pattern meanings tasks, which were accessing ideational fluency. Also, Kenworthy et al., (2009) suggested that semantic word fluency was significantly correlated with social communication and interaction, but not with repetitive behaviours in a group of 34 autistic children who are aged from 6- to 17-year-old.

In terms of individual semantic verbal fluency and ideational fluency, Ditcher et al., (2009) has found that only semantic verbal fluency was associated with social communication trait, but not with repetitive behaviours. Ideational fluency was neither correlated with social communication trait nor repetitive behaviours trait. This study indicated that semantic verbal fluency was related to social communication trait but not repetitive behaviours trait, and ideational fluency remains an unknown relationship with autism characteristics.

A few studies have therefore concluded that semantic verbal fluency was associated with communication but it is unclear for ideational verbal fluency. Neither semantic verbal fluency nor ideational verbal fluency were correlated with RRBI.

In addition, studies have involved a wide age range and potentially contain huge heterogeneity in their samples. In the current study, it was aimed to look at 'pure' autism without co-morbid conditions. It is important to note that some studies have included ASD with co-morbid conditions, such as attention deficit hyperactivity disorder (ADHD). For example, Sinzig, Morsch, Bruning, Schmidt, & Lehmkuhl (2008) reported that there is impairment in children with ASD in planning and shifting abilities while in children with ADHD, inhibition and working memory were impaired. The ASD with ADHD group showed similarities to the ADHD group with

regard to inhibitory but not to working memory deficits. Also, they suggested that EF assessment is not useful for differential diagnosis between ADHD and ASD. It might be useful for evaluating strengths and weaknesses in individual children due to the heterogeneity.

Furthermore, some studies have taken intellectual impairment into account for the associations between working memory and autistic characteristics. Intellectual disability and autism co-vary at very high rates. Greater severity of one of these two disorders appears to have effects on the other disorder on a host of factors (Matson & Shoemaker, 2009). Lamalfa, Lassi, Bertelli, Salvini and Placidi (2004) proposed that around 70% of people with autism have an intellectual disability, while only 40% of individual with intellectual disability have autism. This shows a big number in overlap between autism and intellectual disability. However, Robinson, Goddard, Dritschel, Wisley and Howlin (2009) have investigated executive function in a group of children with autism and a control group matched on the basis of age and intellectual quotient (IQ). They have found that children with autism displayed a multidimensional difficulty in executive function, however, they are independent of IQ and verbal ability and relatively stable across the childhood years.

These findings indicate that we will need to investigate in a smaller age range and identify the links between specific executive process and ASD characteristics. This part of the thesis therefore covers four executive functions, working memory, inhibition, shifting and verbal fluency, and their association with autism characteristics in children with ASD.

5.8 Assessing executive function including laboratory and parent-rating questionnaires

Assessment of children's executive functions can be undertaken via direct assessment using performance-based tasks (as used in the previous studies in this thesis) and by parent-rating questionnaires. Performance-based tasks or laboratory tasks have been found to successfully capture atypical cognition in individuals with ASD (Hill, 2004), however, how executive functions work in real world settings is still uncertain. Chaytor and Schmitter-Edgecombe (2003) have proposed the definition of ecological validity as to the extent of correspondence between

laboratory task performance and real-world performance. Burgess et al., (2006) furthered the definition of ecological validity as a measure of the representativeness of laboratory tasks in real-life and the degree to which laboratory tasks can predict problems in real-life situations. Parent-rating questionnaires can examine real-world experiences of behaviours related to executive function, such as the Behaviour Rating Inventory of Executive Function (BRIEF; Gioia et al., 2002).

The advantage of BRIEF is that it taps multiple subdomains of executive functions. It allows us to look at individual subdomains and to aggregate subdomains into composite scores, such as behavioural regulation index (BRI), metacognition index (MI) and general executive control (GEC). The problem with using BRIEF in autistic populations is that BRIEF is intended to measure executive functions in daily life by applying a standardised method, which is not specific to any particular disorder. There are no standardised norms for research regarding autistic populations. However, BRIEF has been widely used in autistic children for assessing their daily behaviours related to executive functions. For example, Rosenthal et al., (2013) found using the BRIEF, that shifting ability was reported by parents to be the greatest executive difficulty in children aged 5- to 7 years old and oldest children with ASD aged 14- to 18 years old. They indicated that, in terms of every day impact, difficulties with the ability to shift attention may result in difficulties engaging in social interactions.

Kenworthy and colleagues (2009) examined the relationship between BRIEF and autism characteristics and they found that the behaviour regulation index (BRI) was significantly correlated with communication characteristics, reciprocal social interaction characteristics and restricted and repetitive behaviours. Metacognition index (MI) was only significantly correlated with social interaction symptoms. This indicates inhibition and shifting within BRI were linked to three characteristics and working memory within MI was linked to social interaction characteristics.

Furthermore, Leung et al., (2016) found that both BRI and MI were significantly correlated with social characteristics in social responsiveness scale. They also suggested that both BRI and MI predicted social functioning in autistic children. There are less studies on the relationship between ecological validity executive

function and repetitive behaviours trait. Only Boyd and colleagues (2009) found that BRI was significantly correlated to repetitive trait.

Two different perspectives on assessing executive functions are therefore beneficial for evaluating relationships between EF and characteristics of ASD. Two different perspectives on assessing executive functions are therefore beneficial for evaluating relationships between EF and characteristics of ASD. It is worthy to note that only a few studies have investigated the relationship between laboratory tasks and parent-rating tasks in an autism population. Zandt and colleagues (2009) found that correlations between laboratory tasks and parent-rating questionnaires tended to be in the expected direction. More problematic behaviours in laboratory tasks were associated with lower scores in the questionnaires. However, weak relationships between questionnaires and laboratory performance were found and most of them failed to reach significance (Toplak, West, & Stanovich, 2013). Only 24% of the relevant studies reported their correlations were statistically significant, and the overall median correlation was only .19. This indicates that laboratory-based tasks and parental questionnaires might not be measuring the same executive function construct. The executive tasks have poorly adjusted to the demands of real life (Ferrero, Escolano-Pérez, & Bravo-Álvarez, 2017).

5.9 Parental evaluation of autism characteristics in research

Parental-rating questionnaires are beneficial for providing continuous data from research in general population and in educational settings. Yerys et al., (2009) have indicated that examination of the association between executive deficits and RRBI characteristics could be affected because of the use of a summary score from autism diagnostic measurements (i.e. ADI-R or ADOS). He suggested it would be better to use a continuous data measurement, such as social responsiveness scale (Constantino & Gruber, 2012).

The social responsiveness scale (SRS, Bölte, Poustka, & Constantino, 2008; Constantino & Gruber, 2012) as a parental-rating questionnaire provides an insight of everyday autism characteristics and is to measure the severity of autism characteristics as they occur in natural social settings. In a practical way, SRS only requires a teacher or a carer to complete in 20 minutes. SRS has been revised in

2012, providing a picture of a child's social characteristics, such as social awareness, social cognition, social communication and social motivation (Constantino & Gruber, 2012). In addition, SRS-2 included restricted interests and repetitive behaviours scale, which is compatible to DSM-V (APA, 2013). SRS-2 also indicated the severity of autism characteristics with four different bands: within normal limits, mild range, moderate range and severe range, which offered clinical screening function.

SRS-2 has been found to be sensitive to executive tasks. Mostert-Kerckhoffs et al., (2015) found that total score of SRS-2 scale was significant related with performance on a shifting attentional set-visual task, shifting attention set-auditory task and colour word interference test. However, this scale has been identified to be sensitive to shifting function, whether this scale is still sensitive to other executive functions needs to be considered with caution.

In terms of behaviours, the repetitive behaviour questionnaire (RBQ) is one of the most commonly used questionnaires for assessing repetitive behaviours, which was originally developed by Turner (1995). RBQ has been revised and validated in 2012 by Honey and colleagues, which is aim to examine the frequency and intensity of a wide range of restricted interests and repetitive behaviours.

For example, Zandt, Prior, and Kyrios (2009) applied RBQ in the study of the underlying executive functions in repetitive behaviours in children with ASD and with obsessive compulsive disorder. They have found a significant association between repetitive behaviours and BRI in the group of children with ASD, measured by RBQ and BRIEF respectively.

RBQ (Honey, McConachie, Turner, & Rogers, 2012) have found a two-factor solution as insistence on sameness/circumscribed interests (IS) and sensory/motor behaviours (RSMB). Each subdomain was significantly correlated with RRBI algorithm in ADI-R. IS and RSMB in RBQ are keeping consistency with the conceptual categorisation of two different types of RRBI identified by the requisite cognitive demands (Turner, 1999). There are few studies identified the relationships between both types of RRBI and executive functions.

5.10 Executive function heterogeneity in autism

In most of the studies regarding autism, reporting results at a group level is common. There is a wide range of variability across the ASD spectrum and this heterogeneity is being increasingly recognised by the research community. Etiology, phenotype and treatment outcome in heterogeneity are hallmarks of ASD (Masi, DeMayo, Glozier, & Guastella, 2017). These factors can contribute different levels to heterogeneity of an autistic group on communicative functioning and behaviours. It is therefore important to determine whether there are subgroups of children with ASD based on the presence of characteristics of behaviours and to investigate how different subgroups show the differences of their executive function profile.

Some published reports have attempted to focus on the heterogeneity of ASD and categorise children with ASD based on the characteristics. Klopper, Testa, Pantelis and Skafidas (2017) have found children with ASD without Intellectual disability (ID) can be differentiated into two subgroups: moderate social impairment subgroup and a severe social impairment subgroup. They found that children with ASD in the moderate social impairment subgroup demonstrated less severe social interaction and communication impairments, but they displayed severer restricted and repetitive behaviours. In contrast, children in the severe social impairment subgroup showed greater social interaction impairments with lower severity of RRBI. In addition, the severe social impairment group also demonstrated greater difficulties in cognition and language, and poorer adaptive functioning.

Characteristics of communication have been investigated in Japanese children with ASD (Tanaka, et al., 2017). Tanaka and colleagues found two subgroups and significant differences were found between the two subgroups on a child communication checklist scale. One subgroup was associated with low language competence and strong characteristics of autism, the other subgroup was associated with relatively high language competence and milder characteristics.

There is a rare study in cluster analysis looking into different levels of ASD characteristics and how they are profiled in executive functions. Georgiades et al., (2013) found a 'two factor/ three class' model, describing a social communication deficit factor and a fixated interests and repetitive behaviours factor along with three

subgroups based on different severities of the two factors. It is also suggested that children from the three sub-classes were functioning at different levels in terms of adaptive behaviours, language and cognition.

In the study of Geurts, Sinzig, Booth and Happé (2014), the concept of heterogeneity has been explored. They re-analysed data from three of their own separate studies to examine the degree of heterogeneity, and found out that only a small number of children with autism do have EF deficits and a large percentage of children do not have an EF deficit. The importance of looking into results on an individual level appeared. It also showed children can set up a heterogeneous group regarding their EF profile. Identifying the association between similar characteristics and profiles of cognition becomes more important and it is required to gain individual cognition profile in order to target treatments to personal needs.

5.11 Hypotheses

In summary, the aim of this study is to identify the relationship between executive functions (working memory, inhibition, shifting and verbal fluency) and two ASD characteristics (social communication and repetitive behaviours) in two settings: laboratory tasks and parent-rating scales. In addition, this study also aims to investigate the heterogeneity of children with ASD in terms of their abilities in executive function and their ASD characteristics.

It is hypothesised that a) working memory will be correlated with social communication trait in the laboratory task; b) inhibition will be associated with RRBI in the laboratory task; c) shifting will be correlated with social communication trait and repetitive behaviours trait in the laboratory task; d) semantic verbal fluency will be linked with social communication trait and ideational verbal fluency will not be correlated with the two traits when controlled for age and verbal IQ.

In terms of parent-rating questionnaires, a) BRI will be correlated with both ASD traits; b) MI will be only correlated with social communication trait; c) weak correlation will be between laboratory tasks and parent-rating scales.

As for cluster analysis, it is hypothesised that two clusters will be identified by the ASD characteristics from SRS-2 questionnaires and they will display significant

differences on social interaction and communication, repetitive behaviours, and executive functions including working memory, inhibition, shifting and verbal fluency.

Chapter 6. Examining the relationship between executive functions and autism characteristics in children with autism spectrum disorder

In this chapter, a correlational study of the relationship between executive functions and autism characteristics in children with Autism Spectrum Disorder who are from 7 years old to 15 years old is reported. As noted in previous chapters, executive function is a term used to describe a wide range of everyday abilities considered to be necessary for day to day living. It includes skills like being able to plan tasks and activities, pay attention to and remember important information. People with autism spectrum disorder (ASD) are often reported to experience executive function difficulties, which can result in trouble concentrating on chores and schoolwork or getting used to new situations (Leung, Vogan, Powell, Anagnostou & Taylor, 2016). However, whether there is an association between these executive functions and ASD characteristics remains unclear.

In this study, we concentrate on assessing four separate executive functions and explore whether they are related to autism characteristics in children with ASD. The study will investigate executive function in two ways. Firstly, by asking children to complete some game like tasks and secondly by asking the parents of these children to complete a questionnaire which asks about their child's ability to perform these tasks in their everyday lives. By using these two methods, we will be able to see whether the parent reports of their child's skills and difficulties matches the information we get from the tasks completed directly with children themselves. This study will also ask parents to complete questionnaires about their child's autism characteristics, including their social communication and interaction skills, and restricted interests and repetitive behaviours. We will then be able to determine whether there is an association between the degrees of executive difficulties children experience on the tasks and as reported by parents and their autism characteristics. This is important because it will help us to develop an understanding of what might relate to some of the features of ASD, which in turn may lead to the development of educational methods to reduce some of the more challenging aspects of the condition.

6.1 Present Study

The research questions addressed in the study were: a) Are there correlations between specific executive skills and autism characteristics in children with ASD? Which specific executive functions are related to distinct ASD features? b) Is there a relationship between executive functioning in children with ASD and their daily executive performance as rated by parents? c) Can discrete subgroups of children with ASD be identified based on their ASD profiles and can we identify significant differences in ASD profiles and executive functions within subgroups?

6.2 Method

6.2.1 Participants

30 children with Autism Spectrum Disorder and their families participated in this study. Only 28 children remained in the data analysis stage because two participants did not meet the IQ requirements in the screening task ($IQ \geq 70$). There were 21 boys and 7 girls aged between 7- and 14-years-old. The mean age of the participants was 10.29 years old (SD: 2.40). Children with co-morbid Learning Disability (LD) and/or Attention Deficit Hyperactivity Disorder (ADHD) were not included in this study. Recruitment was via an ASD related database (Database of Children with Autism Spectrum Disorder Living in the North East; DASLNE), which is based in the North East of England, United Kingdom. Families were contacted by the database staff. Parental written consent was obtained for children and written assent was obtained from each child. The tasks took place at either participant's home or Newcastle University depending on families' choices. This study gained ethical approval from Newcastle University Ethical Committee.

Due to the studies' design as investigating the relationship between executive functions and autism characteristics in children with autism spectrum disorder, the current study did not recruit a matched healthy control group.

6.2.2 Materials

This study included two types of materials, a set of executive tasks was conducted with the children and three questionnaires were completed by parents.

The set of executive tasks was measured by research administer, in order to obtain a cognitive profile in a pure-experiment environment. In the other hand, questionnaires were set to measure day-to-day activities and daily life behaviours.

Screening Measure:

Wechsler Abbreviated Scale of Intelligence-2nd (WASI-II, Wechsler, 2011) Short Form, including the vocabulary subtest and matrix reasoning was used to determine FSIQ. It takes children 15 minutes to complete the WASI.

Experimental measures:

Working Memory counting recall test (Computerised): This task examines children's working memory ability. It is the same task that typically developing children completed in study one. Refer to chapter 2 for more details.

Simon task (computerised): This task examines children's inhibition ability. This task requires children to inhibit their responses according to the rules (Engel de Abreu et al., 2014). It is the same task that typically developing children completed in study one. Refer to chapter 2 for more details.

It is important to note that in Chapter 2 the average correct response rates for the Simon task were .90, .95, .98 in the 7-year-old group, 10-year-old group and 14-year-old group, respectively. This was considered as a ceiling effect. However, considering the learning ability of the group of children with autism, the current study still employed the Simon task to assess children's inhibition ability. This also helped to maintain consistency of assessment across different studies, and given that some children with autism may be sensitive to the sounds in the Go/No-Go task in the previous study, the Simon Task seemed an appropriate measure for the study.

Wisconsin Card Sorting task (computerised): This task examines children's shifting ability. This task requires participants to sort cards according to one of three dimensions: colour, shape, or number (Heaton, 1993). It is the same task that typically developing children completed in study one. Refer to chapter 2 for more details.

Semantic word verbal fluency test: This task examines children's verbal fluency, especially in word fluency (Brooks, Sherman & Strauss, 2009). Children are encouraged to name as many animals as possible within 1 minute. It is the same task that typically developing children completed in study one Refer to chapter 2 for more details.

Uses of Objects task: This task examines children's verbal fluency ability, especially in ideational fluency. Children are asked to generate as many uses as they can for six different objects: a brick, a pencil, a mug, a piece of silk, a dowel, and a piece of clothing elastic (Turner, 1999). If children are silent for 15 seconds, they are prompted to keep trying. Each trial will be finished in 2 minutes or earlier if children can't provide answers anymore. All answers are recorded. Answers are categorised in two different groups, correct answers and errors. Under categories of errors, there are four different types of answers: a) incorrect answers: answers are impossible or there is no purpose; b) repeated answers: answers are repeated by the one given; c) redundant answers: answers are varied by one element from a previously given answer; and d) unusual answers: answers are technically possible but extremely unlikely. Correct answers are used in the analysis. Recorded answers were categorised by two independent researchers and conclusions were reached.

Parental questionnaires:

Behaviour Rating Inventory of Executive Function (BRIEF) is an 86-item questionnaire measuring different aspects of executive functions in daily lives for parents to complete (Roth, Isquith, & Gioia, 2005). The BRIEF has high internal consistency (alphas = 0.80–0.98) and test–retest reliability ($r = 0.82$) for parents-rating (Gioia et al., 2002). The Behaviour regulation index (BRI) involves three executive abilities: inhibition, shifting and emotional control, and the metacognition index (MI) involves five abilities: initiate, working memory, planning/organisation, organisation of materials and monitor. General executive control (GEC) is the composite score of BRI and MI (Gioia et al., 2002). Cronbach's alphas in this sample for the subscales on working memory, inhibition and shifting are .874, .853 and .760 respectively. For BRI, MI and GEC, the Cronbach's alphas are .848, .914

and .921, respectively. T-scores have been applied in this analysis. BRI and MI are used in the analysis.

Social Responsiveness Scale, Second Edition (SRS-2) is a 65-item parent report questionnaire, measuring characteristics associated with autism (Constantino et al., 2003). It provides 5 subscales capturing characteristics of ASD, namely social awareness (Awr), social cognition (Cog), social communication (Com), social motivation (Mot) and restricted interests and repetitive behaviours (RRB). Social communication index (SCI) includes social awareness, social cognition, social communication and social motivation. RRB forms an index for itself. There are separate coding sheets for females and males. T-score have been applied: scores of 76 or over are considered in the severe range; scores 66 – 75 are in the moderate range; scores 60 – 65 are in the mild range; and scores 59 or lower are within normal limits. The SCI score is used in the analysis to capture social communication and interaction characteristics of the sample. The SRS-2 total score is used in the analysis for ASD characteristics as a whole. The Cronbach's alphas of SCI and total scale in this sample are .873 and .890, respectively.

Repetitive Behaviour Questionnaire (RBQ) is a 33-item measure of repetitive behaviours in children with ASD (Turner, 1995). Using a 3 or 4 point Likert scale parents report their child's specific repetitive behaviours in terms of their severity or frequency. Two domains are included: insistence on sameness/circumscribed interests (IS) and sensory/motor behaviours (RSMB). Validity of RBQ has been examined with children with autism spectrum disorder (Honey, McConachie, Turner, & Rodgers, 2012). The RBQ total score is used in the analysis for restricted, repetitive behaviours and interest trait. The Cronbach's alphas of IS, RSMB and total scale in this sample are .856, .871 and .918 respectively.

6.2.3 Procedure

Each child was asked to complete the screening task and the experimental tasks in one session of one day, with breaks if the child wished. The whole session took approximately one hour. The researcher gave the questionnaires to the parents before the session working with the child and collected the questionnaires

when the child finished his/ her tasks. Parents took approximately half an hour to complete three questionnaires.

6.2.4 Statistics analysis

A range of psychometric analyses will be undertaken, including correlation analysis and Cluster analysis. From previous studies, effect sizes were about 0.5 (e.g. Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). Correlation analysis recommends that statistic power is 0.8, effect size (correlation coefficient) is 0.5, and the probability of type I error is 0.05. According the number present above, a sample size of 26 is necessary, which is calculated by G*Power 3.1.9.2. In this study, we recruited 28 participants and their families to take part.

Bivariate correlations were used to explore the association between key variables of executive function (working memory counting recall scores, Simon task correct responses, Wisconsin card sorting task revised preservative scores, semantic word fluency numbers, uses of objects scores correct items, and ASD features (the SRS-2 SCI score and the RBQ total score). To understand the potential relationship between executive functions and parent reported daily executive scores on the BRIEF, intra-class correlations were used. A hierarchical cluster analysis using the Between-groups method with Squared Euclidean distance measure was employed (Hair, Black, Babin, Anderson, & Tatham, 1998), which will explore possible subgroup of children based on their executive function and ASD profiles. Cluster analysis is a statistical method used to identify patterns within groups based on similar and dissimilar features (Romesburg, 2004; Steele, 2007). This identified subgroups of children with similar social interaction and repetitive behaviours based on SRS-2 scores. Cluster solutions were determined by the agglomeration coefficients and dendrogram. Cluster analysis has been used with small sample sizes and samples of children with developmental disorders (e.g. Barton et al., 2004). The variables used for the study are four different executive function. IQ and chronological age will also be included.

6.3 Results

6.3.1 Data preparation

All data were examined initially for missing data and outliers in SPSS (Version 23). Data were screened for univariate outliers by applying standardised values (z-scores). Z-scores which are larger than the absolute value of 3.29 were identified (Field, 2013). 3 outliers were replaced by the second highest or lowest value in the group (Ghosh & Vogt, 2012). Missing data were replaced by the mean for the sample. Skewness and kurtosis were conducted to test for normality. Values for asymmetry and kurtosis between -2 and +2 and -7 and +7 are considered acceptable in order to prove normal univariate distribution (George & Mallery, 2010; West, Finch, & Curran, 1995). All of variables had acceptable distributions with only minor departures from normality, except the Simon task and the working memory subscale of the BRIEF. The Simon task had skewness and kurtosis values outside the range of -2 and +2, indicating a non-normal distribution, which was negatively skewed and leptokurtic. Scores on the Simon task also indicated the presence of a ceiling effect. For this reason, the task was not included in any further analysis. Working memory in the BRIEF had a leptokurtic curve. Attempts were made to correct for this departure from normality by using logarithmic transformation, however, the results were similar with untransformed data. Therefore, untransformed data were used in the analyses for the ease of interpretation.

6.3.2 Descriptive statistics

Table 6.1 shows the descriptive statistics for all of the variables. Mean SCI and total score from SRS-2 were in the severe range of ASD characteristics (i.e. values ≥ 75). Mean working memory, Inhibition, shifting, BRI, MI and GEC scores of the BRIEF were above the clinically significant cut off level (i.e. values ≥ 65).

Table 6.1 Mean, Standard deviation, Range, Skewness and Kurtosis results for each variable in executive function tasks and parent-rating questionnaires

Variables	Mean	SD	Range	Skew.(SE)	Kurt.(SE)
Screening measure					
Vocabulary	53.21	9.77	35-73	-.10(.44)	-.85(.86)
Matrix	49.64	10.01	29-65	-.42(.44)	-.94(.86)
Reasoning					
FSIQ	101.43	14.40	77-131	-.07(.44)	-.92(.86)
Experimental measures					
WM	3.75	1.53	2-6	.39(.44)	-1.41(.86)
ST	.90	.12	.53-1.00	-2.37(.44)	5.66(.86)
WCST	47.68	4.17	40-54	-.41(.44)	-.89(.86)
SWVF	15.29	5.30	5-26	.16(.44)	-.45(.86)
UoO	8.54	2.81	3-14	.08(.44)	-.55(.86)
Parental questionnaires					
RBQ					
RSMB	10.46	7.04	2-24	.46(.44)	-1.07(.86)
IS	11.25	5.92	1-28	.75(.44)	1.15(.86)
Total	23.29	12.44	6-54	.64(.44)	-.14(.86)
SRS-2 (T score)					
SCI	77.89	7.69	63-90	-.08(.44)	-.40(.86)
Total	79.39	7.37	64-90	-.27(.44)	-.57(.86)
BRIEF (T score)					
Working memory	72.43	9.99	40-92	-.90(.44)	3.08(.86)
Inhibition	68.57	12.00	40-97	.09(.44)	.72(.86)
Shifting	77.61	9.14	57-92	-.14(.44)	-.29(.86)
BRI	72.89	9.25	51-88	-.33(.44)	-.45(.86)
MI	71.11	8.69	45-85	-.91(.44)	1.72(.86)
GEC	73.36	7.84	52-86	-.91(.44)	1.04(.86)

Notes: 1) FSIQ: Full scale IQ; 2) WM: working memory counting recall task correct items; 3) ST: Inhibition Simon task correct rate; 4) WCST: Shifting Wisconsin card sorting task preservative error reverse score; 5) SWVF: Semantic word verbal fluency task correct items; 6) UoO: ideational verbal fluency Uses of objects correct answers; 7) RSMB: RBQ Sensory/ motor behaviours subscale score; 8) IS: RBQ insistence on sameness/ circumscribed interests subscale score; 9) SCI: SRS-2 social communication index; 10) BRI: BRIEF behaviour regulation index; 11) MI: BRIEF metacognition index; 12) GEC: BRIEF general executive control.

6.3.3 Correlations

Table 6.2 displays the Pearson's correlations for the objective executive function tasks and parent-ratings of ASD characteristics. Bonferroni correction has been applied to the correlations to minimise the risk of type 1 error. None of the task variables were significantly correlated with parent-ratings of ASD

characteristics. The correlation between the working memory counting recall task and shifting score on the Wisconsin card sorting task was $r = .526, p = .004$. Ideational verbal fluency uses of objects tasks and WCST correlated at $r = .467, p = .012$ and Parent-rating SCI was associated with RBQ, $r = .521, p = .004$. The Bonferroni adjusted P value was $p = .002$ and therefore these correlations were no longer significant after Bonferroni adjustment.

Table 6.2 Pearson's correlations of laboratory tasks variables and parent-rating ASD characteristics

	1	2	3	4	5	6	7
1. WM	-						
2. ST	.290	-					
3. WCST	.526	.256	-				
4. SWVF	-.137	.195	-.172	-			
5. UoO	.187	.080	.467	.333	-		
6. SCI	.083	-.075	.207	-.311	.018	-	
7. RBQ	-.033	-.099	.052	-.001	.238	.521	-

Notes: 1) WM: working memory counting recall task correct items; 2) ST: Inhibition Simon task correct rate; 3) WCST: Shifting Wisconsin card sorting task preservative error reverse score; 4) SWVF: Semantic word verbal fluency task correct items; 5) UoO: ideational verbal fluency uses of objects correct answers; 6) SCI: SRS-2 social communication index; 7) RBQ: Repetitive behaviour questionnaire total score

Table 6.3 shows the Pearson's correlation of executive functions from parent-rating BRIEF and social trait of ASD characteristics. Shifting in BRIEF correlated with SCI ($r = .504, p = .006$). P value of less than .008 was deemed significant, after Bonferroni adjustment.

Table 6.3 Pearson's correlations of parent-rating executive functions BRIEF and SCI of SRS-2

	1	2	3	4
1. Working memory	-			
2. Inhibition	.342	-		
3. Shifting	-.041	.080	-	
4. SCI	.179	.280	.504**	-

Note: * $p < 0.05$, ** $p < 0.001$.

Table 6.4 shows the Pearson's correlations of executive functions from parent-rating BRIEF and repetitive behaviours and interests of ASD characteristics. Shifting was correlated with RBQ total score ($r = .515, p = .005$) with a P value less than .008 deemed significant, after Bonferroni adjustment.

Table 6.4 Pearson's correlations of parent-rating executive functions BRIEF and ASD characteristics

	1	2	3	4
1. Working memory	-			
2. Inhibition	.342			
3. Shifting	-.041	.080	-	
4. RBQ	-.068	.049	.515**	-

Note: * $p < 0.05$, ** $p < 0.001$.

In order to examine the relationship between laboratory executive tasks and parent-rating executive functions, Table 6.5 displays the results of Pearson's correlation. All p values were higher than .001, which were not significant, after Bonferroni adjustment. No significant correlations were found between laboratory executive tasks (i.e. working memory counting recall task, WCST, semantic word verbal fluency and uses of objects) and BRIEF executive subscales (i.e. working memory, inhibition and shifting).

Table 6.5. Pearson's correlations between laboratory tasks and parent-rating executive functions, age and FSIQ.

Variables	1	2	3	4	5	6	7	8
1. WM	-							
2. ST	.290	-						
3. WCST	.526	.256	-					
4. SWVF	-.137	.195	-.172	-				
5. UoO	.187	.080	.467	.333	-			
6. working memory	-.104	.115	-.107	-.073	-.032	-		
7. inhibition	-.141	.052	.053	-.118	-.100	.342	-	
8. shifting	-.087	.229	.098	.000	.032	-.041	.080	-

Significant associations were found between shifting in BRIEF and social communication trait in SRS-2 and repetitive behaviours and interests trait in RBQ.

6.3.4 Cluster analysis

A hierarchical cluster analysis was employed to test whether heterogeneity was present in the sample in relation to the variables of interest and to cluster participants into sub-groups depending upon levels of social interaction and communication and repetitive behaviours. Between-groups linkage in cluster method and squared Euclidean distance of interval measure have been applied in the hierarchical cluster analysis. The agglomeration coefficients and the dendrogram suggested a three-cluster solution.

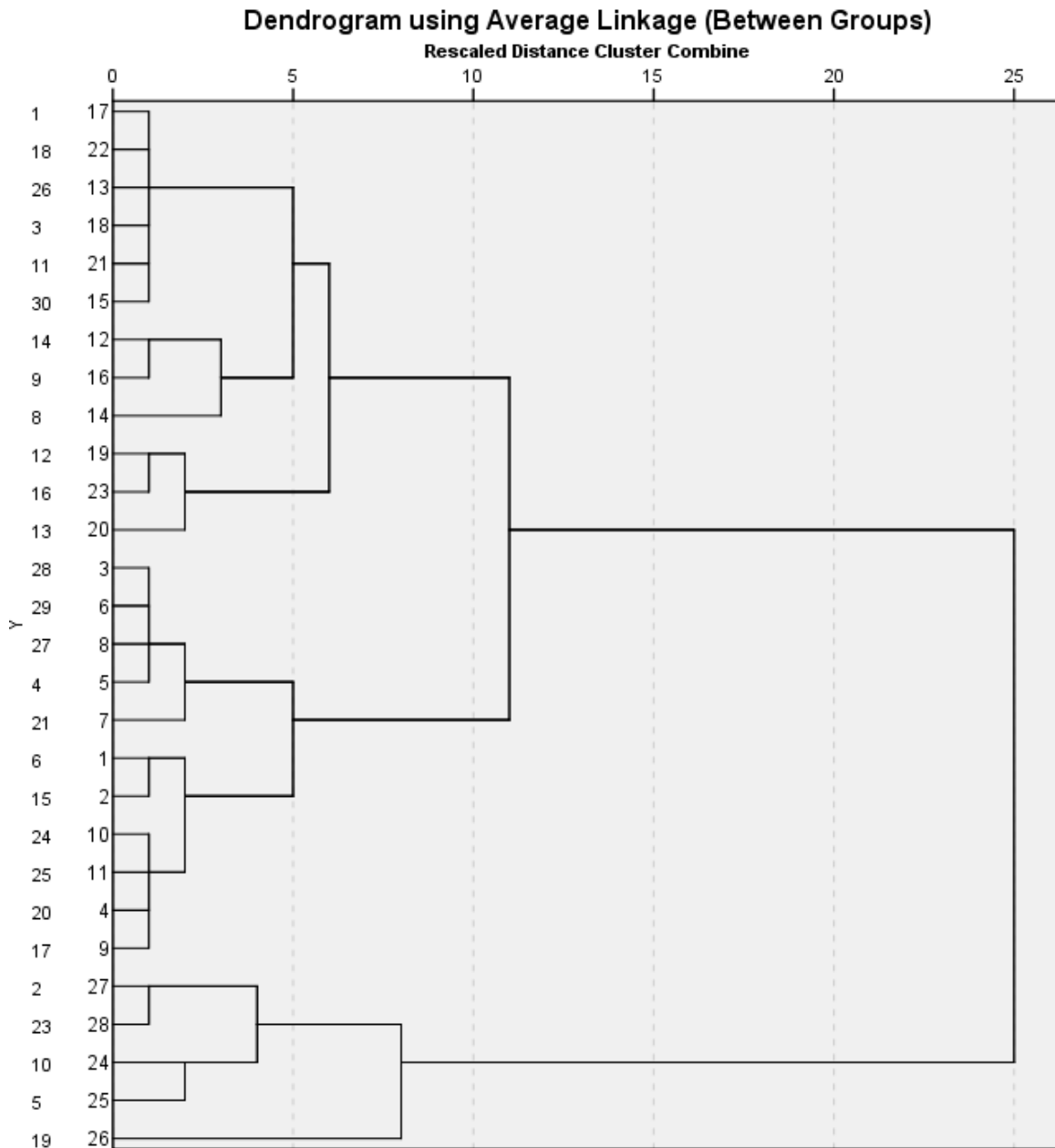


Figure 6.1 Dendrogram of hierarchical cluster analysis based on ASD characteristics in the total score of SRS-2, including SCI and RRB

The hierarchical cluster analysis indicated that the sample occurred at 3 clusters. Table 6.6 displays the profiles of each cluster. Cluster 1 (named the severe group) comprised five participants who showed the most severe social communication and interaction and restricted, repetitive behaviours and interests difficulties scores on the SRS. The Severe group also displayed the most difficulties on the subdomains of RRB as measured by the RBQ (i.e. sensory/motor

behaviours and insistence on sameness/circumscribed interests). They also displayed the poorest scores in a parent-rating of executive functions in all subdomains. Autistic children in cluster 1 had the highest FSIQ and the youngest mean age.

Cluster 2 (the moderate group) consisted of 12 participants. This was the majority of children in the sample. They demonstrated their ASD characteristics and EF in between severe group and mild group.

Cluster 3 (the mild group) comprised 11 children who displayed the least difficulties in terms of their ASD characteristics. Both their SCI and RRB scores were lower than severe range cut off on SRS-2, though they were still within the clinical range. In addition, they demonstrated the least sensory/motor behaviours and insurances on sameness behaviours on the RBQ. They also showed the least difficulties in executive function according to BRIEF. The means of BRIEF in this group were just above clinical severe level cut-off. Children in the cluster 3 had the lowest FSIQ and the oldest mean age.

These data highlighted the heterogeneity within sample of children with ASD. This indicate that some of the postulated relationships between executive function and ASD characteristics are present for some children but not necessarily all. Interestingly the three clusters did not differ markedly in age and full scale IQ scores, indicating that these differences between the sub-groups are not accounted for by chronological age or general ability.

Table 6.6 Mean and standard deviation of ASD characteristics and parent-rated executive functions in each cluster group

	Severe group (cluster 1, n=5) Mean (SD)	Moderate group (cluster 2, n=12) Mean (SD)	Mild group (cluster 3, n=11) Mean (SD)
FSIQ	104.20 (19.28)	101.75 (14.59)	99.82 (13.05)
Age	9.80 (2.28)	10.33 (2.64)	10.45 (2.38)
Executive tasks			
WM	4.00 (1.87)	3.58 (1.73)	3.82 (1.25)
ST	.91 (.04)	.88 (.13)	.93 (.14)
WCST	51.00 (2.24)	45.58 (4.34)	48.45 (3.59)
SWVF	12.60 (5.90)	16.92 (5.84)	14.73 (4.15)
UoO	10.00 (2.45)	8.17 (2.95)	8.27 (2.83)
SRS-2			
SCI	85.00 (6.86)	78.75 (7.16)	73.73 (6.25)
Whole	86.60 (4.98)	81.08 (6.10)	74.27 (6.11)
RBQ			
RSMB	21.20 (2.59)	12.00 (4.20)	3.91 (1.97)
IS	19.40 (5.81)	12.50 (2.88)	6.18 (2.93)
Whole	43.00 (7.14)	25.92 (5.00)	11.45 (3.62)
BRIEF			
Working memory	73.20 (6.22)	72.42 (9.84)	72.09 (12.14)
Inhibition	72.00 (6.08)	68.83 (12.90)	66.73 (13.45)
Shifting	84.80 (8.93)	77.67 (4.74)	74.27 (11.45)
BRI	77.00 (7.52)	72.42 (7.69)	71.55 (11.51)
MI	72.40 (9.97)	71.25 (7.92)	70.36 (9.69)
GEC	75.60 (5.08)	72.92 (6.71)	72.82 (10.15)

Notes: 1) FSIQ: Full scale IQ; 2) WM: working memory counting recall task correct items; 3) ST: Inhibition Simon task correct rate; 4) WCST: Shifting Wisconsin card sorting task preservative error reverse score; 5) SWVF: Semantic word verbal fluency task correct items; 6) UoO: ideational verbal fluency Uses of objects correct answers; 7) SCI: SRS-2 social communication index; 8) RRB: SRS-2 repetitive behaviours index; 9) RSMB: RBQ Sensory/ motor behaviours subscale score; 10) IS: RBQ insistence on sameness/ circumscribed interests subscale score; 11) BRI: BRIEF behaviour regulation index; 12) MI: BRIEF metacognition index; 13) GEC: BRIEF general executive control.

In order to demonstrate the cluster results in a clearer way, figure 6.2 displays the profile of ASD characteristics in the current cluster analysis. The red circles represent the 5 participants in the severe group. The yellow circles represent the 12 participants in the moderate group. The Blue circles represent the 11 participants in the mild group. Some participants shared the same scores and overlapped with each other.

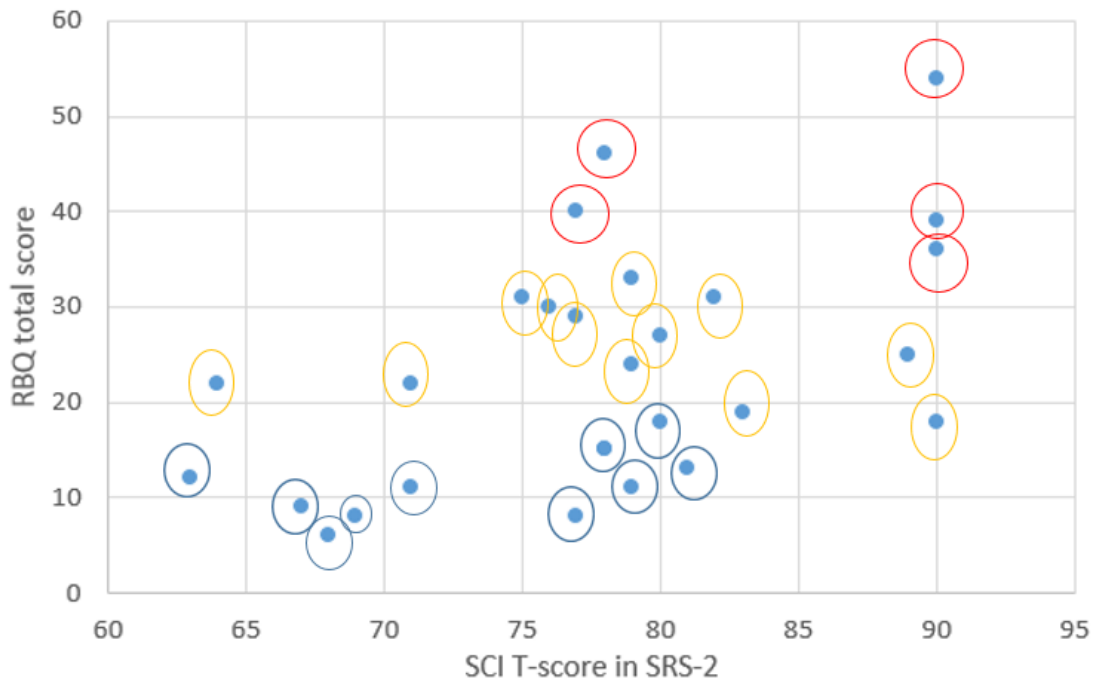


Figure 6.2 the profile of ASD characteristics in three different clusters

To display the deficits of three different groups of children with ASD, four figures have been produced. Figure 6.3 presented the EF profile with laboratory task in three groups with z-scores. Figure 6.4 displayed the SRS-2 social communication index and the whole score. Figure 6.5 presented the scores of RBQ subscales and the whole scale in the groups. Last, Figure 6.6 displayed the EF profile with parent-rating questionnaire's scores.

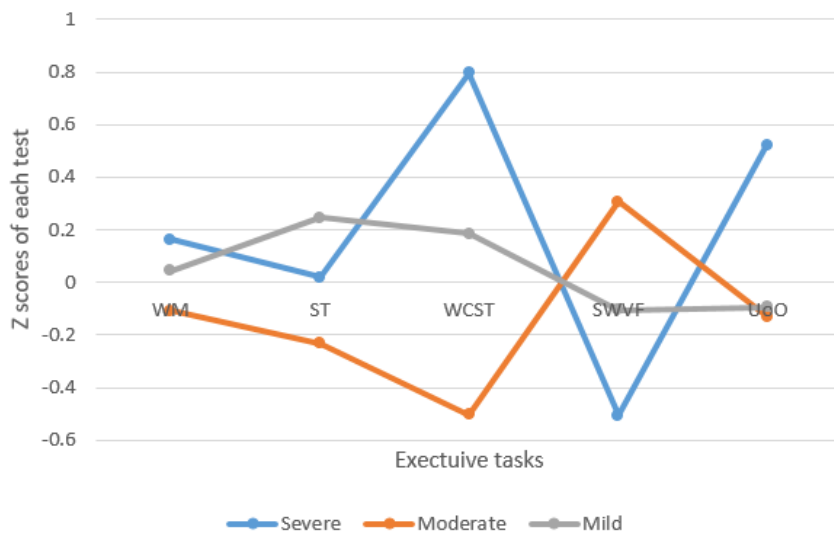


Figure 6.3 the EF profiles of laboratory tasks in three groups

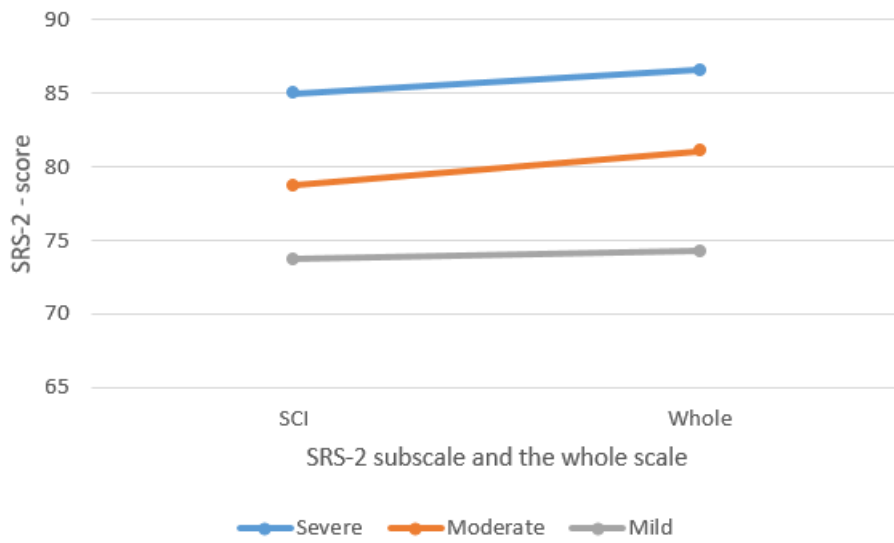


Figure 6.4 SRS-2 scores in three groups

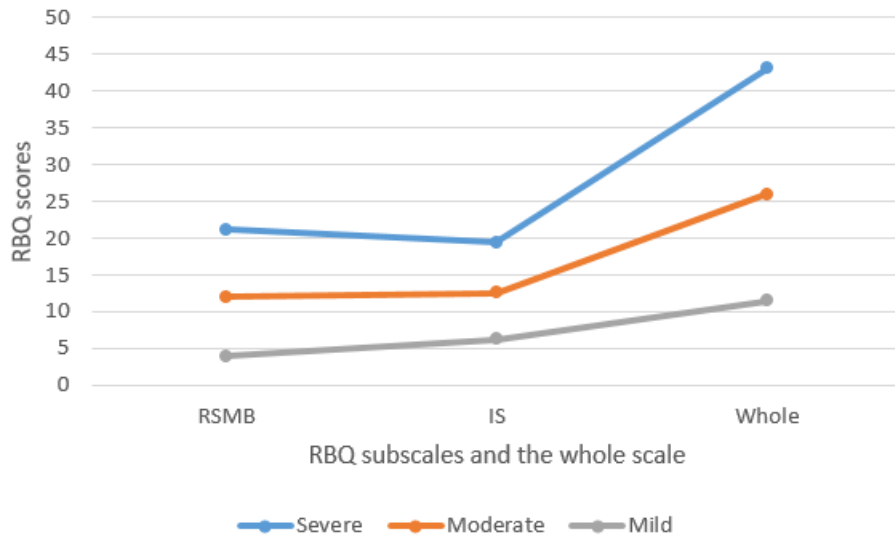


Figure 6.5 RBQ scores in three groups

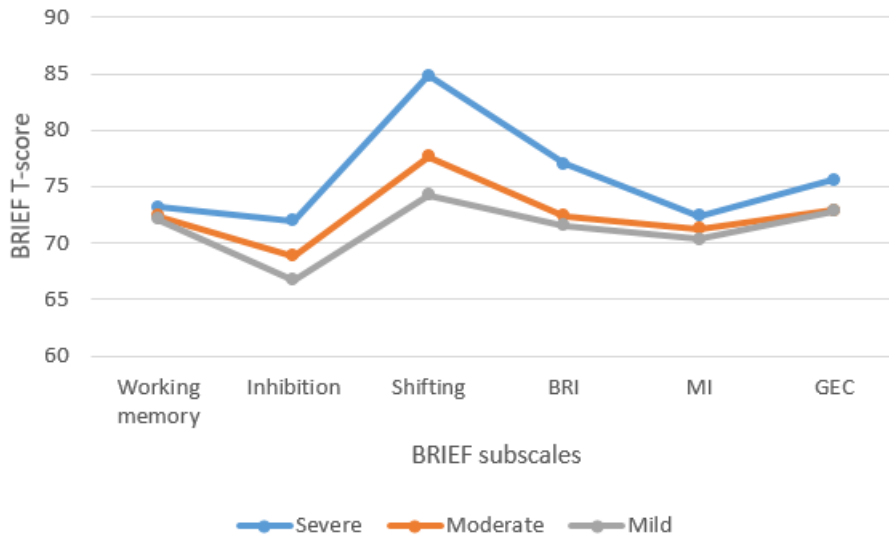


Figure 6.6 the EF profiles of parent-rating scales BRIEF in three groups

In the Figure 6.3, three different groups have presented inconsistent executive abilities on different domains. The severe group has presented the best results on the Working memory task, the Wisconsin Card Sorting Task and the Use of Object task; The moderate group has displayed the best result on the Semantic Word Verbal Fluency task; Mild group only presented the best result on the Simon task. On the other hand, the three groups displayed consistently results across three subscales and three composite scores in BRIEF. Severe group showed the most difficulties on all of the scales, while mild group showed the least difficulties on the all of the scales. Similarly, on both SRS-2 and RBQ questionnaires, severe group presented the most difficulties on both social communication index and repetitive behaviours subscales, while mild group presented the least difficulties on these scores.

6.4 Discussion

The purpose of the present ASD study was to investigate the association between executive function profiles and ASD characteristics: a) the relationship between laboratory executive tasks and parent-rating ASD characteristics; b) the association between parent-rated executive subscales and ASD characteristics; c) the relationship between laboratory executive tasks and parent-rating executive

subscales and d) explore possible heterogeneity in autism and any differences in executive function and ASD characteristics between sub groups.

6.4.1 Association between executive functions laboratory tasks and ASD characteristics

The present study revealed no association between executive laboratory tasks and ASD characteristics in social communication as measured by a Social Responsiveness Scale (SRS-2) and restricted, repetitive behaviours and interests (RRBI) as measured by the Repetitive Behaviour Questionnaire (RBQ). This outcome is contrary to previous studies that found significant associations between executive functions in laboratory tasks and ASD characteristics (i.e. working memory, inhibition and shifting with RRBI in Lopez et al., 2005; semantic verbal fluency and the communication trait in Kenworthy et al., 2009; shifting and RRBI in Yerys et al., 2008). This discrepancy might be explained by the differences in age of Lopez et al., (2005)'s sample which included adults). A further explanation for this might be that different measures of executive functions were employed in each of studies, such as Tower of London in Kenworthy et al., (2009) and Intradimensional\extradimensional (ID\ED) set shifting task in Yerys et al., (2009). Sensitivities of executive tasks and tasks' impurity will be discussed in the chapter 7.

However, the present study has included similar participants' age, sample size and similar tasks in shifting (WCST) and verbal fluency (semantic word verbal fluency task) with previous results (Lopez et al., 2005; South et al., 2007), the discrepancies are still evident. It is important to note that the autism characteristics were measured by parents-rating questionnaires in the present study, rather than clinical diagnostic assessments (i.e. ADOS and ADI-R). Parents-rating questionnaires are based on parents' perspectives and parents' points of view are potentially different from trained clinical administrators.

The current study has tried to examine the entire executive profile which has shown no significant link between working memory, inhibition, shifting, verbal fluency and ASD characteristics.

6.4.2 Parent-rating executive scales and ASD characteristics

The present study closely examined each subscale of executive function and looked for potential associations between executive functions and ASD characteristics. Three of the executive function subscales were found to have average scores for the sample that were above the clinical cut-off suggesting that in the current sample many parents regarded their children to be experiencing severe executive difficulties in everyday activities.

Few studies have examined the correlations between the shifting subscale in BRIEF and ASD characteristics. Rosenthal et al., (2013) and Granader et al., (2014) report shifting to be the greatest executive difficulty in autistic children aged 5- to 7-year old and 14- to 18-year-old. The current study provided further evidence that shifting is challenging for autistic children with parents reporting this subscale as having the highest T-score and significantly higher than two of the other scales (i.e. working memory and inhibition) in the present sample. Rosenthal et al., (2013) found that autistic children did not improve their executive functions quickly enough to keep pace with increased environmental demands, suggesting that the gap between environmental expectations and the actual ability of an autistic child increases over time.

Parent-rating questionnaire have showed that the shifting subscale in BRIEF was significantly correlated with both ASD characteristics, while the laboratory shifting task was not significantly correlated, although WCST appeared to be the most sensitive tool to assess shifting in ASD (Leung & Zakazanis, 2014). In the recent study, both BRIEF and ASD characteristics questionnaires were completed by parents at the same time, and it could therefore be that parent ratings on BRIEF are more closely related to ASD characteristics than laboratory tasks due to common-method variance. It may also because of the assessment characteristics. The BRIEF is based on observations of everyday behaviour, and laboratory tasks are structured measures of the maximum level of performance. Van Eylen, Boets, Steyaert, Wagemans and Noens (2015) found that individuals with ASD often display pronounced EF deficits in daily life, while performing adequately on structured laboratory tasks due to the task characteristics.

Previous literature also reports Behaviour Regulation Index (BRI) to be significantly associated with social communication difficulties and restricted, repetitive behaviours and interests (RRBI; Boyd et al., 2009, Leung et al., 2016; Kenworthy et al., 2009). As predicted, shifting within BRI was found to significantly correlate with both ASD characteristics in the present study. Puglises, Anthony, Strang, Dudley, Wallace and Kenworthy (2015) suggested that autistic children who have problems in shifting, often were described as being rigid. Autistic children often experienced being rejected by peers because they found it hard to cooperate with each other at play or did not want to join with play, which impacts on friendships and communication skills in a group activity or in an after-school club (Puglises et al., 2015). However, observing autistic children in the playground Freeman, Locke, Rotheram-Fuller, & Mandell, (2017) did not find shifting was significantly associated with social behaviours.

Significant associations were also found in our study between the parent-rated shifting and repetitive behaviours and interests suggesting perhaps autistic children who struggle with shifting in their daily lives may tend to stick to the restricted interests and behaviours. This pattern is consistent with results from laboratory shifting tasks and RRB (Brunsdon and Happé, 2014; South et al., 2007; Turner, 1997; Yerys et al., 2009) while there was no literature reporting the relationships between each of BRIEF subscale and RRB. However, it is important to note that there is some similarity in the wording of items on the different questionnaires. For example, item 23 on the BRIEF: 'Resists change of routine, foods, places, etc' is similar to item 20 of the RBQ. It asked parents 'Does he/she insist on eating the same foods, or a very small range of foods, at every meal?' or item 21 'Does he/she insist on moving or travelling by the same route?' Similar wording may have resulted in parents evaluating their children similarly on each item. This can be explained as a type of informant- and content-overlap (Van Den Bergh, Scheeren, Begeer, Koot, & Geurts, 2014).

The findings reported so far suggest that autistic children are reported by their parents to have difficulties on switching between on-going tasks, which may link autistic children's difficulties in socialising and interacting with others and getting used to new situations.

However, neither the inhibition subscale within BRI nor working memory subscale within MI were found to be significantly associated with ASD characteristics, which was inconsistent with previous studies. Kenworthy et al., (2009) highlighted that the MI was significantly associated with reciprocal social interaction symptoms and Leung et al., (2016) suggested weaker metacognitive abilities were related with more autistic social symptoms. Freeman et al., (2017) also indicated that metacognitive skills were linked with autistic children's social functioning, which was assessed by observing children's social functioning on the playground.

6.4.3 Intra-class correlation

In the current study, we have applied both laboratory tasks and parent-rating questionnaires to assess executive functions in order to increase ecological validity. The BRIEF results contribute to the ecological validity as a test of real life executive functions. No significant correlations were found between the laboratory tasks and parent-rating on the BRIEF in all three of the domains, working memory, inhibition and shifting. This result was consistent with a previous finding that the relationships between performance-based tasks and parent-rating questionnaires were generally weak (Kenworthy et al., 2008; Van Den Bergh et al., 2014; Zandt et al., 2009).

There are a few possible reasons why significant relationships were not found in this study. First of all, construct validity problems of the BRIEF in measuring daily executive functions in children with ASD needs to be considered. There is no standardised, validated version of the BRIEF for children with ASD. Parents may actually be rating other behaviours (i.e. non-executive behaviours) when completing the tool. McAuley, Chen, Goos, Schachar, & Crosbie (2010) suggested that rather than measuring executive functions, the BRIEF may be used to identify children who are experiencing behavioural difficulties and who may have school-related problems. Kenworthy et al., (2008) also have suggested that BRIEF must be interpreted cautiously because parents recorded observations of their children's behaviours in real life, which is an uncontrolled setting. Future studies could use the BRIEF as a screening test for parents whose children have real-life difficulties.

Secondly, the two types of assessment are not actually measuring the same construct. There is a difference in administration and scoring between these two types of measurement of executive function. Toplak et al., (2013) also suggested that they are tapping on different cognitive levels. Laboratory tasks are referred to the level of the algorithmic level and psychologists concern the information processing and mechanism in the brain. While parent-rating scale measures are referred to a reflective level of analysis. The reflective level of analysis is referred to the goals and beliefs of the system and the choice of action that is optimal. It is important to distinguish between algorithmic level and the reflective level. Because performance-based measures tell us about the efficiency of processing, while parent-rating scales provide information about success in rational goal pursuit (Toplak et al., 2013).

6.4.4 Groups of autistic children based on their autistic patterns

The hierarchical cluster analysis identified three clusters of children based upon the patterns of scoring on the SRS-2 (social communication traits) and restricted and repetitive behaviours and interests (RBQ scale). The results indicate that this group of autistic children can be differentiated into a severe ASD subgroup (cluster 1) and a moderate ASD subgroup (cluster 2) and a mild ASD group (cluster 3). The severe subgroup showed greater difficulties in social communication and more restricted, repetitive behaviours and interests, across both sensory motor behaviours (RSMB) and insistence on the sameness (IS). This finding was not consistent with a previous study (Klopper et al., 2017). Klopper et al., (2017) found autistic children without intellectual disability could be differentiated into two subgroups: the severe social impairment subgroup and the moderate social impairment subgroup. However, the severe social impairment subgroup had lower level of severity of RRBI. Klopper and colleagues also did not find significant group differences on RSMB and IS. However, in the current study children with autism who have more difficulties in social communication tend to have more difficulties with repetitive behaviours and interests according to parent report.

The three clusters were also differentiated according to parent-rated executive function. The severe group showed the greatest difficulties in all of the areas in

BRIEF, which indicates that children with autism who experience more ASD characteristics, also have more difficulties in daily executive dysfunctions, based on parents' observations. This finding is in line with Klopper et al., (2017) who suggested that the severe social impairment group show greater difficulties in cognition.

In terms of laboratory executive function tasks, the three clusters in the current study gave mixed results. Children in the severe ASD group showed the highest ability in working memory counting recall task, WCST and the uses of object task. Children in the moderate group show the highest scores in semantic word verbal fluency task and the mild group only presented with the strongest result in the Simon task. Different EF profiles in each group suggest that there was no executive dysfunction domain-specific to children with ASD and it is relatively stable in different levels of children with ASD. The structure of executive dysfunction in children with ASD was not supported. This finding is consistent with a meta-analysis of executive function in ASD conducted by Demetriou et al., (2018).

These findings indicate that clusters based on parent-rating questionnaires do not capture the children's actual executive abilities in laboratory tasks. Geurts et al., (2014) reanalysed their previous three autistic studies which included 93 children with ASD and 93 typically developing children to examine the degree of heterogeneity. They found only a small percentage of children with ASD displayed a significant deficit in executive function, which also indicates executive functions cannot be a sole explanation of ASD.

6.4.5 Strengths, limitations and implications

Several strengths were present in the study. Firstly, the current study attempted to identify a significant relationship between executive functions and ASD characteristics by using both laboratory executive tasks and parent-rated executive functions questionnaires. Hill and Bird (2006) suggested that standard measures of executive function would fail to capture the deficits in high-functioning children with autism due to the lack of ecological validity. In this study, two types of executive functions measures have been applied in order to increase the ecological validity. However, we did not identify a significant relationship between laboratory executive

functions and ASD characteristics and between laboratory tasks and parent-rating questionnaires in executive functions. Secondly, although there is no direct link between executive function and ASD characteristics, cluster analysis has categorised autistic children into three different levels based on their social communication traits and restricted and repetitive behaviours and interests. The analysis found that children who showed greater difficulties in social communication were displaying more restricted, repetitive behaviours and interests, across both sensory motor behaviours (RSMB) and insistence on the sameness (IS). The finding also found that children with autism who experienced more severe ASD characteristics, also have more difficulties in daily executive functions based on parents' observations.

Several limitations of this study must also be acknowledged. Firstly, we have not applied a standardised autism diagnostic assessment (i.e. ADOS) in the present study due to the practical issues. There is no control group in the present study, so we will not know whether EF-autism-characteristics links are specific to autism or predictive in a wider population. Also, this study excluded children with intellectual disability and children with medical and/or genetic conditions, therefore, the findings may not generalise to all children on the autism spectrum. Our sample had a wide age range. In a large age-range sample, biological changes may interfere with the findings (Mostert-Kerckhoffs, Staal, Houben, & de Jonge, 2015) and puberty related biological changes and brain development are huge and the effects of these changes are mostly not linear in nature and are highly complex (Giedd, et al., 1999). It is also important to notice that the executive tasks and parent-rating questionnaire (BRIEF) have not been validated in children with ASD. Furthermore, shared methods variance can be a problem in the present study. The BRIEF includes inhibition and shifting related-items, some of them can be interpreted as repetitive behaviours and interests (e.g. Item 30. Has trouble getting used to new situations, classes, groups and friends) and such overlapped measurement could impact the relationship between executive functions and repetitive behaviours and interests in children with ASD.

In addition, it is worthy to notice that the Simon task presented a ceiling effect in the current study. The Simon task was supposed to measure the ability of inhibiting the learned association during tasks and suppressing the effect of irrelevant

information, most of children with ASD achieved high scores in this task, and only two of them had 54% correct rates. This finding suggests that Simon task is relatively easy for these participants and it has not sensitively captured the inhibition ability in the study.

Last but not least, the current study only recruited 30 participants and 28 participants were included in the analysis. Although the current sample size was sufficient to conduct the statistical analysis, the issue of generalisation and low-reproducibility of the results has been considered.

6.5 Conclusion

In summary, the current study did not find significant associations between laboratory tasks of executive functions and autistic characteristics. We also found no association between laboratory executive tasks and parent-rating executive questionnaires. Only shifting in the parent-rated executive subscales was found to be significantly associated with both autistic traits.

This study contributes to the literature by expanding the understanding of the association between executive functions and two autistic characteristics, social communication difficulties and repetitive behaviours and interests. Although executive dysfunction assessed by laboratory tasks could not fully explain the association with autism characteristics, this study confirms that children with ASD experience executive difficulties in daily life particularly difficulties with shifting ability. We also revealed the heterogeneity of autism in the cluster analysis which shows the range of associations between different aspects of functioning across the autism spectrum.

Chapter 7. General Discussion

7.1 Overview

The studies presented in this thesis investigated the structure and developmental trends of executive functions and the relationship between executive functions and educational attainment in typically developing children, as well as exploring executive functions in children with autism spectrum disorder in relation to their autism characteristics. This chapter will begin with a brief summary of what has been included in each chapter in the thesis. Next, it will move on to synthesise the evidence across these chapters and discuss the findings and the implications in relation to the broader literature and to methodology. It will then explore the strengths and limitations of the current thesis, as well as the implications for future research.

This thesis focuses on the structure, developmental trends and impact of executive functions on both typically developing children and children with ASD. A general introduction to the structure and developmental trends of executive functions can be found in Chapter 1. Miyake and his colleagues' model (2000) provided the theoretical stand point on executive function adopted here. In this approach, three relatively correlated but separable executive functions were identified, namely working memory, inhibition and shifting. Verbal fluency as a fourth executive function has been considered by Fisk and Sharp (2004). The literature review in Chapter 1 discussed the unity and diversity view of the structure of executive functions and the developmental executive functions theories. Diamond (2006) has suggested a componential model, which was similar to Miyake's research with working memory, inhibition and shifting. Diamond's componential model has further explained how these abilities were essential to all forms of cognitive performance and that it is possible to relate one ability to another and to disassemble and recombine different abilities in a fresh new perspective. Diamond also suggested that the model can change at the different points of time in the development of a child. In this approach, components and the developmental trends of executive functions were presented. As a result, the structures of four executive functions were summarised in the literature. In addition, other researchers have suggested that there is a unitary structure in children's early

childhood, a two-factor structure including a working memory factor and a combined inhibition and shifting factor in late childhood (i.e. Brydges et al. (2014)). It was therefore suggested that different patterns of executive functions may appear in children, and a full picture of executive functions was needed.

Chapter 2 aimed to explore how executive function develops during childhood. Data were presented from a study of the structure and developmental trends of executive function in children who were aged 7- to 14-years-old. The results revealed significant age-related differences in three working memory tasks and semantic verbal fluency. There were also significant differences between age groups on the trail making task assessing shifting ability, while scores on the Wisconsin card sorting task did not show age-related differences. Two inhibition tasks showed different patterns of age-related differences. For the Simon task, there were significant differences between 7 and 10-year-old groups, while for the Go/No go task there were significant differences between 10 and 14-year-old groups. Confirmatory factor analysis suggested a four relatively separate factor model.

Chapter 3 presented a literature review on the relationship between four executive functions and scholastic attainments (i.e. English and mathematics) and age differences on the strength of the associations. Working memory has been found to contribute significantly to English and mathematics. Inhibition may be associated with English and maths in mid-childhood. The magnitude of the associations between working memory and attainments in English and maths, however, may be higher than the associations between inhibition and attainments (e.g. St Clair-Thompson & Gathercole, 2006). Some studies have found associations between shifting and academic achievement, suggesting it might be important for reading comprehension (Cartwright, 2002). Whereas others haven't found significant associations between shifting and either English or mathematics (Maye et al., 2009; Van Der Ven, et al., 2012). Verbal fluency has been found to be associated with English, predicting reading comprehension and performance on a written task (Altemeier et al., 2006; Aran-Filippetti & Richaud, 2015). More details of the role of verbal fluency needed to be explored.

Chapter 4 presented data indicating that although the majority of the executive functions were correlated to scholastic attainment, there were clear developmental differences in terms of the extent to which executive functions predicted attainments. For working memory, the phonological loop predicted English at 7 years old. Inhibition and semantic verbal fluency predicted mathematics at 7 years old. The visuo-spatial sketchpad and shifting predicted English and mathematics at 10 years old. The semantic verbal fluency also predicted English at 10 years old. In the oldest group (14 years old) there were no significant associations between executive functions and attainments.

Another research focus in this thesis was to examine executive function in children with ASD. Chapter 5 presented a literature review on the relationships between executive functions and autism characteristics, as well as executive function heterogeneity in autism. As revealed in the review, a majority of the papers have explored and discussed the associations between some executive functions and both autism characteristics: social and interaction difficulties and restricted, repetitive behaviours and interests. Few studies have focused on verbal fluency and the heterogeneity of executive functions in autism, highlighting the need to have more empirical work in this area.

The empirical work on the relationships between executive functions and autistic characteristics was reported in Chapter 7. The study included two different types of measurement: laboratory tasks and parent-rating questionnaires of executive functions included to increase the ecological validity of the study. The current study did not find significant associations between laboratory tasks of executive functions and autistic characteristics. We also did not find association between laboratory executive tasks and parent-rating executive questionnaires. Only shifting in the parent-rated executive subscales was found to be significantly associated with both autistic traits. The heterogeneity of executive functions in autism was described. The cluster analysis identified three groups of children based upon the patterns of scores of social communication and restricted and repetitive behaviours and interests. The severe subgroup showed greater difficulties in social communication and more restricted, repetitive behaviours and interests, across both sensory motor behaviours (RSMB) and insistence on sameness (IS).

7.2 Synthesising the evidence: the structure of executive function in typically developing children and children with autism

Unity and diversity of executive function has been investigated many times in samples of different ages. The findings presented in this thesis revealed that a four-factor model best described the data in this sample of 7- to 14-year-old children. These findings are consistent with the previous findings of the diversity view of the structure of executive function in typically developing children (i.e. Aran-Filippetti, 2013; Lehto et al., 2003; Rose et al., 2011; Wu et al., 2011). In addition, verbal fluency has been identified as a fourth distinct latent variable in the current model, which further supports the previous literature (i.e. Cassidy, 2016; Klenberg et al., 2001). However, the current findings are not consistent with studies which have indicated a unitary structure of executive functions (Fuhs & Day, 2011; Hughes, Ensor, Wilson & Graham, 2009; Miller, Giesbrecht, Müller, McInerney & Kerns, 2012; Wiebe, Espy & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier & Espy, 2011; Willoughby, Blair, Wirth, & Greenberg, 2010).

The structure of executive functions in typically developing children have been investigated regarding different age groups. It was best represented as a unitary construct in pre-schoolers (Wiebe, et al., 2008, 2011), while Miller et al., (2012) and Longigan et al., (2016) found that a two-factor model explained the structure of EF in preschool children, although the nature of these components is still in debate. Shing et al., (2010) and Xu et al., (2013) also displayed that a one-factor model represented the structure of EF in 7- to 9.5-years-old, 7- to 9-years-old and 10- to 12-years-old. However, Shing et al., (2010) only examined two specific executive components, memory maintenance and inhibitory control in the group of 7- to 9.5-years-old. Xu et al., (2013) have examined three executive functions in three different age groups, which consisted of a total sample of 457 children and adolescents. The discrepancy between these findings and our current study could be attributed to the different settings of the age groups. Additionally, the specific timing of documented changes in cortical functioning has been discussed (Xu et al., 2013). It has been suggested that at the functional level, there are critical changes in the patterns of prefrontal cortex activation that are elicited during EF performance, including enhanced activation in critical regions and attenuation in others between 9 years and 12 years (Durstun, Davidson, Tottenham, Galvan,

Spicer, Fossella, & Casey, 2006). This finding therefore supported that critical changes in prefrontal cortex has an impact on how executive functions develops from late childhood to early adolescence.

Further longitudinal studies to investigate developmental changes among the structure of executive functions are needed, in order to enhance the understanding of the structure of executive functions across childhood, especially at the age of 12.

The structure of EF was investigated in typically developing children, this therefore brought up the question of the structure of EF in children with autism spectrum disorder. In terms of investigating the structure of executive functions in children with autism spectrum disorder, this was not a main research aim in the current thesis. Regarding the previous literature, it has been suggested that an overall and not fractionated impairment of executive functions exists in children with autism spectrum disorder, based on parent-rating measures, such as BRIEF (Demetriou et al., 2017). The current study also found that the parents' rating met clinical criteria for autism on every aspect of executive function, which indicated that children with autism experienced executive dysfunction on different aspects of their daily lives.

7.3 Synthesising the evidence: the importance of executive function in typically developing children and children with autism

We followed the four-factor model and examined the associations between executive functions and daily functions with typically developing children and children with autism, scholastic attainment and autistic characteristics respectively. To our knowledge, an investigation of four executive functions with scholastic achievements and their age-related differences has not been conducted. We carried out the examination of the associations between four executive functions and English results and mathematics results in three age groups (7-year-old, 10-year-old and 14-year-old). The findings suggested the strength of associations between executive functions and academic achievement reduced over the three age groups and throughout childhood. This investigation also showed that the different executive tasks contributed differently to each year groups' English and mathematics performance. The phonological loop within working memory was

found to be important for English at 7-years-old whereas the visuo-spatial sketchpad within working memory, shifting and semantic verbal fluency contributed significantly to the 10 year old's English. Inhibition and semantic verbal fluency were found to be important for mathematics at 10 years old and the visuo-sketchpad, and shifting contributed significantly to the 10 year old's mathematics. This suggests that executive functions contribute to English and mathematics' attainments differently at different ages. Also, the magnitude of associations between working memory and scholastic attainment decreased over the years, which is consistent with previous findings related to executive functions assessed by a general cognitive assessment system and scholastic attainments assessed by a general achievement test. Research has suggested associations were large when children were aged 5-6, moderate when children were aged 8-9 years old and diminished in late adolescence (Best et al., 2011). Further longitudinal studies to investigate developmental changes among different executive functions and scholastic attainment are needed, in order to enhance our understanding of developmental trajectories in scholastic attainment through childhood.

To further investigate the association between executive functions and autistic children's characteristics, an examination of the association between executive functions, social communication characteristics and repetitive behaviours and interests was conducted (Chapter 6). Previous studies have mainly discussed whether children with autism are experiencing significant executive dysfunction compared to typically developing children and other populations (Robinson et al., 2009). The present study switched to focus on the association between executive function and autistic characteristics. In order to potentially increase ecological validity, laboratory executive functions tasks and parent-rating executive function questionnaires were both applied. There was no significant relationship found between laboratory executive functions and parent-rating autistic characteristics. The finding suggests that there is no direct link between executive functions and parent-rated autistic characteristics. In terms of the associations between parent-rated executive functions and parent-rated autistic characteristics, only shifting was significantly related with social communication difficulties and repetitive behaviours. This finding supports that greater shifting problems are associated with autistic children's difficulties in socialising and interacting with others and with autistic

children's repetitive style including getting stuck in a set routine. It also supports previous studies that difficulties in shifting can be as an explanation of the role to autistic characteristics (Brunsdon and Happé, 2014; Puglises et al., 2015; South et al., 2007; Turner, 1997; Yerys et al., 2009).

A cluster analysis was undertaken to investigate the heterogeneity in autistic children, suggesting some heterogeneity within autistic children regarding different levels of executive functions. Although the cluster of autistic children into different groups has been reported (Georgiades et al., 2013; Geurts et al., 2014), it is rare for a study to look into different levels of ASD characteristics and how they are profiled in executive functions. The current study found that the severe subgroup, which had five participants, showed the greatest difficulties in social communication and more restricted, repetitive behaviours and interests, across both motor behaviours (RSMB) and insistence on sameness (IS). Also, this group appeared to show the greatest difficulties across the areas of BRIEF. This indicates that children with autism who experienced more ASD characteristics, also had more difficulties in daily executive dysfunctions based on the parents' observations. This further suggests that this group shows greater difficulties in cognition because of the higher level of social impairment and repetitive behaviours. It is worthy to note that although there is no direct link between executive functions and ASD characteristics, executive function difficulties may be co-occurring with ASD characteristics rather than the ASD characteristics being a cause of executive dysfunction or executive dysfunction causing ASD characteristics.

7.4 Measurement

One main discussion point in executive function studies is the task impurity problem (Friedman & Miyake, 2017). It seems that the task impurity problem is unavoidable in studies in this area because executive functions are higher-order cognitive processes, which may involve lower-level /non-executive cognitive processes. Each executive function involves non-executive processes, which could influence the performance of executive functions (Friedman & Miyake, 2017). Cassidy (2016) pointed out that traditional statistical techniques (i.e. correlational analysis and exploratory factor analysis) failed to adequately measure the

associations between each executive function due to a multitude of irrelevant factors. Latent variable modelling (i.e. confirmatory factor analysis) has been suggested as a method for eliminating the influence of reliability and task impurity. CFA is a statistical method, which can create theoretically meaningful latent constructs across multiple manifest indicators (i.e. different executive tasks) through combining shared variance components (Cassidy, 2016). Miyake et al., (2000) were the first researchers to examine the associations of three of the most common executive functions at the level of latent variables, namely updating (working memory), pre-potent response inhibition (inhibition) and set-shifting (shifting). It effectively launched a novel approach to investigate executive functions.

Also, there is the possibility that the EF tasks did not tap higher-level processes, because these EF tasks were confounded by more basic processes. For example, working memory ability can be confounded by the reading ability. Wang and Gathercole (2013) suggested that children with reading difficulties showed significant group differences on both the verbal and visuospatial complex span tasks even controlled for relevant simple span task performance. This indicated that a primary storage deficit results to disrupted performance on more complex memory span tasks. In the current study, the word recall working memory task and the verbal fluency tasks may have been related to a primary language storage. It should be noted that these EF tasks might therefore be confounded by the storage abilities and the low-level processes, rather than specifically measuring working memory and verbal fluency.

It is worthy to note that cognitive tasks have also been used for assessing the same construct of cognitive ability but under different names of executive functions, such as the semantic verbal fluency tasks were used for assessing verbal fluency function and the trail making task was used for assessing shifting function in the current study. While some researchers argue that verbal fluency can assess the central executive (i.e. Andersson, 2008) or shifting because when percipients switch categories in the task (i.e. from beginning with letter S to an animal category), it assessed the shifting ability. Also, it has been argued that when participants were doing the trail making task, they had to inhibit their pre-potent response to connect just numbers or letters, which has been suggested as an inhibition task. Different names can cause confusion in interpretation, however, it is

essential to make distinct the actual content that tasks are assessing in the factor analysis. The trail making task has loaded on to shifting function and verbal fluency task has loaded on to verbal fluency function. In the current thesis, the central executive is only counted as the attention control system of the phonological loop and the visuo-spatial sketchpad. Only counting recall task in the current thesis assessed the central executive. Baddeley (1996) suggested that temporary activation and manipulation of long-term memory was one of the central executive. In the current CFA, it has been singled out as verbal fluency as a fourth function.

The current study has found relatively low correlation coefficients ($r_s = .17$ to $.56$) between executive tasks except when tasks were designed to measure the same construct. It also found that tasks clustered into four targeted executive functions and the associations of latent variables were higher ($r_s = .73$ to $.91$) than individual task correlations. These results are consistent with Miyake's studies (Friedman & Miyake, 2017; Miyake et al., 2000). The present study showed the advance that a four-correlated-factor model was identified when the influences of unreliability and task impurity were reduced.

In terms of measuring executive functions, we have applied both laboratory tasks and parent-rating questionnaires in order to increase ecological validity. BRIEF results contribute to the ecological validity of laboratory as a test of real life executive functions. No significant correlations were found between laboratory tasks and parent-rating BRIEF in all three of the domains, working memory, inhibition and shifting. This is consistent with the findings of several previous studies (Anderson, Anderson, Northam, Jacob & Mikiewicz, 2002; Bodnar, Prahme, Cutting, Denckla & Mahone, 2007; Mahone, et al., 2002). The exception is that Loplak and colleagues have found that executive function performance-based measures were significantly associated with both parents' and teachers' ratings in an ADHD sample (Loplak, Bucciarelli, Jain & Tannock, 2008).

There are several possible reasons why significant relations were not found in this study. First of all, construct validity problems of the BRIEF in measuring daily executive functions in children with ASD. There is no standardised BRIEF for children with ASD. Parents are rating other behaviours (i.e. non-executive behaviours) in the daily lives of their children. McAuley, Chen, Goos, & Crosbie

(2010) suggested that rather than measuring executive functions, the BRIEF may be used to identify children who are experiencing behavioural difficulties and who may have school-related problems. Future studies could use the BRIEF as a screening test for children who have behavioural difficulties. Secondly, the two types of assessment are not actually measuring the same construct. It is different in the administration and scoring between these two types of measurement of executive functions. Toplak et al., (2013) also suggested that they are tapping on different cognitive levels. Laboratory tasks provide findings on an algorithmic level whereas psychologists are concerned with the information processing and mechanism in the brain. While parent-rating scales measures provide a reflective level of analysis. The reflective level of analysis refers to the goals and beliefs of the system and the choice of action that is optimal. It is important to distinguish between the algorithmic level and the reflective level. Because performance-based measures tell us about the efficiency of processing, while parent-rating scales provide information about success in rational goal pursuit (Toplak et al., 2013).

Furthermore, two types of shifting tasks are involved in the current study, one in which rules have been explicitly explained to children (i.e. trail making task) and one in which rules have not been explicitly presented (i.e. Wisconsin card sorting task). Andersson (2008), using the trail making task with explicit rules, reported a significant association with reading and math scores after controlling for age. Bull and Scerif (2001) also suggested shifting tasks with implicit rules can predict mathematic ability. Yeniad et al., (2013) have suggested that task demands may be important in relation to this association. They assert that whether or not the switching rule is explicit may moderate the relationship between shifting performance and academic achievements. The findings showed that, the trail making task, which is a shifting task with explicit rules, contributed unique variance to English and maths in the 10-year-old group. The result suggests that shifting is related to English and mathematics learning. However, the shifting task with implicit rules (i.e. WCST) did not contribute to English and maths in the current study. Yeniad and colleagues have argued that shifting tasks with implicit rules are involved in more cognitive processes than purely shifting, such as language and intelligence (Yeniad et al., 2013). Therefore, WCST may not have been as sensitive

as the trail making task in the current study for assessing the contribution of shifting to academic achievement.

7.5 Strengths and limitations

7.5.1 Strengths

The literature review of the structure of executive functions in children and adolescents is one of the first in the field to systematically explore all of the four executive functions; working memory, inhibition, shifting and verbal fluency. The first study in this thesis included nine executive tasks in these four domains. Verbal fluency as a distinct latent construct was first published in 2016 (Cassidy, 2016). The current study was carried out in 2015, hence it was novel to acknowledge the importance of verbal fluency as an executive function in a child and adolescent sample group. Moreover, for the first time, four executive functions were examined in detail by applying confirmatory factor analysis, including an overview of the age-related difference across three age groups. In addition, an exploration of the relationship between four executive functions and scholastic attainment was described.

The main focus of autism work is to investigate the relationship between executive functions and autistic characteristics and the heterogeneity among children with ASD based on executive function. This study suggested that a significant association between executive functions and autistic characteristics has not yet been identified. However, a cluster analysis categorised autistic children into three different levels based on their social communication traits and restricted and repetitive behaviours and interests. The analysis found that children who showed greater difficulties in social communication were displaying more restricted, repetitive behaviours and interests, across both sensory motor behaviours (RSMB) and insistence on the sameness (IS). The finding also found that children with autism who experienced more ASD characteristics, also have more difficulties in daily executive dysfunctions based on parents' observations.

In terms of measurement, the first study (Chapter 2) has applied confirmatory factor analysis to tackle the task impurity problem. Also, in order to assess three different aspects of working memory, lucid recall working memory tests have been applied. Furthermore, two types of shifting tasks are included in the current study,

the trail making test in which the rules will be explicitly explained to children and the WCST where the rules have not been explicitly presented. This further supports Yeniad et al., (2013) that shifting tasks with implicit rules are involved in more cognitive processes than shifting tasks with explicit rules. Therefore, WCST may not have been as sensitive as the trail making task in the current study for assessing shifting function. Also, a cluster analysis in the ASD study (Chapter 6) was a strength. It helped us to understand the heterogeneity of executive functions and characteristics within autism spectrum.

7.5.2 Limitations

A few limitations can be noted. First, correlations between executive functions might be influenced by the use of strategies (Friedman & Mikaye, 2017). When children grow older, there may also be changes in these strategies. Therefore, a specific EF task might not capture the same EF ability across different ages (Huizinga et al., 2006). Secondly, in the first study (Chapter 2), we formed our model based on an age range from 7- to 14-year-old children and adolescents, which might be less accurate due to the wide age range. In the ASD study (Chapter 6), a small sample size (28 participants) with a broad age range between 7- and 14-years-old was used. Although this was due to practical considerations and methodological approval, the findings needed to be interpreted with caution.

Last but not least, in order to gain ecological validity, both perspectives of executive functions measurements have been applied, however, we have found that the associations between parent-rating questionnaires on executive functions and laboratory executive tasks are not significant. The finding suggests that they may not be measuring the same construct of executive function. It is also important to notice that the parent-rating questionnaire (BRIEF) has not been validated in children with ASD. The means of all of the subscales from BRIEF achieved the clinical significant level. Furthermore, the BRIEF includes inhibition and shifting related-items, some of them can be interpreted as repetitive behaviours and interests (e.g. Item 30. Has trouble getting used to new situations, classes, groups and friends) and such overlapped measurement could impact the relationship

between executive functions and repetitive behaviours and interests in children with ASD.

7.6 Educational and clinical implications

The associations between executive functions and academic outcomes have been reported in typically developing children, especially working memory (Chapter 4). This finding suggests that executive functions contributed to children's learning from childhood to early adolescence. This suggests that training programs for improving working memory might help to enhance English and mathematics via strategies training (i.e. Memory Booster; Alloway, 2012; St Clair-Thompson et al., 2010). Direct training has also been applied in education settings (i.e. CogMed). It has been applied to typically developing children at their early childhood age (Blakey & Carroll, 2015). It is, however, worthy of note that there is a continuing debate about the effectiveness of working memory training (Melby-Lervåg & Hulme, (2013). Also, training targeting other executive functions (inhibition, shifting and verbal fluency) are yet to be fully investigated. A working memory and inhibition training programme has been applied in children with attention-deficit hyperactivity disorder (ADHD; Johnstone, Roodenry, Philips, Watt, & Mantz, 2010). Researchers have applied computer-based working memory and inhibition training program for 5 weeks. The results showed they increased the training effects, however, they failed to reach standard levels of statistical significance on improvement. In addition, different strengths of associations between executive functions and scholastic attainment have been found at different ages, it suggests that training programs will need to have targeted age groups for the effectiveness of the training.

As reported in the thesis, there is no direct link between executive functions and autism characteristics, but heterogeneity within autism has been explored. Clinically, the associations between EF and ASD characteristics are still not fully understood, which might impact the role of executive functions on autism diagnosis, treatment and services provided to individuals with autism and their families. Children with autism who experienced more ASD characteristics reported more difficulties in daily executive dysfunctions based on parents' observations (Chapter 6). It suggests that individuals with autism, who have greater difficulties in social

communication and restricted, repetitive behaviours and interests may need extra support on daily structure of executive functions, not only to help with ASD characteristics, but also other co-occurring executive dysfunction difficulties. The checklist of executive dysfunction has been indicated in BRIEF, but the autism-specific list has not been made yet. Further support and individual profiles of executive functions in children with autism requires more research.

7.7 Future directions

Firstly, more research into developmental changes in the structure of executive functions in typically developing children is required. Only a few research studies have examined age-related changes, longitudinal studies examining the developmental trajectory of the structure of executive functions are needed. It is also important to understand whether other executive functions (i.e. planning) are important in children's development. Furthermore, Bull and Scerif (2001) also suggested that children will be more able to retrieve arithmetic facts and well-practice strategies from long-term memory when children are older, it leads to less executive processes are needed when a skill becomes more automatic. Therefore, longitudinal studies are required to examine the constancy in the uses of strategy and execution functions.

As shown in Chapter 6, children's autistic characteristics were measured by parents-rating questionnaires. In future research, it may be helpful if children can be assessed by clinicians while children are doing a laboratory task, which may help to keep the study objective. When the aim of a study is about exploring autistic children's daily behaviours, parents will rate their children on a daily basis. Also, it would be helpful to investigate what strategies are used when autistic children are doing their executive tasks. It would give us more details of how they process executive functions in a qualitative study.

It would be interesting to further explore the broader autism spectrum including children with lower ability, and relationships of their symptoms with executive functions. As shown in chapter 6, children with autism who took part in the current research all had IQ scores higher than 70. The heterogeneity suggested that children will display high executive dysfunction when they have more difficulties

related to their autistic characteristics. Future studies can benefit from investigating the role of executive function in autistic children from a broader spectrum.

7.8 Conclusion

Executive functions are a range of goal-directed cognitive abilities, including working memory, inhibition, shifting and verbal fluency. A four-factor structure has been found in typically developing children from 7-year-old to 14-year-old. Also, clear developmental differences have been identified in terms of the extent to which executive functions predict attainment. In addition, examination of relationships between executive functions and characteristics in children with autism allowed us to capture the heterogeneity in those with ASD. Further investigation of executive functions could help us better understand and facilitate learning and behaviour in children with and without ASD.

References

- Agostino, A., Johnson, J., & Pascual-Leone, J. (2010). Executive functions underlying multiplicative reasoning: Problem type matters. *Journal of experimental child psychology*, 105(4), 286-305.
- Alloway, T. (2012). Can interactive working memory training improving learning?. *Journal of Interactive Learning Research*, 23(3), 197-207.
- Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of experimental child psychology*, 106(1), 20-29.
- Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable?. *Child development*, 77(6), 1698-1716.
- Alloway, T. P., Gathercole, S. E., Willis, C., & Adams, A. M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of experimental child psychology*, 87(2), 85-106.
- Altemeier, L., Jones, J., Abbott, R. D., & Berninger, V. W. (2006). Executive functions in becoming writing readers and reading writers: Note taking and report writing in third and fifth graders. *Developmental neuropsychology*, 29(1), 161-173.
- American Psychiatry Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders*. Washington, DC: Am. Psychiatry. Publ. 5th ed.
- Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child neuropsychology*, 8(2), 71-82.
- Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Mikiewicz, O. (2002). Relationships between cognitive and behavioral measures of executive function in children with brain disease. *Child Neuropsychology*, 8(4), 231-240.
- Andersson, U. (2008). Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. *British Journal of Educational Psychology*, 78(2), 181-203.

Arán-Filippetti, V. (2013). Structure and invariance of executive functioning tasks across socioeconomic status: evidence from spanish-speaking children. *The Spanish Journal of Psychology*, 16, E101.

Arán-Filippetti, V., & Lopez, M. B. (2016). Predictors of Reading Comprehension in Children and Adolescents: The Role of Age, Sex and Executive Functions. *Cuadernos de Neuropsicología-Panamerican Journal of Neuropsychology*, 10(1), 23-44.

Arán-Filippetti, V., & Richaud, M. C. (2015). Do Executive Functions Predict Written Composition? Effects Beyond Age, Verbal Intelligence and Reading Comprehension, *Acta Neuropsychologica*, 13(4).

Asperger, H. (1944). Die „Autistischen Psychopathen“ im Kindesalter. *Archiv für psychiatrie und nervenkrankheiten*, 117(1), 76-136.

Baddeley, A. D. (1986). *Working memory*. Oxford, England: Oxford University Press.

Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology: Section A*, 49(1), 5-28.

Baddeley, A. D. (1998). The central executive: A concept and some misconceptions. *Journal of the International Neuropsychological Society*, 4, 523–526.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory?. *Trends in cognitive sciences*, 4(11), 417-423.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. *The psychology of learning and motivation*, 8, 47-89. Academic press.

Baddeley, A., Lewis, V., Eldridge, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General*, 113(4), 518.

Baldo, J. V., Schwartz, S., Wilkins, D., & Dronkers, N. F. (2006). Role of frontal versus temporal cortex in verbal fluency as revealed by voxel-based lesion symptom mapping. *Journal of the International Neuropsychological Society*, 12(6), 896-900.

Bathelt, J., Gathercole, S. E., Johnson, A., & Astle, D. E. (2018). Differences in brain morphology and working memory capacity across childhood. *Developmental science*, 21(3), e12579.

Bauminger, N. (2002). The facilitation of social-emotional understanding and social interaction in high-functioning children with autism: Intervention outcomes. *Journal of autism and developmental disorders*, 32(4), 283-298.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychological bulletin*, 121(1), 65.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of autism and developmental disorders*, 31(1), 5-17.

Bechara, A. (2004). The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition*, 55, 30–40.

Becker, M. G., Isaac, W., & Hynd, G. W. (1987). Neuropsychological development of nonverbal behaviors attributed to “frontal lobe” functioning. *Developmental Neuropsychology*, 3(3-4), 275-298.

Bedard, A. C., Nichols, S., Barbosa, J. A., Schachar, R., Logan, G. D., & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental neuropsychology*, 21(1), 93-111.

Bentler, P. M. (2007). On tests and indices for evaluating structural models. *Personality and Individual differences*, 42(5), 825-829.

Berg, D. H. (2008). Working memory and arithmetic calculation in children: The contributory roles of processing speed, short-term memory, and reading. *Journal of experimental child psychology*, 99(4), 288-308.

Berger, H. J., Aerts, F. H., Spaendonck, K. P. V., Cools, A. R., & Teunisse, J. P. (2003). Central coherence and cognitive shifting in relation to social improvement in

high-functioning young adults with autism. *Journal of clinical and experimental neuropsychology*, 25(4), 502-511.

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and individual differences*, 21(4), 327-336.

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental review*, 29(3), 180-200.

Bishop, D. V., & Norbury, C. F. (2005). Executive functions in children with communication impairments, in relation to autistic symptomatology. I: Generativity. *Autism*, 9(1), 7-27.

Bishop, D. V., & Norbury, C. F. (2005b). Executive functions in children with communication impairments, in relation to autistic symptomatology. 2: Response inhibition. *Autism*, 9(1), 29-43.

Blakey, E., & Carroll, D. J. (2015). A short executive function training program improves preschoolers' working memory. *Frontiers in psychology*, 6, 1827.

Blunch, N. (2012). *Introduction to structural equation modeling using IBM SPSS statistics and AMOS*. Sage.

Bodfish, J. W., Symons, F. J., Parker, D. E., & Lewis, M. H. (2000). Varieties of repetitive behavior in autism: Comparisons to mental retardation. *Journal of autism and developmental disorders*, 30(3), 237-243.

Bodnar, L. E., Prahme, M. C., Cutting, L. E., Denckla, M. B., & Mahone, E. M. (2007). Construct validity of parent ratings of inhibitory control. *Child Neuropsychology*, 13(4), 345-362.

Bölte, S., Poustka, F., & Constantino, J. N. (2008). Assessing autistic traits: cross-cultural validation of the social responsiveness scale (SRS). *Autism Research*, 1(6), 354-363.

Bookheimer, S. (2002). Functional MRI of language: new approaches to understanding the cortical organization of semantic processing. *Annual review of neuroscience*, 25(1), 151-188.

- Borella, E., Carretti, B., & Pelegrina, S. (2010). The specific role of inhibition in reading comprehension in good and poor comprehenders. *Journal of Learning disabilities, 43*(6), 541-552.
- Boyd, B. A., McBee, M., Holtzclaw, T., Baranek, G. T., & Bodfish, J. W. (2009). Relationships among repetitive behaviors, sensory features, and executive functions in high functioning autism. *Research in autism spectrum disorders, 3*(4), 959-966.
- Broadway, J. M., & Engle, R. W. (2010). Validating running memory span: Measurement of working memory capacity and links with fluid intelligence. *Behavior Research Methods, 42*(2), 563-570.
- Brooks, B. L., Sherman, E. M., & Strauss, E. (2009). NEPSY-II: A developmental neuropsychological assessment. *Child Neuropsychology, 16*(1), 80-101.
- Brunsdon, V. E., & Happé, F. (2014). Exploring the 'fractionation' of autism at the cognitive level. *Autism, 18*(1), 17-30.
- Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014). The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis. *Intelligence, 47*, 34-43.
- Brydges, C. R., Reid, C. L., Fox, A. M., & Anderson, M. (2012). A unitary executive function predicts intelligence in children. *Intelligence, 40*(5), 458-469.
- Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental neuropsychology, 33*(3), 205-228.
- Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental neuropsychology, 19*(3), 273-293.
- Burgess, P. W., Alderman, N., Forbes, C., Costello, A., LAURE, M. C., Dawson, D. R., ... & Channon, S. (2006). The case for the development and use of "ecologically valid" measures of executive function in experimental and clinical

neuropsychology. *Journal of the international neuropsychological society*, 12(2), 194-209.

Butler, M., Retzlaff, P. D., & Vanderploeg, R. (1991). Neuropsychological test usage. *Professional psychology: Research and practice*, 22(6), 510-512.

Cartwright, K. B. (2002). Cognitive development and reading: The relation of reading-specific multiple classification skill to reading comprehension in elementary school children. *Journal of Educational Psychology*, 94(1), 56.

Cassidy, A. R. (2016). Executive function and psychosocial adjustment in healthy children and adolescents: A latent variable modelling investigation. *Child Neuropsychology*, 22(3), 292-317.

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology review*, 13(4), 181-197.

Christ, S. E., Holt, D. D., White, D. A., & Green, L. (2007). Inhibitory control in children with autism spectrum disorder. *Journal of autism and developmental disorders*, 37(6), 1155-1165.

Christensen, D. L., Bilder, D. A., Zahorodny, W., Pettygrove, S., Durkin, M. S., Fitzgerald, R. T., ... & Yeargin-Allsopp, M. (2016). Prevalence and characteristics of autism spectrum disorder among 4-year-old children in the autism and developmental disabilities monitoring network. *Journal of Developmental & Behavioral Paediatrics*, 37(1), 1-8.

Chung, K. K., & McBride-Chang, C. (2011). Executive functioning skills uniquely predict Chinese word reading. *Journal of Educational Psychology*, 103(4), 909.

Clark, C. A., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental psychology*, 46(5), 1176.

Cohen, J. (1992). A power primer. *Psychological bulletin*, 112(1), 155.

Colom, R., Rebollo, I., Palacios, A., Juan-Espinosa, M., & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence*, 32(3), 277-296.

- Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale (SRS)*. Torrance, CA: Western Psychological Services.
- Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic bulletin & review*, 12(5), 769-786.
- Cowan, N. (1999). An embedded-processes model of working memory. *Models of working memory: Mechanisms of active maintenance and executive control*, 20, 506.
- Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in neuroscience and education*, 3(2), 63-68.
- Cragg, L., & Nation, K. (2008). Go or no-go? Developmental improvements in the efficiency of response inhibition in mid-childhood. *Developmental Science*, 11(6), 819-827.
- Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and human brain*. New York: Grosset/Putnam.
- Das, J. P., Naglieri, J. A., & Kirby, J. R. (1994). *Assessment of cognitive processes: The PASS theory of intelligence*. Allyn & Bacon.
- Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, 44(11), 2037-2078.
- Davis, A. S., Finch, W. H., Drapeau, C., Nogin, M., E. Moss, L., & Moore, B. (2016). Predicting verbal fluency using Word Reading: Implications for pre-morbid functioning. *Applied Neuropsychology: Adult*, 23(6), 403-410.
- D'Cruz, A. M., Ragozzino, M. E., Mosconi, M. W., Shrestha, S., Cook, E. H., & Sweeney, J. A. (2013). Reduced behavioral flexibility in autism spectrum disorders. *Neuropsychology*, 27(2), 152.

De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of experimental child psychology*, 103(2), 186-201.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System®(D-KEFS®): Examiner's Manual: Flexibility of Thinking, Concept Formation, Problem Solving, Planning, Creativity, Impulse Control, Inhibition*. Pearson.

Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., Pye, J. E., ... & Guastella, A. J. (2018). Autism spectrum disorders: a meta-analysis of executive function. *Molecular psychiatry*, 23(5), 1198.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental review*, 12(1), 45-75.

Dempster, F. N. (1993). Resistance to interference: Developmental changes in a basic processing mechanism. In *Emerging themes in cognitive development* (pp. 3-27). Springer, New York, NY.

Department for Education, (2013). The national curriculum in England: Key stages 1 and 2 framework document. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/425601/PRIMARY_national_curriculum.pdf.

Diamond, A. (2006). The early development of executive functions. In E. Bialystock & F. I. M. Craik (Eds.), *The early development of executive functions. Lifespan cognition: Mechanisms of change* (pp. 70–95). Oxford, England: Oxford University Press.

Dias, R., Robbins, T. W., & Roberts, A. C. (1996). Dissociation in prefrontal cortex of affective and attentional shifts. *Nature*, 380(6569), 69-72.

Dichter, G. S., Lam, K. S., Turner-Brown, L. M., Holtzclaw, T. N., & Bodfish, J. W. (2009). Generativity abilities predict communication deficits but not repetitive

behaviors in autism spectrum disorders. *Journal of autism and developmental disorders*, 39(9), 1298.

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11-to 12-year-old children. *Psychological Test and Assessment Modeling*, 52(4), 419.

Duncan, J., Burgess, P., & Emslie, H. (1995). *Fluid intelligence after frontal lobe lesions. Neuropsychologia*, 33(3), 261-268.

Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: The organization of goal-directed behavior. *Cognitive Psychology*, 30, 257– 303.

Durston, S., Davidson, M. C., Tottenham, N., Galvan, A., Spicer, J., Fossella, J. A., & Casey, B. J. (2006). A shift from diffuse to focal cortical activity with development. *Developmental science*, 9(1), 1-8.

Durston, S., Thomas, K. M., Yang, Y., Uluğ, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science*, 5(4), F9-F16.

Engel de Abreu, P. M., Abreu, N., Nikaedo, C. C., Puglisi, M. L., Tourinho, C. J., Miranda, M. C., ... & Martin, R. (2014). Executive functioning and reading achievement in school: a study of Brazilian children assessed by their teachers as “poor readers”. *Frontiers in psychology*, 5, 550.

Engel de Abreu, P. M., Nikaedo, C., Abreu, N., Tourinho, C. J., Miranda, M. C., Bueno, O. F., & Martin, R. (2014). Working memory screening, school context, and socioeconomic status: an analysis of the effectiveness of the working memory rating scale in Brazil. *Journal of attention disorders*, 18(4), 346-356.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). New York: Cambridge Univ. Press.

- Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental neuropsychology*, 26(1), 465-486.
- Fancello, G. S., Vio, C., & Cianchetti, C. (2006). Test TOL: Torre di Londra (Test di valutazione delle funzioni esecutive). Trento, Italy: Erickson.
- Ferrero, M.A., Escolano-Pérez, E., & Bravo-Álvarez, M. Á. (2017). Transferring learning to everyday life in autism spectrum disorder through an Executive Functions training programme/Generalización del aprendizaje a la vida cotidiana en trastorno del espectro autista a través de un programa de entrenamiento en Funciones Ejecutivas. *Estudios de Psicología*, 38(2), 523-536.
- Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. Sage.
- Fisk, J. E., & Sharp, C. A. (2004). Age-related impairment in executive functioning: Updating, inhibition, shifting, and access. *Journal of Clinical and Experimental Neuropsychology*, 26(7), 874-8
- Freeman, L. M., Locke, J., Rotheram-Fuller, E., & Mandell, D. (2017). Brief report: Examining executive and social functioning in elementary-aged children with autism. *Journal of autism and developmental disorders*, 47(6), 1890-1895.
- Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex*, 86, 186-204.
- Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological science*, 17(2), 172-179.
- Frith, U. (1989). *Autism: Explaining the enigma*. Oxford: Blackwell.
- Frith, U., & Happé, F. (1994). Autism: Beyond “theory of mind”. *Cognition*, 50(1-3), 115-132.
- Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, 10(4), 483-527. 90.

Fuhs, M. W., & Day, J. D. (2011). Verbal ability and executive functioning development in preschoolers at head start. *Developmental Psychology*, 47(2), 404.

Fuster, J. M. (1997). *The prefrontal cortex: Anatomy, physiology, and neuropsychology of the frontal lobe* (3rd ed.). New York: Raven Press.

Garcia-Barrera, M. A., Kamphaus, R. W., & Bandalos, D. (2011). Theoretical and statistical derivation of a screener for the behavioral assessment of executive functions in children. *Psychological Assessment*, 23(1), 64.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological bulletin*, 134(1), 31.

Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviours in children with poor working memory. *Learning and individual differences*, 18(2), 214-223.

Gathercole, S. E., & Hitch, G. J. (1993). Developmental changes in short-term memory: A revised working memory perspective. *Theories of memory*, 1, 189-209.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, 70(2), 177-194.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental psychology*, 40(2), 177.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, 18(1), 1-16.

George, D., & Mallery, M. (2010). *SPSS for windows step by step: A simple study guide and reference, 17.0 update, (10a ed.)*. Boston: Pearson.

Georgiades, S., Szatmari, P., Boyle, M., Hanna, S., Duku, E., Zwaigenbaum, L., ... & Smith, I. (2013). Investigating phenotypic heterogeneity in children with autism spectrum disorder: a factor mixture modeling approach. *Journal of Child Psychology and Psychiatry*, 54(2), 206-215.

- Georgiou, G. K., & Das, J. P. (2018). Direct and indirect effects of executive function on reading comprehension in young adults. *Journal of Research in Reading, 41*(2), 243-258.
- Geurts, H. M., Van Den Bergh, S. F., & Ruzzano, L. (2014). Prepotent response inhibition and interference control in autism spectrum disorders: Two meta-analyses. *Autism Research, 7*(4), 407-420.
- Geurts, H., Sinzig, J., Booth, R., & Happé, F. (2014). Neuropsychological heterogeneity in executive functioning in autism spectrum disorders. *International Journal of Developmental Disabilities, 60*(3), 155-162.
- Ghosh, D., & Vogt, A. (2012). Outliers: An evaluation of methodologies. In *Joint Statistical Meetings* (pp. 3455-3460). San Diego, CA: American Statistical Association.
- Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., ... & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature neuroscience, 2*(10), 861.
- Gioia, G. A., Isquith, P. K., Retzlaff, P. D., & Espy, K. A. (2002). Confirmatory factor analysis of the Behavior Rating Inventory of Executive Function (BRIEF) in a clinical sample. *Child Neuropsychology, 8*(4), 249-257.
- Giovagnoli, A. R., Del Pesce, M., Mascheroni, S., Simoncelli, M., Laiacona, M., & Capitani, E. (1996). Trail making test: normative values from 287 normal adult controls. *The Italian journal of neurological sciences, 17*(4), 305-309.
- Goldstein, K. (1936). The modifications of behaviour consequent to cerebral lesions. *Psychiatric Quarterly, 10*, 586-610.
- Goldstein, K. (1944). The mental changes due to frontal lobe damage. *Journal of Psychology, 17*, 187-208.
- Gourovitch, M. L., Kirkby, B. S., Goldberg, T. E., Weinberger, D. R., Gold, J. M., Esposito, G., ... & Berman, K. F. (2000). A comparison of rCBF patterns during letter and semantic fluency. *Neuropsychology, 14*(3), 353.

Granader, Y., Wallace, G. L., Hardy, K. K., Yerys, B. E., Lawson, R. A., Rosenthal, M., ... & Schultz, R. T. (2014). Characterizing the factor structure of parent reported executive function in autism spectrum disorders: The impact of cognitive inflexibility. *Journal of Autism and Developmental Disorders*, *44*(12), 3056-3062.

Griffith, E. M., Pennington, B. F., Wehner, E. A., & Rogers, S. J. (1999). Executive functions in young children with autism. *Child development*, *70*(4), 817-832.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (1998). *Multivariate data analysis* (Vol. 5, No. 3, pp. 207-219). Upper Saddle River, NJ: Prentice hall.

Hamilton, C., Coates, R., & Heffernan, T. (2003). What develops in visuo-spatial working memory development?. *European Journal of Cognitive Psychology*, *15*(1), 43-69.

Happé, F. G. (1994). An advanced test of theory of mind: Understanding of story characters' thoughts and feelings by able autistic, mentally handicapped, and normal children and adults. *Journal of autism and Developmental disorders*, *24*(2), 129-154.

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of autism and developmental disorders*, *36*(1), 5-25.

Heaton, R. K. (1993). Wisconsin card sorting test: computer version 2. Odessa: *Psychological Assessment Resources*.

Hill, E. L. (2004). Executive dysfunction in autism. *Trends in cognitive sciences*, *8*(1), 26-32.

Hill, E. L., & Bird, C. M. (2006). Executive processes in Asperger syndrome: Patterns of performance in a multiple case series. *Neuropsychologia*, *44*(14), 2822-2835.

Hitch, G. J., Halliday, M. S., Hulme, C., Le Voi, M. E., Routh, D. A., & Conway, A. (1983). Working memory in children [and discussion]. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *302*(1110), 325-340.

- Hitch, G. J., Towse, J. N., & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology: General*, 130(2), 184.
- Holmes, J., & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, 26(3), 339-366.
- Holmes, J., Adams, J. W., & Hamilton, C. J. (2008). The relationship between visuospatial sketchpad capacity and children's mathematical skills. *European Journal of Cognitive Psychology*, 20(2), 272-289.
- Honey, E., McConachie, H., Turner, M., & Rodgers, J. (2012). Validation of the repetitive behaviour questionnaire for use with children with autism spectrum disorder. *Research in Autism Spectrum Disorders*, 6(1), 355-364.
- Hongwanishkul, D., Happaney, K. R., Lee, W. S., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental neuropsychology*, 28(2), 617-644.
- Howard, S. J., Okely, A. D., & Ellis, Y. G. (2015). Evaluation of a differentiation model of preschoolers' executive functions. *Frontiers in psychology*, 6, 285.
- Hu, L. T., & Bentler, P. M. (1998). Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological methods*, 3(4), 424-453.
- Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *The British Journal of Developmental Psychology*, 16, 233.
- Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2009). Tracking executive function across the transition to school: A latent variable approach. *Developmental neuropsychology*, 35(1), 20-36.
- Huizinga, M., Dolan, C. V., & Van Der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, 44(11), 2017-2036.

- Inokuchi, E., & Kamio, Y. (2013). Qualitative analyses of verbal fluency in adolescents and young adults with high-functioning autism spectrum disorder. *Research in Autism Spectrum Disorders*, 7(11), 1403-1410.
- Jacobsen, G. M., Prando, M. L., Moraes, A. L., Pureza, J. D. R., Gonçalves, H. A., Siqueira, L. D. S., ... & Fonseca, R. P. (2017). Effects of age and school type on unconstrained, phonemic, and semantic verbal fluency in children. *Applied Neuropsychology: Child*, 6(1), 41-54.
- Jaeggi, S. M., Buschkuhl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory*, 18(4), 394-412.
- Jahanshahi, M., Profice, P., Brown, R. G., Ridding, M. C., Dirnberger, G., & Rothwell, J. C. (1998). The effects of transcranial magnetic stimulation over the dorsolateral prefrontal cortex on suppression of habitual counting during random number generation. *Brain: a journal of neurology*, 121(8), 1533-1544.
- Jarvis, H. L., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology*, 20(3), 123-140.
- Johnstone, S. J., Roodenrys, S., Phillips, E., Watt, A. J., & Mantz, S. (2010). A pilot study of combined working memory and inhibition training for children with AD/HD. *ADHD Attention Deficit and Hyperactivity Disorders*, 2(1), 31-42.
- Jonides, J., & Smith, E. E. (1997). The architecture of working. In M. D. Rugg (Ed.), *Cognitive neuroscience* (pp. 243-276). Cambridge, MA: MIT Press.
- Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of experimental psychology: General*, 132(1), 47.
- Kenny, D. A., & McCoach, D. B. (2003). Effect of the number of variables on measures of fit in structural equation modeling. *Structural Equation Modeling*, 10, 333-351.

- Kenworthy, L., Black, D. O., Harrison, B., Della Rosa, A., & Wallace, G. L. (2009). Are executive control functions related to autism symptoms in high-functioning children?. *Child Neuropsychology*, *15*(5), 425-440.
- Kercood, S., Grskovic, J. A., Banda, D., & Begeske, J. (2014). Working memory and autism: A review of literature. *Research in Autism Spectrum Disorders*, *8*(10), 1316-1332.
- Kharitonova, M., Winter, W., & Sheridan, M. A. (2015). As Working Memory Grows: A Developmental Account of Neural Bases of Working Memory Capacity in 5-to 8-Year Old Children and Adults. *Journal of cognitive neuroscience*, *27*(9), 1775-1788.
- Kiefer, M., Marzinzik, F., Weisbrod, M., Scherg, M., & Spitzer, M. (1998). The time course of brain activations during response inhibition: evidence from event-related potentials in a go/no go task. *Neuroreport*, *9*(4), 765-770.
- Kilincaslan, A., Mukaddes, N. M., Kucuykazici, G. S., & Gurvit, H. (2010). Assessment of executive/attentional performance in Asperger's disorder. *Turk Psikiyatri Dergisi*, *21*(4), 289.
- Klenberg, L., Korkman, M., & Lahti-Nuutila, P. (2001). Differential development of attention and executive functions in 3-to 12-year-old Finnish children. *Developmental neuropsychology*, *20*(1), 407-428.
- Klopper, F., Testa, R., Pantelis, C., & Skafidas, E. (2017). A cluster analysis exploration of autism spectrum disorder subgroups in children without intellectual disability. *Research in Autism Spectrum Disorders*, *36*, 66-78.
- Kurtz, M. M., Ragland, J. D., Moberg, P. J., & Gur, R. C. (2004). The Penn Conditional Exclusion Test: a new measure of executive-function with alternate forms for repeat administration. *Archives of Clinical Neuropsychology*, *19*(2), 191-201.
- La Malfa, G., Lassi, S., Bertelli, M., Salvini, R., & Placidi, G. F. (2004). Autism and intellectual disability: a study of prevalence on a sample of the Italian population. *Journal of intellectual disability research*, *48*(3), 262-267.

- Latzman, R. D., Elkovitch, N., Young, J., & Clark, L. A. (2010). The contribution of executive functioning to academic achievement among male adolescents. *Journal of Clinical and Experimental Neuropsychology*, 32(5), 455-462.
- Lee, K., Bull, R., & Ho, R. M. (2013). Developmental changes in executive functioning. *Child development*, 84(6), 1933-1953.
- Lee, K., Ng, S. F., Ng, E. L., & Lim, Z. Y. (2004). Working memory and literacy as predictors of performance on algebraic word problems. *Journal of Experimental Child Psychology*, 89(2), 140-158.
- Lee, K., Ng, S. F., Pe, M. L., Ang, S. Y., Hasshim, M. N. A. M., & Bull, R. (2012). The cognitive underpinnings of emerging mathematical skills: Executive functioning, patterns, numeracy, and arithmetic. *British Journal of Educational Psychology*, 82(1), 82-99.
- Leekam, S. R., Prior, M. R., & Uljarevic, M. (2011). Restricted and repetitive behaviors in autism spectrum disorders: a review of research in the last decade. *Psychological bulletin*, 137(4), 562.
- Lehto, J. (1996). Are executive function tests dependent on working memory capacity?. *The Quarterly Journal of Experimental Psychology: Section A*, 49(1), 29-50.
- Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, 21(1), 59-80.
- Lerner, M. D., & Lonigan, C. J. (2014). Executive function among preschool children: Unitary versus distinct abilities. *Journal of psychopathology and behavioral assessment*, 36(4), 626-639.
- Leslie, A. M. (1987). Pretence and representation: The origins of "Theory of Mind." *Psychological Review*, 94, 412-426.
- Leung, R. C., Vogan, V. M., Powell, T. L., Anagnostou, E., & Taylor, M. J. (2016). The role of executive functions in social impairment in Autism Spectrum Disorder. *Child Neuropsychology*, 22(3), 336-344.

- Leung, R. C., & Zakzanis, K. K. (2014). Brief Report: Cognitive flexibility in autism spectrum disorders: A quantitative review. *Journal of autism and developmental disorders*, 44(10), 2628-2645.
- Loehr, A. M., Miller, M. R., DeCaro, M. S., & Rittle-Johnson, B. (2013). Semantic Verbal Fluency Predicts Mathematical Learning. In *Poster presented at the Association for Psychological Science 25th Annual Convention, Washington, DC*.
- Logan, G. D. (1994). *On the ability to inhibit thought and action: A users' guide to the stop signal paradigm*.
- Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological science*, 8(1), 60-64.
- Logie, R. H., & Pearson, D. G. (1997). The inner eye and the inner scribe of visuo-spatial working memory: Evidence from developmental fractionation. *European Journal of cognitive psychology*, 9(3), 241-257.
- Lonigan, C. J., Lerner, M. D., Goodrich, J. M., Farrington, A. L., & Allan, D. M. (2016). Executive function of Spanish-speaking language-minority preschoolers: Structure and relations with early literacy skills and behavioral outcomes. *Journal of experimental child psychology*, 144, 46-65.
- Lopez, B. R., Lincoln, A. J., Ozonoff, S., & Lai, Z. (2005). Examining the relationship between executive functions and restricted, repetitive symptoms of autistic disorder. *Journal of autism and developmental disorders*, 35(4), 445-460.
- Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., ... & Rutter, M. (2000). The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of autism and developmental disorders*, 30(3), 205-223.
- Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of autism and developmental disorders*, 24(5), 659-685.

Luo, L., Luk, G., & Bialystok, E. (2010). Effect of language proficiency and executive control on verbal fluency performance in bilinguals. *Cognition*, 114(1), 29-41.

Luria, A. R. (1959). The directive function of speech in development and dissolution. *Word*, 15(2), 341-352.

Luria, A. R. (1976). *The working brain: An introduction to neuropsychology*. Basic Books.

Lyall, K., Croen, L., Daniels, J., Fallin, M. D., Ladd-Acosta, C., Lee, B. K., ... & Windham, G. C. (2017). The changing epidemiology of autism spectrum disorders. *Annual review of public health*, 38, 81-102.

MacLeod, W. B. (2007). Can contract theory explain social preferences?. *American Economic Review*, 97(2), 187-192.

Mahone, E. M., Cirino, P. T., Cutting, L. E., Cerrone, P. M., Hagelthorn, K. M., Hiemenz, J. R., ... & Denckla, M. B. (2002). Validity of the behavior rating inventory of executive function in children with ADHD and/or Tourette syndrome. *Archives of Clinical Neuropsychology*, 17(7), 643-662.

Manly, T., Robertson, I. H., Anderson, V., & Nimmo-Smith, I. (1999). tEa-ch. *Test of everyday attention for children*. Thames Valley Test Company Limited, Bury St. Edmunds, UK.

Masi, A., DeMayo, M. M., Glozier, N., & Guastella, A. J. (2017). An overview of autism spectrum disorder, heterogeneity and treatment options. *Neuroscience Bulletin*, 1-11.

Matson, J. L., & Shoemaker, M. (2009). Intellectual disability and its relationship to autism spectrum disorders. *Research in developmental disabilities*, 30(6), 1107-1114.

Mayes, S. D., Calhoun, S. L., Bixler, E. O., & Zimmerman, D. N. (2009). IQ and neuropsychological predictors of academic achievement. *Learning and Individual Differences*, 19(2), 238-241.

McAuley, T., Chen, S., Goos, L., Schachar, R., & Crosbie, J. (2010). Is the behavior rating inventory of executive function more strongly associated with measures of impairment or executive function?. *Journal of the International Neuropsychological Society*, 16(3), 495-505.

McAuley, T., & White, D. A. (2011). A latent variables examination of processing speed, response inhibition, and working memory during typical development. *Journal of experimental child psychology*, 108(3), 453-468.

McCabe, D. P., Roediger III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). *The relationship between working memory capacity and executive functioning: evidence for a common executive attention construct*. *Neuropsychology*, 24(2), 222.

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of experimental child psychology*, 74(3), 240-260.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental psychology*, 49(2), 270.

Meyer, M. L., Salimpoor, V. N., Wu, S. S., Geary, D. C., & Menon, V. (2010). Differential contribution of specific working memory components to mathematics achievement in 2nd and 3rd graders. *Learning and Individual Differences*, 20(2), 101-109.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, 24(1), 167-202.

Miller, H. L., Ragozzino, M. E., Cook, E. H., Sweeney, J. A., & Mosconi, M. W. (2015). Cognitive set shifting deficits and their relationship to repetitive behaviors in autism spectrum disorder. *Journal of autism and developmental disorders*, 45(3), 805-815.

Miller, M., Nevado-Montenegro, A. J., & Hinshaw, S. P. (2012). Childhood executive function continues to predict outcomes in young adult females with and without childhood-diagnosed ADHD. *Journal of abnormal child psychology*, 40(5), 657-668.

- Miller, M. R., Giesbrecht, G. F., Müller, U., McInerney, R. J., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. *Journal of Cognition and Development, 13*(3), 395-423.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology, 41*(1), 49-100.
- Monette, S., Bigras, M., & Guay, M. C. (2011). The role of the executive functions in school achievement at the end of Grade 1. *Journal of experimental child psychology, 109*(2), 158-173.
- Monette, S., Bigras, M., & Lafrenière, M. A. (2015). Structure of executive functions in typically developing kindergarteners. *Journal of experimental child psychology, 140*, 120-139.
- Monsell, S. (1996). Control of mental processes. *Unsolved mysteries of the mind: Tutorial essays in cognition, 93-148*.
- Morris, R. G., Craik, F. I., & Gick, M. L. (1990). Age differences in working memory tasks: The role of secondary memory and the central executive system. *The Quarterly Journal of Experimental Psychology, 42*(1), 67-86.
- Mosconi, M. W., Kay, M., D'cruz, A. M., Seidenfeld, A., Guter, S., Stanford, L. D., & Sweeney, J. A. (2009). Impaired inhibitory control is associated with higher-order repetitive behaviors in autism spectrum disorders. *Psychological medicine, 39*(9), 1559-1566.
- Mostert-Kerckhoffs, M. A., Staal, W. G., Houben, R. H., & de Jonge, M. V. (2015). Stop and change: inhibition and flexibility skills are related to repetitive behavior in children and young adults with autism spectrum disorders. *Journal of autism and developmental disorders, 45*(10), 3148-3158.
- Mummery, C. J., Patterson, K., Hodges, J. R., & Wise, R. J. (1996). Generating 'tiger' as an animal name or a word beginning with T: differences in brain activation. *Proc. R. Soc. Lond. B, 263*(1373), 989-995.

- Munakata, Y. (2001). Graded representations in behavioural dissociations. *Trends in cognitive sciences*, 5(7), 309-315.
- Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current directions in psychological science*, 21(2), 71-77.
- Muthén, L. K., & Muthén, B. O. (2002). How to use a Monte Carlo study to decide on sample size and determine power. *Structural equation modeling*, 9(4), 599-620.
- Nagahama, Y., Fukuyama, H., & Shibasaki, H. (2002). Dissociable mechanisms of attentional shifts within the human prefrontal cortex. In *International Congress Series*, 1232, 137-145. Elsevier
- Narra, M., & Mathew, B. (2012). Developmental Differences on Cognitive Inhibition in Children and Adults: Evidence from Vigilance Task. *International Journal of Brain and Cognitive Sciences*, 1(1), 1-5.
- National Curriculum Expectations. (2011). Retrieved from http://www.isb.edu.bn/wp-content/uploads/2016/01/NC_expectations.pdf
- Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological bulletin*, 126(2), 220.
- Norman, D., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R. Davidson, G. Schwartz, & D. Shapiro (Ed.), *Consciousness and self-regulation* (Vol. 4, pp. 1–18). New York: Plenum Press.
- Quill, K. A. (2002). The complexity of autism. *Do, watch, listen, say: Social and communication intervention for children with autism*, 1-20.
- Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human brain mapping*, 25(1), 46-59.
- Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of child Psychology and Psychiatry*, 32(7), 1081-1105.

Ozonoff, S., & Strayer, D. L. (2001). Further evidence of intact working memory in autism. *Journal of autism and developmental disorders*, 31(3), 257-263.

Pastor-Cerezuela, G., Fernández-Andrés, M. I., Feo-Álvarez, M., & González-Sala, F. (2016). Semantic verbal fluency in children with and without autism spectrum disorder: Relationship with chronological age and IQ. *Frontiers in psychology*, 7, 921.

Pickering, S., & Gathercole, S. E. (2001). *Working memory test battery for children (WMTB-C)*. London: Psychological Corporation.

Pickering, S. J., Gathercole, S. E., & Peaker, S. M. (1998). Verbal and visuospatial short-term memory in children: Evidence for common and distinct mechanisms. *Memory & cognition*, 26(6), 1117-1130.

Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M. D., & Zelazo, P. D. (2011). Development of hot and cool executive function during the transition to adolescence. *Journal of experimental child psychology*, 108(3), 621-637.

Pugliese, C. E., Anthony, L. G., Strang, J. F., Dudley, K., Wallace, G. L., Naiman, D. Q., & Kenworthy, L. (2016). Longitudinal examination of adaptive behavior in autism spectrum disorders: Influence of executive function. *Journal of autism and developmental disorders*, 46(2), 467-477.

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and individual differences*, 20(2), 110-122.

Ragland, J. D., Turetsky, B. I., Gur, R. C., Gunning-Dixon, F., Turner, T., Schroeder, L., ... & Gur, R. E. (2002). Working memory for complex figures: an fMRI comparison of letter and fractal n-back tasks. *Neuropsychology*, 16(3), 370.

Rajendran, G., & Mitchell, P. (2007). Cognitive theories of autism. *Developmental Review*, 27(2), 224-260.

Reed, P., Watts, H., & Truzoli, R. (2013). Flexibility in young people with autism spectrum disorders on a card sort task. *Autism*, 17(2), 162-171.

- Reitan, R. M., & Wolfson, D. (2004). The Trail Making Test as an initial screening procedure for neuropsychological impairment in older children. *Archives of Clinical Neuropsychology*, *19*(2), 281-288.
- Richler, J., Bishop, S. L., Kleinke, J. R., & Lord, C. (2007). Restricted and repetitive behaviors in young children with autism spectrum disorders. *Journal of autism and developmental disorders*, *37*(1), 73-85.
- Ridderinkhof, K. R., & Molen, M. W. (1995). A psychophysiological analysis of developmental differences in the ability to resist interference. *Child Development*, *66*(4), 1040-1056.
- Ritvo, E. R., & Freeman, B. J. (1977). National Society for Autistic Children definition of the syndrome of autism. *Journal of Pediatric Psychology*, *2*(4), 146-148.
- Riva, D., Nichelli, F., & Devoti, M. (2000). Developmental aspects of verbal fluency and confrontation naming in children. *Brain and language*, *71*(2), 267-284.
- Robbins, T. W., James, M., Owen, A. M., Sahakian, B. J., McInnes, L., & Rabbitt, P. (1994). Cambridge Neuropsychological Test Automated Battery (CANTAB): a factor analytic study of a large sample of normal elderly volunteers. *Dementia and Geriatric Cognitive Disorders*, *5*(5), 266-281.w
- Robinson, S., Goddard, L., Dritschel, B., Wisley, M., & Howlin, P. (2009). Executive functions in children with autism spectrum disorders. *Brain and cognition*, *71*(3), 362-368.
- Ropovik, I. (2014). Do executive functions predict the ability to learn problem-solving principles?. *Intelligence*, *44*, 64-74.
- Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental science*, *14*(5), 1161-1175.
- Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*(3), 211-227.

Rosenthal, M., Wallace, G. L., Lawson, R., Wills, M. C., Dixon, E., Yerys, B. E., & Kenworthy, L. (2013). Impairments in real-world executive function increase from childhood to adolescence in autism spectrum disorders. *Neuropsychology*, *27*(1), 13.

Roth, R. M., Isquith, P. K., & Gioia, G. A. (2005). *BRIEF-A: Behavior rating inventory of executive function--adult version: Professional manual*. Psychological Assessment Resources.

Rushworth, M. F., Passingham, R. E., & Nobre, A. C. (2005). Components of attentional set-switching. *Experimental psychology*, *52*(2), 83-98.

Russell J. (1998). *Autism as an Executive Disorder*. Oxford University Press: Oxford.

Sauzéon, H., Lestage, P., Raboutet, C., N'Kaoua, B., & Claverie, B. (2004). Verbal fluency output in children aged 7–16 as a function of the production criterion: Qualitative analysis of clustering, switching processes, and semantic network exploitation. *Brain and Language*, *89*(1), 192-202.

Scheres, A., Oosterlaan, J., Geurts, H., Morein-Zamir, S., Meiran, N., Schut, H., ... & Sergeant, J. A. (2004). Executive functioning in boys with ADHD: primarily an inhibition deficit?. *Archives of Clinical Neuropsychology*, *19*(4), 569-594.

Schneider, E., & Zuccoloto, A. (2007). E-prime 2.0 [Computer software]: Pittsburg, PA: *Psychological Software Tools*.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder?. *Behavioural brain research*, *130*(1-2), 3-28.

Shah, P., & Miyake, A. (1999). Models of working memory. *Models of working memory: Mechanisms of active maintenance and executive control*, 1-27.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *298*(1089), 199-209.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain*, *114*, 727–741.

Shallice, T., & Burgess, P. (1996). The domain of supervisory processes and temporal organization of behaviour. *Phil. Trans. R. Soc. Lond. B*, 351(1346), 1405-1412.

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S. C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. *Developmental Neuropsychology*, 35(6), 679-697.

Siegel, L. S. (1994). Working memory and reading: A life-span perspective. *International Journal of Behavioral Development*, 17(1), 109-124.

Sikora, D. M., Haley, P., Edwards, J., & Butler, R. W. (2002). Tower of London test performance in children with poor arithmetic skills. *Developmental neuropsychology*, 21(3), 243-254.

Simon, H. A. (1975). The functional equivalence of problem solving skills. *Cognitive Psychology*, 7(2), 268-288.

Simon, J. R., & Berbaum, K. (1990). Effect of conflicting cues on information processing: the 'Stroop effect' vs the 'Simon effect'. *Acta psychologica*, 73(2), 159-170.

Sinzig, J., Morsch, D., Bruning, N., Schmidt, M. H., & Lehmkuhl, G. (2008). Inhibition, flexibility, working memory and planning in autism spectrum disorders with and without comorbid ADHD-symptoms. *Child and adolescent psychiatry and mental health*, 2(1), 4.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science*, 283(5408), 1657-1661.

South, M., Ozonoff, S., & McMahon, W. M. (2007). The relationship between executive functioning, central coherence, and repetitive behaviors in the high-functioning autism spectrum. *Autism*, 11(5), 437-451.

St Clair-Thompson, H. L. (2015) Lucid recall computerised assessment of working memory and processing speed for 7 to 16 years. Administrator's Manual. Retrieved from http://lucid-research.net/documents/manuals/manual_rc.pdf

St Clair-Thompson, H. L. (2013) Working Memory and Children's Scholastic Attainment from 7 to 15 Years of Age: Developmental Differences and the Contribution of Speed of Processing. In: H.L. St Clair-Thompson (Ed.), *Working Memory: Developmental Differences, Component Processes and Improvement Mechanisms* (pp.1-16). Novascience

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The quarterly journal of experimental psychology*, 59(4), 745-759.

St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology*, 30(2), 203-219.

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods*, 42(4), 1096-1104.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, 18(6), 643.

Stuss, D. T., Levine, B., Alexander, M. P., Hong, J., Palumbo, C., Hamer, L., Murphy, K. J., and Isukawa, D. (2000). Wisconsin Card Sorting Test performance in patients with focal frontal and posterior brain damage: Effects of lesion location and test structure on separable cognitive processes. *Neuropsychologia* 38: 388–402.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology*, 96(3), 471.

Szatmari, P., Georgiades, S., Bryson, S., Zwaigenbaum, L., Roberts, W., Mahoney, W., ... & Tuff, L. (2006). Investigating the structure of the restricted, repetitive behaviours and interests domain of autism. *Journal of Child Psychology and Psychiatry*, 47(6), 582-590.

Tanaka, S., Oi, M., Fujino, H., Kikuchi, M., Yoshimura, Y., Miura, Y., ... & Ohoka, H. (2017). Characteristics of communication among Japanese children with autism spectrum disorder: A cluster analysis using the Children's Communication Checklist-2. *Clinical linguistics & phonetics*, 31(3), 234-249.

Teunisse, J. P., Cools, A. R., Van Spaendonck, K. P., Aerts, F. H., & Berger, H. J. (2001). Cognitive styles in high-functioning adolescents with autistic disorder. *Journal of autism and developmental disorders*, 31(1), 55-66.

Thurstone, L. L. (1938). *Primary mental abilities*. Chicago: University of Chicago Press.

Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. *Archives of clinical neuropsychology*, 14(2), 167-177.

Toms, M., Morris, N., & Ward, D. (1993). Working memory and conditional reasoning. *The Quarterly Journal of Experimental Psychology*, 46(4), 679-699.

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner Review: Do performance-based measures and ratings of executive function assess the same construct?. *Journal of Child Psychology and Psychiatry*, 54(2), 131-143.

Troyer, A. K., Moscovitch, M., Winocur, G., Alexander, M. P., & Stuss, D. (1998). Clustering and switching on verbal fluency: The effects of focal frontal-and temporal-lobe lesions. *Neuropsychologia*, 36(6), 499-504.

Turner, M. (1995) 'Repetitive Behaviour and Cognitive Functioning in Autism', Unpublished PhD thesis, University of Cambridge.

Turner, M. (1997). Towards an executive dysfunction account of repetitive behaviour in autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 57-100). New York, NY, US: Oxford University Press.

Turner, M. A. (1999). Generating Novel Ideas: Fluency Performance in High-functioning and Learning Disabled Individuals with Autism. *Journal of Child Psychology and Psychiatry*, 40(2), 189-201.

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: an examination of simple and complex span and their relation to higher order abilities. *Psychological bulletin*, 133(6), 1038.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2010). Variation in verbal fluency: A latent variable analysis of clustering, switching, and overall performance. *Quarterly Journal of Experimental Psychology*, *64*(3), 447-466.

Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in five-and six-year-old children: a longitudinal study. *European Journal of Developmental Psychology*, *11*(4), 447-462.

Van Boxtel, G. J., Van der Molen, M. W., Jennings, J. R., & Brunia, C. H. (2001). A psychophysiological analysis of inhibitory motor control in the stop-signal paradigm. *Biological psychology*, *58*(3), 229-262.

Van Den Bergh, S. F., Scheeren, A. M., Begeer, S., Koot, H. M., & Geurts, H. M. (2014). Age related differences of executive functioning problems in everyday life of children and adolescents in the autism spectrum. *Journal of autism and developmental disorders*, *44*(8), 1959-1971.

Van Der Sluis, S., de Jong, P. F., & Van Der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, *35*(5), 427-449.

Van Der Ven, S. H., Kroesbergen, E. H., Boom, J., & Leseman, P. P. (2012). The development of executive functions and early mathematics: A dynamic relationship. *British Journal of Educational Psychology*, *82*(1), 100-119.

Van Der Ven, S. H., Kroesbergen, E. H., Boom, J., & Leseman, P. P. (2013). The structure of executive functions in children: A closer examination of inhibition, shifting, and updating. *British Journal of Developmental Psychology*, *31*(1), 70-87.

Van Eylen, L., Boets, B., Steyaert, J., Evers, K., Wagemans, J., & Noens, I. (2011). Cognitive flexibility in autism spectrum disorder: Explaining the inconsistencies?. *Research in Autism Spectrum Disorders*, *5*(4), 1390-1401.

Van Eylen, L., Boets, B., Steyaert, J., Wagemans, J., & Noens, I. (2015). Executive functioning in autism spectrum disorders: Influence of task and sample characteristics and relation to symptom severity. *European child & adolescent psychiatry*, *24*(11), 1399-1417.

Visu-Petra, L., Cheie, L., Benga, O., & Miclea, M. (2011). Cognitive control goes to school: The impact of executive functions on academic performance. *Procedia-Social and Behavioral Sciences*, 11, 240-244.

Viterbori, P., Usai, M. C., Traverso, L., & De Franchis, V. (2015). How preschool executive functioning predicts several aspects of math achievement in Grades 1 and 3: A longitudinal study. *Journal of experimental child psychology*, 140, 38-55.

Vygotsky, L. S. (1963). Learning and mental development at school age. *Educational psychology in the USSR*, 1, 21-34.

Wang, S., Allen, R. J., Lee, J. R., & Hsieh, C. E. (2015). Evaluating the developmental trajectory of the episodic buffer component of working memory and its relation to word recognition in children. *Journal of experimental child psychology*, 133, 16-28.

Wang, S., & Gathercole, S. E. (2013). Working memory deficits in children with reading difficulties: Memory span and dual task coordination. *Journal of Experimental Child Psychology*, 115(1), 188-197.

Wang, L., Kakigi, R., & Hoshiyama, M. (2001). Neural activities during Wisconsin Card Sorting Test—MEG observation. *Cognitive Brain Research*, 12(1), 19-31.

Wang, Y., Zhang, Y. B., Liu, L. L., Cui, J. F., Wang, J., Shum, D. H., ... & Chan, R. C. (2017). A Meta-Analysis of Working Memory Impairments in Autism Spectrum Disorders. *Neuropsychology review*, 1-16.

Wechsler, D. (1997). *WAIS-III: Wechsler adult intelligence scale*. Psychological Corporation.

Wechsler, D. (2008). *Wechsler adult intelligence scale—Fourth Edition (WAIS—IV)*. San Antonio, TX: NCS Pearson, 22, 498.

Wechsler, D. (2011). *WASI-II: Wechsler abbreviated scale of intelligence*. Psychological Corporation.

Wechsler, D. (2014). *Wechsler Intelligence Scales for Children—Fifth Edition (WISC-V)*.

- Weiss, E. M., Siedentopf, C., Hofer, A., Deisenhammer, E. A., Hoptman, M. J., Kremser, C., ... & Delazer, M. (2003). Brain activation pattern during a verbal fluency test in healthy male and female volunteers: a functional magnetic resonance imaging study. *Neuroscience Letters*, *352*(3), 191-194.
- Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental neuropsychology*, *7*(2), 131-149.
- West, S. G., Finch, J. F., & Curran, P. J. (1995). *Structural equation models with nonnormal variables: Problems and remedies*.
- Wheaton, B., Muthen, B., Alwin, D. F., & Summers, G. F. (1977). Assessing reliability and stability in panel models. *Sociological methodology*, *8*, 84-136.
- White, S. J., & Saldaña, D. (2011). Performance of children with autism on the Embedded Figures Test: a closer look at a popular task. *Journal of autism and developmental disorders*, *41*(11), 1565-1572.
- Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental psychology*, *44*(2), 575.
- Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of experimental child psychology*, *108*(3), 436-452.
- Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological psychiatry*, *57*(11), 1336-1346.
- Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental psychology*, *35*(1), 205.
- Williams, D. L., Goldstein, G., Carpenter, P. A., & Minshew, N. J. (2005). Verbal and spatial working memory in autism. *Journal of autism and developmental disorders*, *35*(6), 747.

Willoughby, M., & Blair, C. (2011). Test-retest reliability of a new executive function battery for use in early childhood. *Child Neuropsychology*, *17*(6), 564-579.

Willoughby, M. T., Blair, C. B., Wirth, R. J., & Greenberg, M. (2010). The measurement of executive function at age 3 years: Psychometric properties and criterion validity of a new battery of tasks. *Psychological assessment*, *22*(2), 306.

Wilson, J. T., Scott, J. H., & Power, K. G. (1987). Developmental differences in the span of visual memory for pattern. *British Journal of Developmental Psychology*, *5*(3), 249-255.

Wolfberg, P. J., & Schuler, A. L. (1999). Fostering peer interaction, imaginative play and spontaneous language in children with autism. *Child Language Teaching and Therapy*, *15*(1), 41-52.

Woodcock, R. W., & Johnson, M. B. (1989). Woodcock–Johnson Revised tests of cognitive ability: Standard and supplemental batteries. Itasca, IL: Riverside Publishing.

Wu, K. K., Chan, S. K., Leung, P. W., Liu, W. S., Leung, F. L., & Ng, R. (2011). Components and developmental differences of executive functioning for school-aged children. *Developmental Neuropsychology*, *36*(3), 319-337.

Xu, F., Han, Y., Sabbagh, M. A., Wang, T., Ren, X., & Li, C. (2013). Developmental differences in the structure of executive function in middle childhood and adolescence. *PloS one*, *8*(10), e77770.

Yeniad, N., Malda, M., Mesman, J., Van IJzendoorn, M. H., Emmen, R. A., & Prevo, M. J. (2014). Cognitive flexibility children across the transition to school: A longitudinal study. *Cognitive Development*, *31*, 35-47.

Yeniad, N., Malda, M., Mesman, J., Van IJzendoorn, M. H., & Pieper, S. (2013). Shifting ability predicts math and reading performance in children: A meta-analytical study. *Learning and Individual Differences*, *23*, 1-9.

Yerys, B. E., Wallace, G. L., Harrison, B., Celano, M. J., Giedd, J. N., & Kenworthy, L. E. (2009). Set-shifting in children with autism spectrum disorders: Reversal

shifting deficits on the Intradimensional/Extradimensional Shift Test correlate with repetitive behaviors. *Autism*, 13(5), 523-538.

Zandt, F., Prior, M., & Kyrios, M. (2009). Similarities and differences between children and adolescents with autism spectrum disorder and those with obsessive compulsive disorder: executive functioning and repetitive behaviour. *Autism*, 13(1), 43-57.

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols-Electronic Edition*, 1(1), 297.

Zelazo, P. D., & Frye, D. (1998). Cognitive complexity and control: II. The development of executive function in childhood. *Current Directions in Psychological Science*.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445–469). Oxford: Blackwell.

Zorza, J. P., Marino, J., & Mesas, A. A. (2016). Executive Functions as Predictors of School Performance and Social Relationships: Primary and Secondary School Students—ERRATUM. *The Spanish journal of psychology*, 19.

Appendices

Appendix A: “How Children Develop Their Learning Skills” Ethical Approval letter

Appendix B: Year 3 and Year 6 child Information sheet for “How Children Develop Their Learning Skills” study

Appendix C: Year 9 young people information sheet for “How Children Develop Their Learning Skills” study

Appendix D: Parent/Carer Information sheet for “How Children Develop Their Learning Skills” study

Appendix E: Year 3 and Year 6 child assent forms for “How Children Develop Their Learning Skills” study

Appendix F: Year 9 young people assent form for “How Children Develop Their Learning Skills” study

Appendix G: Parent/Carer consent form for “How Children Develop Their Learning Skills” study

Appendix H: Debrief sheet for parents “How Children Develop Their Learning Skills” study

Appendix I: The “Think and Do” study Ethical Approval letter

Appendix J: Child information sheet for the “Think and Do” study

Appendix K: Child assent form for the “Think and Do” study

Appendix L: Parent/Carer information sheet for the “Think and Do” study

Appendix M: Parent/Carer consent form for the “Think and Do” study

Appendix N: Debrief sheet for parents the “Think and Do” study

Appendix O: Repetitive Behaviours Questionnaire

Appendix P: Social Responsiveness Scale -2

Appendix Q: Behaviour Rating Inventory of Executive Function questionnaire



Yunhong Wen (Catherine Wen)
PhD Student
Institute of Neuroscience
The Henry Wellcome Building

Faculty of Medical Sciences
Newcastle University
The Medical School
Framlington Place
Newcastle upon Tyne
NE2 4HH United Kingdom

FACULTY OF MEDICAL SCIENCES: ETHICS COMMITTEE

Dear Catherine,

Title: Investigating the Fractionations of Executive Functions in Typically Developing Children

Application No: 00872 2015

Start date to end date: 01-05-2015 to 31-10-2015

On behalf of the Faculty of Medical Sciences Ethics Committee, I am writing to confirm that the ethical aspects of your proposal have been considered and your study has been given ethical approval.

The approval is limited to this project: **00872/2015**. If you wish for a further approval to extend this project, please submit a re-application to the FMS Ethics Committee and this will be considered.

During the course of your research project you may find it necessary to revise your protocol. Substantial changes in methodology, or changes that impact on the interface between the researcher and the participants must be considered by the FMS Ethics Committee, prior to implementation.*

At the close of your research project, please report any adverse events that have occurred and the actions that were taken to the FMS Ethics Committee.*

Best wishes,
Yours sincerely


Kimberley Sutherland
On behalf of Faculty Ethics Committee

cc.
Professor Daniel Nettle, Chair of FMS Ethics Committee
Ms Lois Neal, Assistant Registrar (Research Strategy)

*Please refer to the latest guidance available on the internal Newcastle web-site.

tel: +44 (0) 191 222 6000
fax: +44 (0) 191 222 6621

www.ncl.ac.uk
The University of Newcastle upon Tyne trading as Newcastle University





Child Information Sheet



What is this about?

My name is Catherine and you are being asked to take part in a study. I am a student at Newcastle University and I am doing this study as part of my research. We want to know more about how children develop their skills, which we call executive functions. These are skills linked to memory and attention.

Before you decide to take part, we want you to know what you will have to do.

Why have I been asked to take part?

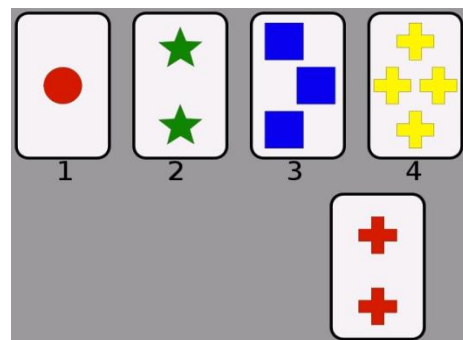
We would like you to take part because you are in year 3 or year 6.

Do I have to take part?

No, it depends on you. If you do take part, you can stop at any time. You do not have to give a reason to stop.

What would I have to do?

There are two parts of the study. In the first part, you will be in a group of 5 children in a school computer room and you will be asked to answer some questions using a computer. The second part is on your own. You will answer more questions on a computer and do some pencil-and-paper tasks. For example, you will be shown some words on the screen, and you need to click on them in the same order you heard them. The tasks do not have right or wrong answers and you may find them fun. Each part will take about 50 minutes.



Where will I take part?

I will come to your school to do the activities.

**Who will know I am taking part and what activities I have done?**

Only people in our research team and your parents will know what you take part in. Your parents may get to know some of your test results.

Some tasks are easy, but some of them might be harder. You just need to try your best to answer the questions.

What should I do now?

Please talk to your parents about taking part. If you would like to take part, you can ask your parents to fill in the consent form, help you fill in your assent form and return it back to the main office in your school.

Thank you!

Catherine Yunhong Wen

PhD student in Institute of Neuroscience

Newcastle University



Young People Information Sheet



What is this about?

My name is Catherine and you are being asked to take part in a study. I am a student at Newcastle University and I am doing this study as part of my research. We want to know more about how young people develop their skills, especially some skills that are important for learning at school, which we call executive functions. These skills can help the growth of linguistic, reasoning and mathematical abilities.

Before you decide if you wish to take part, we want you to know what you will have to do.

Why have I been asked to take part?

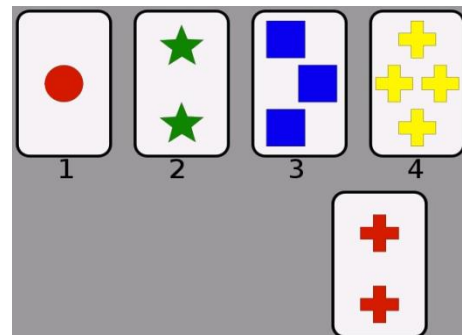
We would like you to take part because you are in year 9.

Do I have to take part?

No, it depends on you. If you promise to take part, but you want to quit, you can stop at any time with no reason.

What would I have to do?

There are two parts of the study. In the first part, there will be 5-8 young people in a school computer room and you will be asked to answer some questions using a computer. For example, you will be shown some words on the screen, and you need to click on them in the same order you heard them. The second part is individual. You will be asked to do more tasks on a computer and do some pencil-and-paper tasks. For example, you need to draw a line to connect the numbers and letters in a required order. All the tasks do not have right or wrong answers. You may meet some difficulties, but you need to know all the tasks are designed, so that not everyone should be able to give correct answers to all of them during the time allowed. Each part will take about 50 minutes.



Where will I take part?

I will come to your school to do the tasks.

Who will know I am taking part and what activities I have done?

Only people in our research team and your parents will know what you take part in. Your parents will get know a part of your test results if they require.

Some tasks are easy, but some of them might be harder. You just need to try your best to answer the questions.

What should I do now?

Please talk to your parents about taking part. If you would like to take part, you can fill in your assent form, ask your parents to fill in the consent form and return it back to the main office of your school.

Thank you!

Catherine Yunhong Wen

PhD student in Institute of Neuroscience

Newcastle University



Parent/Carer Information sheet

We would like to invite your child to take part in a research study being conducted within their school. This is student research which will contribute to the researcher's PhD in Psychology at Newcastle University. Before you decide whether you want your child to take part, you need to understand why the research is being done and what it would involve.

We are interested in looking at how children develop their cognitive skills, particularly in terms of working memory, inhibition, shifting and accessing long-term memory. Inhibition in daily life might be not being able to control temper or blurting out answers in class instead of waiting to be asked, or constantly interrupting other people when they are talking. Shifting refers to the ability to switch between two ongoing activities. For example, lack of shifting might be shown as someone who tries the same approach to a problem repeatedly even when it does not work, or thinks about the same topic constantly. Updating requires people concentrate in a busy environment, taking in new information and not checking irrelevant work. In terms of accessing long-term memory, it refers to recalling things from the past. These skills are important to academic learning and achievements in school. However, there are various studies which have led to different views of development because of choice of tasks and age groups.

Does my child have to join in?

No. It depends on you and your child. If your child takes part in the study, you are still free to withdraw at anytime without providing reason.

What will my child be asked to do?

There are two parts in this study. Each part of the study may take about 50 minutes during their school day, and will be carried out in the school.

In the first part, 5-8 children will be asked to sit in a computer cluster and finish the tasks on the computer. For example, children will hear some words on the screen, and they need to click on them on screen in the same order they heard them. In the second part, children will complete tasks individually. They need to complete more computer tasks and pencil-and-paper tasks. For example, children need to draw a line to connect the numbers and letters in a required order.

What are the possible disadvantages and risks of taking part?

Children may worry about their results at the end of the tasks. However, there are no wrong or right answers in these tasks. If for any reason your child does become distressed, the researcher would stop the tasks and respond appropriately and sensitively to your child's needs. Under these circumstances, you would be contacted to discuss any concerns raised.

What are the possible benefits of taking part?

The information we gather from this study will help us to extend our understanding of the structure of executive functions and how children develop these executive functions as they grow up. The findings could have important implications for education and for understanding learning difficulties.

Will information be kept confidential?

Information which is collected about you and your child will be kept strictly confidential. The only identifiable information will be your child's name and both of your signatures which are required to give consent, and your child's unique participation number, all of which will only be accessible to the research team. Throughout and after the experiment your participation in this study will be completely confidential. All answers will be anonymous and will be put together with all of the other participants' scores. The only people who will see these will be the research team. Data will be stored for 5 years and will then be destroyed.

Please note that any information that you or your child discloses to the researcher will remain confidential to the research team, unless we believe that harm has or might occur to yourself or others.

What will happen if you or your child does not want to carry on with the study?

If you or your child changes their mind and decides to stop, it is acceptable at any time. You do not need to give a reason. If you have a concern about any details of this study, please speak to Dr. Helen St.Clair-Thompson on 0191 222 6175. Or email her at helen.st-clair-thompson@ncl.ac.uk. Dr St. Clair-Thompson is the lead supervisor for the study and will do her best to answer any questions you may have.

What will happen to the results of the research study?

We will write up a summary of this study when it is finished. A copy of the results of this study will be sent to you via email if you wish. Also, if you wish to receive a copy of your child's working memory results, we can enclose the results with the summary of this study upon request.

Who is organising the research?

The research is being organised and conducted by Yunhong Wen (Catherine), who is a PhD student at the Newcastle University, Department of Psychology and Dr. Helen St.Clair-Thompson and Dr. Jacqui Rodgers, Senior Lecturers at Newcastle University, School of Psychology.

Who has reviewed the study?

All research at Newcastle University is approved by an independent group of people, called The University's Ethics Committee, to protect your rights.

Thank you for reading the information above and please help your child read through the child information sheet. If you agree to your child participating in the study, please complete the consent form and help your child complete the assent form attached, and return it to the main office in your child's school.

If you have any further questions about this study, please do not hesitate to contact us at Newcastle University. Please email me at y.wen4@newcastle.ac.uk, or

alternatively you may call 0191 222 6175 to speak with Dr. Helen St.Clair-Thompson.

Catherine Yunhong Wen

PhD student in Institute of Neuroscience

Newcastle University



Child Assent Form

Project Title: How Children Develop Their Learning Skills

Researcher: Yunhong Wen (PhD student)

Name (Print):

Gender: Male / Female

1. Have you read the information sheet?



2. Did you talk to your parent/carer about the study?



3. Do you understand that you can stop at any time?



4. Do you want to join in this study?



Signature:

Researcher's signature:

Date:



Young People Assent Form

Project Title: How Children Develop Their Learning Skills

Researcher: Yunhong Wen (Catherine; PhD student)

Name (Print):

Gender: Male / Female

D.O.B:.....

Please tick the relevant corresponding boxes:

I confirm that I have read and understand the young people information sheet for Yunhong Wen's study. I have had the opportunity to consider the information, ask questions and have had these answered.

I have talked to my parents about this study.

I am willing to take part in this study.

I understood that I can withdraw from the study at any time without giving any reason.

Signature:

Research signature:

Date:.....

Parent/Carer Consent Form

Project Title: How Children Develop Their Learning Skills

Researcher: Yunhong Wen (PhD student)

Parent/Carer name (Print): Relationship to child:

Telephone No. Email Address:

Child's name (Print):

D.O.B..... Gender: Male / Female

School name: Class:

Please tick the relevant corresponding boxes:

I confirm that I have read and understood the parent/carers information sheet for Yunhong Wen's study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I confirm that I have spoken to my child about the study.

I understood that I or my child may withdraw from the study at any time without giving any reason.

I am willing for my child to participate in this study.

I would like to receive a copy of the results of working memory test and the summary of this study via email.

Parent/Carer signature:

.....

Research signature:

Date:.....



Participant Debrief Letter

THANK YOU!

We would like to say thank you to your child for joining in this study! We are really grateful for their time and effort in this study, and we hope your child enjoyed it, too.

What is next?

We have over 100 children who will be taking part in the study. If you ticked that you would like to receive a copy of your child's results and a copy of the summary of the results of this study on the parent/carer consent form, you will receive them once the study is completed in 2015.

Contact Details

If you have any questions about the study, you can email me on y.wen4@newcastle.ac.uk, or you can speak to the supervisor Dr. Helen St.Clair-Thompson on 0191 222 6175.

Catherine Yunhong Wen

PhD student in Institute of Neuroscience

Newcastle University



20 June 2016

Yunhong Wen
Institute of Neuroscience

Faculty of Medical Sciences

Newcastle University
The Medical School
Framlington Place
Newcastle upon Tyne
NE2 4HH United Kingdom

FACULTY OF MEDICAL SCIENCES: ETHICS COMMITTEE

Dear Yunhong

Title: Examining the relationship between executive functions and autism characteristics in children with Autism Spectrum Disorder (The Think & Do Project).

Application No: 01072/2016

Start date to end date: 01/06/16 to 01/12/17

On behalf of the Faculty of Medical Sciences Ethics Committee, I am writing to confirm that the ethical aspects of your proposal have been considered and your study has been given ethical approval.

The approval is limited to this project: **01072/2016**. If you wish for a further approval to extend this project, please submit a re-application to the FMS Ethics Committee and this will be considered.

During the course of your research project you may find it necessary to revise your protocol. Substantial changes in methodology, or changes that impact on the interface between the researcher and the participants must be considered by the FMS Ethics Committee, prior to implementation.*

At the close of your research project, please report any adverse events that have occurred and the actions that were taken to the FMS Ethics Committee.*

Best wishes,

Yours sincerely

A handwritten signature in black ink, appearing to read "M. Holbrough".

Marjorie Holbrough
On behalf of Faculty Ethics Committee

cc:
Professor Daniel Nettle, Chair of FMS Ethics Committee
Ms Lois Neal, Assistant Registrar (Research Strategy)

*Please refer to the latest guidance available on the internal Newcastle web-site.

tel: +44 (0) 191 208 6000
fax: +44 (0) 191 208 6621

www.ncl.ac.uk

The University of Newcastle upon Tyne trading as Newcastle University





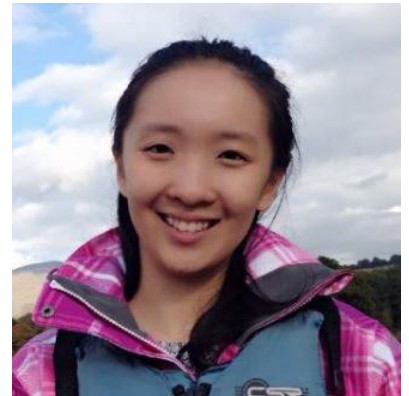
The Think & Do Project

Child Information Sheet



What is this about?

My name is Catherine. I am a student at Newcastle University. I am writing to you to ask you if you would like to take part in a study. If you say 'yes' I will ask you to complete some puzzles and games. I will also ask your Mum or Dad some questions about you, too.



Before you decide if you want to take part, we want you to know what you will do.

Why have I been asked to take part?

We want you to take part because you are at the age of 6 and 11 years old.

Do I have to take part?

No, it is up to you. If you do take part, you can stop at any time. You do not have to give a reason to stop.

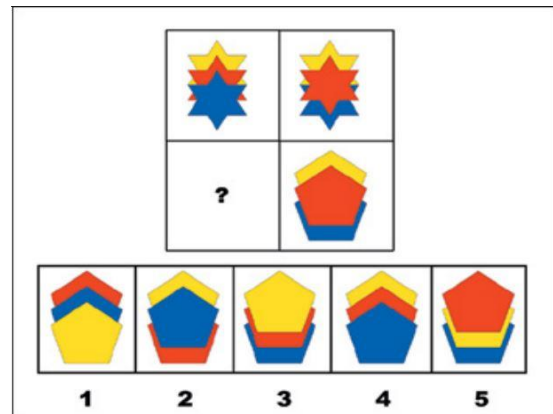
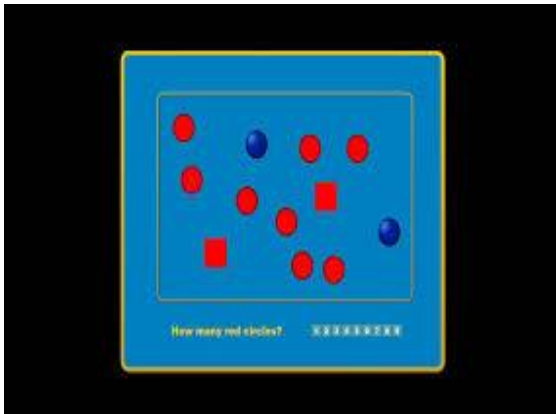
What will happen if I take part?

If you decide to take part, I will ask you to:

- Answer some questions

- Complete some games on the computer

The Computer games will be look a bit like this:



Other children have told us that the games are really fun. It will take about 1 hour to do all of the games and you can have a break if you wish.

Where will I take part?

You and your family can decide where you want to take part. I can come to your home or you and your parent can come to university.

Who will know that I am taking part?

Only people in our research team and your parents will know that you have taken part.

What should I do now?

If you or your parents have any questions and/or you are interested in taking part in the study your parents can call or email me. If you want to take part in this study, you and your parents can fill in the forms sent with this letter and send them back and I will get in touch to arrange a time to meet.

Thank you!



The Think & Do Project

Child Assent Form

Name (Print):

Please draw a circle around your answer to these questions.

1. Have you read the information sheet?



2. Did you talk to your parent/carer about the study?



3. Do you want to join in this study?



4. Do you understand that you can stop at any time?



Signature: Researcher's signature:

Date:

The Think & Do Project

Parent and Carer Information Sheet



We would like to invite you and your child to take part in a research study. Before you decide whether you want your child to take part, it is important for you to understand why the research is being done and what it involves. Please take time to read the following information carefully. If there is anything that is not clear or if you would like some more information, please contact us on following details.

What is this study about?

Executive function is a term used to describe a wide range of everyday abilities considered to be necessary for day to day living. It includes skills like being able to plan tasks and activities, pay attention to and remember important information. People with autism spectrum disorder (ASD) are often reported to experience executive function difficulties, which can result in having trouble concentrating on chores and schoolwork or getting used to new situations. We are looking at whether these difficulties contribute to autism characteristics in children with ASD aged 6 and 11 years old. This is important because it will help us to develop an understanding of what might underlie some of the features of ASD, which in turn may lead to the development of educational methods to reduce some of the more challenging aspects of the condition.

Why have we been asked to take part?

Families with a child with ASD aged between 6 and 11 years old are being invited to take part in this study.

Do we have to take part in the study?

You do not have to take part in this study. Taking part in this study is entirely voluntary. If you do decide to take part, you can withdraw from the study at any time without giving an explanation. If you do withdraw from the study, we will ask you if we can use data collected from you up until that point.

What will happen if we take part?

If you decide to take part, we will ask you and your child to sign a consent form for parent/carer and an assent form for child and send them back to us via a stamped addressed envelope. We will then arrange to a time meet at either your home or university depending on your choice.

What will my child be asked to do?

We will ask your child to complete seven activities including answering some questions and completing some games on the researcher's computer. Usually, it will take 25 minutes to answer the questions, and 35 minutes to complete the games. We will schedule a slightly longer session to allow children to take breaks if they want to. Your child will be asked some questions, such as "Can you tell me as many Disney movies as possible?" or "How can we use a newspaper? Tell me other ways we could use a newspaper". In terms of computer games, for example, the computer screen will display a set of shapes, asking your child to count red circles among. After a few sets of shapes, they will need to recall each total number of red circles on the screen in the same order as shapes were presented. All the questions and games have been developed for use with children.

What will I be asked to do?

We will ask you to complete three questionnaires: *Behaviour Rating Inventory of Executive Function* (BRIEF), *Social Responsiveness Scale* (Second Edition, SRS-2), and *Repetitive Behaviour Questionnaire* (RBQ). You will only need to circle your answers in all of the questionnaires. It might take 30 minutes to finish. These questionnaires will provide us with information about your child's autism characteristics and their everyday abilities.

What are the benefits of taking part in the study?

There are no direct benefits from participating in this study. However, we hope this research will benefit the families with children with ASD by providing a better understanding of how everyday behaviours are related to autism characteristics in children with ASD, and potentially could inform new educational strategies order to improve quality of life for children with ASD.

What are the disadvantages of taking part in the study?

Children may feel worried during the session and they may worry about their results at the end of the tasks. However, there are no wrong or right answers in these tasks. Children also may feel tired whilst completing the tests, if for any reason your child does become too tired or distressed, the researcher will stop the tasks and respond appropriately and sensitively to your child's needs.

What will happen to the data?

All information collected from you and your child will be kept confidential. The information you provide in the consent form and questionnaires is anonymised; your name, your child's name and any identifiable personal details will not be recorded in the same place we store answers to the questionnaires. The information from the tasks and questionnaires will be stored securely on an encrypted computer system. The information we get from you and your child will be kept private, unless you and your child mention something that makes us think there is a risk to yourself or others. If that happened, we might need to tell someone who could help, and would try to discuss this with you first. Data will be stored for 5 years and will then be destroyed.

What will happen to the results?

The results of this study will be available in a report. A copy of this report will be available on request. Summaries will be prepared for the database family newsletters, and placed on the website. If you are willing the results of this project will be shared with the autism database DASLNE. It will not be possible to identify participants from the summaries and reports. Unfortunately we are not able to provide families with a summary of their child's scores of the tasks.

If you would like to take part in this project please sign the consent form and assent form and send them back to us with your address.

If you have any further questions, we would be happy to discuss them with you. You can contact us using the detail below:

Researcher: Catherine Wen y.wen4@ncl.ac.uk

Supervisor: Dr. Jacqui Rodgers Jacqui.rodgers@ncl.ac.uk , 0191 222 7562

Institute of Neuroscience,
Newcastle University
Newcastle upon Tyne,
NE1 7RU

Thank you for reading this information sheet.



The Think & Do Project

Parent and Carer Consent Form

Parent/Carer name (Print): Relationship to child:

Telephone No.Email Address:

Child's name (Print):

D.O.B..... Gender: Male / Female

Please tick the relevant corresponding boxes:

I confirm that I have read and understand the parent/carer information sheet for this study. I have had the opportunity to consider the information, ask questions and have had these answered.

I confirm that I have spoken to my child about the study.

I understood that I or my child may withdraw from the study at any time without giving any reason. If I withdraw from the study, I understand that you will ask me if data collected from me up until that point can still be included in the study.

I am willing to participate in this study.

I am willing for my child to participate in this study.

I would like to receive a copy of the summary of this study via email.

I am willing for my data to be shared with autism database DASLNE.

Parent/Carer signature:

Researcher signature:

Date:.....



The Think & Do Project

Debrief Sheet



Thank you

We would like to say thank you to your family for joining in this study! We are really grateful for your time and effort in this study, and we hope your child enjoyed it, too.

What is next?

We have over 30 children who will be taking part in the study. If you ticked that you would like to receive a copy of the summary of the results of this study on the parent and carer consent form, you will receive them once the study is completed in 2016.

Contact Details

If you have any questions about the study, you can email me on y.wen4@newcastle.ac.uk, or you can speak to the supervisor Dr. Jacqui Rodgers on 0191 222 7562.

Yunhong Wen (Catherine)

REPETITIVE BEHAVIOUR QUESTIONNAIRE

Please record the behaviour that your son or daughter shows at the moment (over the last three months). For those items that ask about the frequency with which behaviour is shown, please rate how frequently your son or daughter might display the behaviour over the course of the day if you were watching them all day. Think about this either in terms of the number of bouts of this behaviour he/she would show over the course of the entire day, or if it is more appropriate, the number of bouts of this behaviour that might occur in a typical hour.

Please tick the circle of your answer and try to complete each question as accurately as you can and try not to leave any question.

Thank you.

1. Does he/she operate light switches, taps, the toilet flush etc. repeatedly when it is not necessary to do so?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

2. Does he/she arrange toys or other items in rows or patterns?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

3. Does he/she repeatedly fiddle with toys or other items?

For example, does he/she spin, twiddle, bang, tap, twist, flick or wave anything repetitively?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

4. Does he/she touch parts of his/her body or clothing repeatedly?

For example, does he/she repeatedly rub his legs, pull at the buttons on his/her clothing, or touch his/ her ear or elbow etc.?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

5. Is he/she attached to anything in particular?

For example, does he/she carry a teddy, a blanket or stick etc. around with him/her?

- No** particular attachment to any object
- Attachment to an object commonly used as a comforter (e.g. teddy, blanket etc.)
- Attachment to an unusual object (e.g. stick, glove etc.)

6. Does he/she obsessively collect or hoard items of any sort?

- No** obsessive or unusually keen collecting or hoarding
- Very keen collector of **usual** items (e.g. stamps, football cards etc.)
- Very keen collector of **unusual** or odd items (e.g. leaflets, jar lids, sticks etc.)

7. Does he/she spin him/herself around and around?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

8. Does he/she rock backwards and forwards, or side to side, either when sitting or when standing?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

9. Does he/she bang his/her head? Does he/she do this repetitively?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

10. Does he/she pace or move around repetitively?

For example, does he/she walk to and from across a room, or around the house or garden repetitively?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

11. Does he/she make repetitive hand and/or finger movements?

For example, does he/she repetitively wave, flick, flap or twiddle his/her hands or fingers repetitively?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

12. Does he/she make other repetitive body movements?

For example, does he/she repeatedly clasp his/her hands, tap his/her feet, swing his/her legs or jump etc.?

- Never** or rarely

- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

13. Does he/she ever injure him/herself?

For example, does he/she bite, scratch, knock or pick him/herself? Does he/ she do this repeatedly?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

14. Does he/she insist on things about the house staying the same?

For example, does he/she insist on furniture staying in the same place, or curtains being open or closed etc.?

- No**
- Mild** problem which does not affect others
- Serious** problem which affects others on a regular basis

15. Does he/she insist on other items being put out, kept or stored in the same way?

For example, does he/she like ornaments, toys or cassette tapes kept in the same places or positions?

- No**
- Mild** problem which does not affect others
- Serious** problem which affects others on a regular basis

16. Does he/she play the same music, game or video, or read the same book repeatedly?

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

17. Does he/she insist on using the same objects or items in any other situation?

For example, does he/she insist on using the same chair, plate, bed linen or door? (DO NOT count any insistence on using the same mug or cup)

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

18. Does he/she insist on wearing the same clothes or refuses to wear new clothes?

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

19. Does he/she insist that certain items of clothing must always be worn or worn in the same situation or in the same way?

For example, does he/she insist on always wearing a vest, or wearing a hat to the shops, or always buttoning a shirt to the collar?

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

20. Does he/she insist on eating the same foods, or a very small range of foods, at every meal?

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

21. Does he/she insist on moving or travelling by the same route?

For example, does he/she insist on taking the same route when moving about the house, going for a walk, or travelling in the car?

- Never** or rarely
- Regular** feature of behaviour, but will tolerate alternatives when necessary
- Highly regular** and **highly rigid** feature of behaviour. Will not tolerate any alternatives

22. How does he/she react if any changes are made to his/her surroundings at home?

For example, if you move the furniture, or rearrange the way that certain items are stored or organised?

- May comment on, or notice the change but shows no negative reaction
- Accepts the change, but shows some degree of anxiety or mildly negative reaction
- Will accept the change, but shows extreme anxiety or strong negative reaction (e.g. tantrum)
- Will **not** accept the change. Persistently attempts to rearrange the items

23. Are there any aspects of routine that he/she insists must remain the same?

For example, does he/she insist on always bathing before breakfast, ongoing to the shops every afternoon, or on watching a video after every meal?

- No**
- Mild** problem which does not affect others
- Serious** problem which affects others on a regular basis

24. Does he/she make rituals out of everyday activities such as eating, dressing, getting in the car, walking upstairs etc.?

- No**
- Mild** problem which does not affect others
- Serious** problem which affects others on a regular basis

25. Does he or have any rituals that are linked to particular occasions or places?

For example, does he/she have specific rituals for the supermarket, the Doctor's surgery or a relative's house?

- No**
- Mild** problem which does not affect others
- Serious** problem which affects others on a regular basis

26. How does he/she react his/her daily routine is changed?

- May comment on, or notice the change but shows no negative reaction
- Accepts the change, but shows some degree of anxiety or mildly negative reaction
- Will accept the change, but shows extreme anxiety or strong negative reaction (e.g. tantrum)
- Will **not** accept any change to routine

27. Does he/she 'echo' or repeat what other people say?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

28. Does he/she say the same things, or make the same noises, repeatedly?

For example, does he/she say the same word repeatedly or other sounds such as hums or growls or clicking noises? Or does he/she use the same 'stock phrases' frequently?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)


29. Does he/she talk about the same topic over and over again?

- Never** or rarely
- One** or more bouts of this behaviour daily
- 15** or more bouts of this behaviour daily (or at least one bout an hour)
- 30** or more bouts of this behaviour daily (or at least two bouts an hour)

30. In summary would you say that he/she has:

- A varied pattern of interests which he/she will pursue spontaneously and without prompting
- One or more obsessional interests, but also other usual interests which he/she will pursue spontaneously and without prompting
- Only obsessional interests which he/she will pursue spontaneously
- Has no particular interests or hobbies that he/she will pursue spontaneously

Social Responsiveness Scale, Second Edition (SRS-2)



John N. Constantino, MD

Assessment ID _____

SRS-2 AutoScore™ Form

School-Age

MALE

FEMALE

INSTRUCTIONS

For each question, please darken the circle that best describes this child's behavior over the past 6 months.

Child's name _____ Child's age in years _____

Rater's name _____ Date of rating _____

Relationship to rated individual Mother Father Other custodial adult Teacher Other specialist

Grade _____ School or clinic _____

PLEASE PRESS HARD WHEN MARKING YOUR RESPONSES.

1 = NOT TRUE

2 = SOMETIMES TRUE

3 = OFTEN TRUE

4 = ALMOST ALWAYS TRUE

1. Seems much more fidgety in social situations than when alone.	(1 2 3 4)
2. Expressions on his or her face don't match what he or she is saying.	(1 2 3 4)
3. Seems self-confident when interacting with others.	(1 2 3 4)
4. When under stress, he or she shows rigid or inflexible patterns of behavior that seem odd.	(1 2 3 4)
5. Doesn't recognize when others are trying to take advantage of him or her.	(1 2 3 4)
6. Would rather be alone than with others.	(1 2 3 4)
7. Is aware of what others are thinking or feeling.	(1 2 3 4)
8. Behaves in ways that seem strange or bizarre.	(1 2 3 4)
9. Clings to adults, seems too dependent on them.	(1 2 3 4)
10. Takes things too literally and doesn't get the real meaning of a conversation.	(1 2 3 4)
11. Has good self-confidence.	(1 2 3 4)
12. Is able to communicate his or her feelings to others.	(1 2 3 4)
13. Is awkward in turn-taking interactions with peers (for example, doesn't seem to understand the give-and-take of conversations).	(1 2 3 4)
14. Is not well coordinated.	(1 2 3 4)
15. Is able to understand the meaning of other people's tone of voice and facial expressions.	(1 2 3 4)
16. Avoids eye contact or has unusual eye contact.	(1 2 3 4)
17. Recognizes when something is unfair.	(1 2 3 4)
18. Has difficulty making friends, even when trying his or her best.	(1 2 3 4)
19. Gets frustrated trying to get ideas across in conversations.	(1 2 3 4)
20. Shows unusual sensory interests (for example, mouthing or spinning objects) or strange ways of playing with toys.	(1 2 3 4)
21. Is able to imitate others' actions.	(1 2 3 4)
22. Plays appropriately with children his or her age.	(1 2 3 4)
23. Does not join group activities unless told to do so.	(1 2 3 4)
24. Has more difficulty than other children with changes in his or her routine.	(1 2 3 4)
25. Doesn't seem to mind being out of step with or "not on the same wavelength" as others.	(1 2 3 4)
26. Offers comfort to others when they are sad.	(1 2 3 4)
27. Avoids starting social interactions with peers or adults.	(1 2 3 4)
28. Thinks or talks about the same thing over and over.	(1 2 3 4)
29. Is regarded by other children as odd or weird.	(1 2 3 4)
30. Becomes upset in a situation with lots of things going on.	(1 2 3 4)
31. Can't get his or her mind off something once he or she starts thinking about it.	(1 2 3 4)
32. Has good personal hygiene.	(1 2 3 4)

Continue on back page

Additional copies of this form (9-6084) may be purchased from WPS. Please contact us at 800.648.8897 or www.wpspublish.com.

Copyright © 2002 by Western Psychological Services. Not to be reproduced, adapted, and/or formatted in whole or in part without joint written permission of WPS (www.wpspublish.com). All rights reserved. Printed in USA. 23456789

PLEASE PRESS HARD WHEN MARKING YOUR RESPONSES.

1 = NOT TRUE 2 = SOMETIMES TRUE 3 = OFTEN TRUE 4 = ALMOST ALWAYS TRUE

33. Is socially awkward, even when he or she is trying to be polite. 1 2 3 4
34. Avoids people who want to be emotionally close to him or her. 1 2 3 4
35. Has trouble keeping up with the flow of a normal conversation. 1 2 3 4
36. Has difficulty relating to adults. 1 2 3 4
37. Has difficulty relating to peers. 1 2 3 4
38. Responds appropriately to mood changes in others (for example, when a friend's or playmate's mood changes from happy to sad). 1 2 3 4
39. Has an unusually narrow range of interests. 1 2 3 4
40. Is imaginative, good at pretending (without losing touch with reality). 1 2 3 4
41. Wanders aimlessly from one activity to another. 1 2 3 4
42. Seems overly sensitive to sounds, textures, or smells. 1 2 3 4
43. Separates easily from caregivers. 1 2 3 4
44. Doesn't understand how events relate to one another (cause and effect) the way other children his or her age do. 1 2 3 4
45. Focuses his or her attention to where others are looking or listening. 1 2 3 4
46. Has overly serious facial expressions. 1 2 3 4
47. Is too silly or laughs inappropriately. 1 2 3 4
48. Has a sense of humor, understands jokes. 1 2 3 4
49. Does extremely well at a few tasks, but does not do as well at most other tasks. 1 2 3 4
50. Has repetitive, odd behaviors such as hand flapping or rocking. 1 2 3 4
51. Has difficulty answering questions directly and ends up talking around the subject. 1 2 3 4
52. Knows when he or she is talking too loud or making too much noise. 1 2 3 4
53. Talks to people with an unusual tone of voice (for example, talks like a robot or like he or she is giving a lecture). 1 2 3 4
54. Seems to react to people as if they are objects. 1 2 3 4
55. Knows when he or she is too close to someone or is invading someone's space. 1 2 3 4
56. Walks in between two people who are talking. 1 2 3 4
57. Gets teased a lot. 1 2 3 4
58. Concentrates too much on parts of things rather than seeing the whole picture. For example, if asked to describe what happened in a story, he or she may talk only about the kind of clothes the characters were wearing. 1 2 3 4
59. Is overly suspicious. 1 2 3 4
60. Is emotionally distant, doesn't show his or her feelings. 1 2 3 4
61. Is inflexible, has a hard time changing his or her mind. 1 2 3 4
62. Gives unusual or illogical reasons for doing things. 1 2 3 4
63. Touches others in an unusual way (for example, he or she may touch someone just to make contact and then walk away without saying anything). 1 2 3 4
64. Is too tense in social settings. 1 2 3 4
65. Stares or gazes off into space. 1 2 3 4

Behaviour Rating Inventory of Executive Function (BRIEF)

Child's Name _____ Gender _____ Grade _____ Age _____ Birth Date ____/____/____

Your Name _____ Relationship to Child _____ Today's Date ____/____/____

N = Never S = Sometimes O = Often

1. Overreacts to small problems	N	S	O
2. When given three things to do, remembers only the first or last	N	S	O
3. Is not a self-starter	N	S	O
4. Leaves playroom a mess	N	S	O
5. Resists or has trouble accepting a different way to solve a problem with schoolwork, friends, chores, etc.	N	S	O
6. Becomes upset with new situations	N	S	O
7. Has explosive, angry outbursts	N	S	O
8. Tries the same approach to a problem over and over even when it does not work	N	S	O
9. Has a short attention span	N	S	O
10. Needs to be told to begin a task even when willing	N	S	O
11. Does not bring home homework, assignment sheets, materials, etc.	N	S	O
12. Acts upset by a change in plans	N	S	O
13. Is disturbed by change of teacher or class	N	S	O
14. Does not check work for mistakes	N	S	O
15. Has good ideas but cannot get them on paper	N	S	O
16. Has trouble coming up with ideas for what to do in play or free time	N	S	O
17. Has trouble concentrating on chores, schoolwork, etc.	N	S	O
18. Does not connect doing tonight's homework with grades	N	S	O
19. Is easily distracted by noises, activity, sights, etc.	N	S	O
20. Becomes tearful easily	N	S	O
21. Makes careless errors	N	S	O
22. Forgets to hand in homework, even when completed	N	S	O
23. Resists change of routine, foods, places, etc.	N	S	O
24. Has trouble with chores or tasks that have more than one step	N	S	O
25. Has outbursts for little reason	N	S	O
26. Mood changes frequently	N	S	O
27. Needs help from an adult to stay on task	N	S	O
28. Gets caught up in details and misses the big picture	N	S	O
29. Keeps room messy	N	S	O
30. Has trouble getting used to new situations (classes, groups, friends)	N	S	O
31. Has poor handwriting	N	S	O
32. Forgets what he/she was doing	N	S	O
33. When sent to get something, forgets what he/she is supposed to get	N	S	O
34. Is unaware of how his/her behavior affects or bothers others	N	S	O
35. Has good ideas but does not get job done (lacks follow-through)	N	S	O
36. Becomes overwhelmed by large assignments	N	S	O
37. Has trouble finishing tasks (chores, homework)	N	S	O
38. Acts wilder or sillier than others in groups (birthday parties, recess)	N	S	O
39. Thinks too much about the same topic	N	S	O
40. Underestimates time needed to finish tasks	N	S	O
41. Interrupts others	N	S	O
42. Does not notice when his/her behavior causes negative reactions	N	S	O
43. Gets out of seat at the wrong times	N	S	O
44. Gets out of control more than friends	N	S	O

N = Never S = Sometimes O = Often

45. Reacts more strongly to situations than other children	N	S	O
46. Starts assignments or chores at the last minute	N	S	O
47. Has trouble getting started on homework or chores	N	S	O
48. Has trouble organizing activities with friends	N	S	O
49. Blurts things out	N	S	O
50. Mood is easily influenced by the situation	N	S	O
51. Does not plan ahead for school assignments	N	S	O
52. Has poor understanding of own strengths and weaknesses	N	S	O
53. Written work is poorly organized	N	S	O
54. Acts too wild or "out of control"	N	S	O
55. Has trouble putting the brakes on his/her actions	N	S	O
56. Gets in trouble if not supervised by an adult	N	S	O
57. Has trouble remembering things, even for a few minutes	N	S	O
58. Has trouble carrying out the actions needed to reach goals (saving money for special item, studying to get a good grade)	N	S	O
59. Becomes too silly	N	S	O
60. Work is sloppy	N	S	O
61. Does not take initiative	N	S	O
62. Angry or tearful outbursts are intense but end suddenly	N	S	O
63. Does not realize that certain actions bother others	N	S	O
64. Small events trigger big reactions	N	S	O
65. Talks at the wrong time	N	S	O
66. Complains there is nothing to do	N	S	O
67. Cannot find things in room or school desk	N	S	O
68. Leaves a trail of belongings wherever he/she goes	N	S	O
69. Leaves messes that others have to clean up	N	S	O
70. Becomes upset too easily	N	S	O
71. Lies around the house a lot ("couch potato")	N	S	O
72. Has a messy closet	N	S	O
73. Has trouble waiting for turn	N	S	O
74. Loses lunch box, lunch money, permission slips, homework, etc.	N	S	O
75. Cannot find clothes, glasses, shoes, toys, books, pencils, etc.	N	S	O
76. Tests poorly even when knows correct answers	N	S	O
77. Does not finish long-term projects	N	S	O
78. Has to be closely supervised	N	S	O
79. Does not think before doing	N	S	O
80. Has trouble moving from one activity to another	N	S	O
81. Is fidgety	N	S	O
82. Is impulsive	N	S	O
83. Cannot stay on the same topic when talking	N	S	O
84. Gets stuck on one topic or activity	N	S	O
85. Says the same things over and over	N	S	O
86. Has trouble getting through morning routine in getting ready for school	N	S	O