Computerized Assessment of the Development of Inhibition and Attention in Typically Developed Children

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Abstract

The development of executive functioning (EF) in children is considered critical for cognitive and educational attainment. Despite this, the trajectory of development across executive skills is poorly understood in typically developing school-aged children. An investigation of the surrounding literature revealed that there are numerous contradictions regarding the ages at which executive skill maturation occurs, and the individual factors which influence development. A significant factor in this confusion resulted from inconsistent methodologies and the past use of inexact physical tests. This study aimed to clarify our understanding of the developmental trajectories of EF skills. Participants (N = 25) aged between 7 and 12 completed a series of computerised tests which assessed EF skills by recording the accuracy and reaction time with which they responded to predefined stimuli. Social demographics and behavioural questionnaires were also completed. The results indicated that EF development did occur across the age groups assessed, manifesting as discrete improvements to reaction time on attentional measures. Technology use was found to effect reaction time within a real-life scenario. Thus, the previous inconsistent findings could be attributed to the utilisation of non-computerised assessments which were unable to assess the improvements to speed which evidence this stage of EF development.

Declaration

This thesis contains no material which has been accepted for the award of any other degree of diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time.

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CHAPTER 1: INTRODUCTION

1.1 Executive Functioning and Childhood Education

The successful application of executive functioning (EF) skills is critical within most higher-order activities required of an individual during education. Essentially underpinning all forms of cognitive performance (Diamond, 2006), the core EF domains are collectively responsible for allowing children to organise information in new ways (Raver & Blair, 2016). EF skills grant children with increasing degrees of cognitive and behavioural control, providing the ability to assess and solve complex problems both academically and socially (Zelazo, Carlson & Kesek, 2008). EF has also been demonstrated repeatedly to predict academic performance during childhood, even when controlling for individual differences, general cognitive abilities and social-emotional competence (Blair & Razza, 2015; Friedman-Krauss & Raver, 2015). Given this link, gaining an understanding of such skills within school aged children is now more important than ever. Especially so when considering that formal educational services, which are commonly guided by intensively developed standard curricula (Bassok, Latham & Rorem, 2014), are being aimed at progressively younger age groups (Raver & Blair, 2016). These early learning opportunities involve effortful work on academic content which aims to develop universal proficiencies in mathematics and reading skills before the commencement of the first year of schooling (Raver & Blair, 2016). Reaching such goals requires the successful development and application of the numerous higher-order cognitive abilities and strategies which make up EF (Raver & Blair, 2016). However, an investigation into the surrounding literature suggests that our knowledge regarding the development of these skills may not be as concrete as assumed.

1.2 Defining Executive Function

EF is an umbrella term for cognitive abilities which are used within situations that without conscious, attentive, and effortful processing, one's chosen goals could not be attained (Anderson, 1998). Such situations include: when an individual is required to perform a novel task, when one is asked to make a conscious choice, or in any situation whereby an individual is required to concentrate, plan, problem solve or coordinate an action or response. The core processes most commonly included in recent definitions of EF are:

1. Inhibition, which is most commonly defined as the ability to ignore stimuli and inhibit responses which are irrelevant or unhelpful to the task at hand.
2. Attention, which encompasses a number of functions, but is operationalised as the ability to flexibly shift and switch attention across stimuli.
3. Working memory, the ability to temporarily store, recall and process information in one's mind (Diamond, 2006).

Inhibition in particular has received a large amount of academic interest due to the central role which it is stated to play in child development. Inhibition primarily underpins the performance of memory encoding, recognition and retrieval and determines how these processes collaborate in the successful performance of a task. Depending on the context within which inhibition is being studied, this function may be referred to as behavioural inhibition, cognitive inhibition or response inhibition. However, these terms tend to refer to the same function. The parent term of inhibition is more widely used when discussing this function as they are suitable descriptors in any context. EF processes provide an individual with the ability to execute the optimal strategy for performing a task. This ability could not be successfully implemented without the ability to inhibit inappropriate strategies following task errors or changes to task demands (Logan, 1985). Failures in inhibitory control within children in educational contexts are most commonly experienced as impulsive behaviours, such as premature responses to a task, responses made prior to the availability of all sufficient information, failing to address inappropriate or incorrect answers, and allowing one's attention to be held by irrelevant, distracting stimuli (Schachar & Logan, 1999). Whilst such failures are commonplace in children during early school years, indicative of immature inhibitive abilities, significant deficits to inhibitory control, indicated by severe, persistent failures to inhibit responses, may underlie numerous developmental and learning disorders such as ADHD (Theissen et al., 2014; Tibu et al., 2016; Tarle, Alderson, Patros, Arrington & Roberts, 2018). Such disorders which may significantly affect one's ability to participate constructively within educational environments (Weyandt, 2005).

Attention, simply stated, is the ability to direct attention only to stimuli which are relevant to a current task or goal (Corbetta & Shulman, 2002). It is responsible for numerous every-day higher order functions, such as those known as concentration and multitasking (Matlin, 2013). Correct performance on attentional tasks will often going unnoticed, as the filtering of irrelevant stimuli occurs automatically, while relevant stimuli brought into focus by effective attentional systems fills our experience of the world around us (Lavie, Hirst, Fockert & Viding, 2004). Attention is perhaps the better-known domain of EF, as despite the multitude of components which are suggested to comprise it, and the even broader range of operationalisations, it is the EF skill which constitutes a large degree of our effortful conscious processing (Anderson, 2004), and it is also the skill which produces the most noticeable failures. Atypical attentional development has been consistently linked to a number of disorders such as ADHD (Sonuga-Barkem Koerting, Smith, McCann & Thompson, 2011), autism spectrum disorder (ASD) (Elsabbagh et al., 2009) and anxiety (Rothbart, Ellis, Rueda & Posner, 2003). Thus, given the clear importance of understanding attention in such populations, studies which have investigated attention have primarily done so through an atypical lens (Best et al., 2009). Attention is commonly described and measured by the three constituent abilities: singular, divided and switching attention, which are defined in regards to the demand placed on one's attentional ability by a given task (Sohlberg & Maher, 1989). Singular attention is performed in situations where one must perform specific and consistent task of attention in the face of distracting stimuli which compete for attentional resources. Divided attention occurs when one's attention simultaneously performs multiple attentional tasks. Switching attention refers to one's ability to adapt between singular and divided demands on attention (Sohlberg & Maher, 1989). These attentional processes are primarily responsible for allowing individuals to quickly adapt to a variety of changes in one's environment without losing focus on one's current goal, or to switch one's goal under the new circumstances, applying the most appropriate action for the situation (Monsell, 2003).

Working memory (WM), is perhaps the simplest of the core domains of EF, presupposing attention and inhibition as the skill which is required to function typically before either of the other skills can be performed (Davidson, Amso, Anderson & Diamond, 2006; Zanto & Gazzaley, 2009). WM is responsible for temporarily storing information, primarily consisting of the stimuli presented by our lived experience within the world around us, so that it can be used within all functions of cognitive processing (Miyake & Shah, 1999). WM has been demonstrated to possess a significant link to academic achievement, with one study stating that WM ability served as a greater predictor of academic ability than IQ in children aged five (Alloway & Alloway, 2010). Previous research has also demonstrated WM's ability to indicate an individual's ability to control their attention, with participants in Wood, Vine & Wilson's (2016) study performing much more poorly on attentional tasks if they had also scored poorly on measures of WM capacity. It has also, much like the other components of EF, been shown to play a significant role in learning disorders, such as dyslexia (Wagner & Muse, 2006) and ADHD (Alloway, 2006). However, in contrast to attention and inhibition, WM's role as a core cognitive function outside of EF research has provided it with a more reliable literature base regardless of the target population (Best et al., 2009), and more is known about the WM abilities of typically developed individuals than can be said for the other EF skills. Working memory is known to have a limited capacity, with typically developed children being able to remember and recall between 4 to 8 "chunks" of information (Cowan, 2001). This knowledge makes WM a suitable indicator of the typical development of EF, because one's assessed ability to recall information using tests such as the Corsi Block-Tapping Task (CBTT) (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000) can be compared to normative values and because WM presupposes the other EF components. Thus, a non-normative WM score logically indicates atypical development (Wood et al., 2015).

Although the list of the core EF domains has been subject to a large degree of change over the last few decades and is still subject to some debate, as each skill is compressed of numerous sub-skills, the skills and definitions of said skills provided above are generally the most agreed upon (Diamond, 2006). Possessing the ability to control one's attentional direction, to ignore distracting stimuli and to also inhibit behavioural responses provides us with control over our actions. Without inhibition and attentional control, we would be influenced greatly by external stimuli, our emotions and our learned behavioural tendencies (Diamond, 2006). The ability to store information in one's mind provided by a functioning working memory enables us to make decisions which are influenced by given instructions and the possible alternatives, all the while being able to decide in relation to past instances (Diamond, 2006).

However, despite the apparent soundness of these concepts and their applications, there exist criticisms of the measures applied in the research upon which they are based. A predominant suggestion is that theoretical and methodological issues have contributed to a large majority of research into EF failing to provide an accurate picture of the developmental progression and staging of these skills.

1.3 Assessment of Executive Functions Across Childhood

There exists a variety of measures used to evaluate EF performance in children. A review of the findings obtained through the use of these measures can identify gaps in our knowledge, as well as key aspects of EF development that can inform the targeted educational curriculum which draws from such findings. Best, Miller & Jones' 2009 review notes that the most commonly employed measure of EF is the Wisconsin Card Sorting Test (WCST), commonly applied within the literature mentioned as a physically administered task; one which used tangible items and relies on the researcher to manually note results. The WCST assesses a variety of higher-level cognitive functions such as attention, perseverance, working memory and abstract thinking (Eling, Derckx & Maes, 2008). It was suggested that the WCST's inherent complexity and the requirement of the performance of a variety of cognitive processes, rather than one specific process, has resulted in a significant degree of task impurity. While this measure is highly sensitive in assessing the strategies employed by participants to complete the task, it performs poorly at identifying the factual knowledge which was retrieved to complete the task (Best et al., 2009). Subsequently, it is difficult to determine which of the higher-level processes measured by the WCST were employed, the degree to which they functioned during the task, and thus the degree to which deficits in these skills affected performance (Best et al., 2009). Whilst the WCST has since fallen largely out of use, having instead being replaced by measures which possess greater validity and suitability for children, the issues surrounding the prior use of this task in providing understandings within this field still persist. Other tasks which attracted similar criticisms include the similarly administered Tower of Hanoi (TOH)

(Baker, Segalowitz, & Ferlisi, 2001) and the stop-signal task, which was determined not to be a significant predictor of variance in attention, despite this task often being cited as being the premier metric of behavioural inhibition. The issues regarding the stop-signal task were stated as being caused by a bottleneck in working memory resources, especially in atypically developed children, and thus the stop-signal task may in fact be an impure estimate of inhibition when compared to the Go/No-Go task (GNG). An ideal metric should not be affected by other forms of EF (Tarle et al., 2019). Much of these measurement issues are further related to the ages of the participants most commonly included in developmental EF literature. Whilst developing an understanding of these skills during the formative schooling years is of great importance, a significant proportion of developmental research has only investigated narrow age ranges within populations of pre-schoolers and young primary schoolers (Best & Miller, 2010). Investigations of EF development during late childhood and early adolescence remains vastly understudied (Reuter et al., 2019). The lack of studies which investigated the population of older children, coupled with the limitations of the primary tools used to assess EF in this age, has resulted in an incomplete and inaccurate account of EF development. Furthermore, a significant amount of research into EF focused on atypical populations, such as those with ADHD or ASD (Hughes & Graham, 2002). Whilst there is a great deal of worth in understanding EF in young children and those with psychopathological disorders rooted in executive dysfunction, the lack of focus on a broader age range, involving typically developed individuals and using sound methodologies has resulted in three main issues, which are, as of yet, largely unaddressed.

First, the focus on atypical development and clinical conditions during early childhood makes it difficult to determine the EF abilities that are expected at each stage of typical child development. The expected scores for each domain and the developmental trajectories of each domain remain largely unknown, as do the interactions between developmental patterns during late childhood. Whilst the implications of poorly understanding how several higher-order cognitive processes develop are considerable on their own; without the normative mean scores which would be provided through a broader research focus, we cannot determine what would indeed fall within 'normal' ranges. Gaining such knowledge is crucial in the design of educational programs that foster EF development for child at specific stages of typical cognitive development. This is of specific importance when one considers that many such programs, with the understanding that the performance of higher-order cognitive skills is intrinsically linked to academic ability, specifically attempt to account for individual ability by applying developmental understandings of EF regarding the level of skill which would be expected within a targeted age group (Raver & Blair, 2016; Abel, Jones & Raver, 2006).

Second, previously applied methodologies such as the WCST, the TOH and the stop-signal task, whilst suitable for use in this population at a practical level, are inherently unable to measure discrete changes to higher-order task performance (Tarle et al., 2019), as well as possessing limited validity for specific EF domains (Best et al., 2009). Furthermore, the majority of past research has only implemented tasks that incorporate lower-order functions, and have done so using largely clinical and structured methodologies. Consequently, such findings may not be generalizable to real-life contexts amongst typically developing children, nor identify executive dysfunction in such contexts (Anderson, Anderson, Northam, Jacobs & Catroppa, 2001).

Third, there is limited understanding of the factors which exert influence upon the development of EF development. This issue is predominantly the result of the two aforementioned problems regarding the previous research into this area. Without mean normative score ranges obtained using valid methodologies, we cannot determine the effect which any external factors had on an individual's development. Lacking data which would indicate the typical ranges of what we could expect to see leaves us unable to posturise and investigate the causes of an above or below average score. Subsequently, it is difficult to identify any of the possible causes of executive dysfunction in typically developed individuals, or the ideal circumstances in which one can foster EF development. It is likely we will also be limited in our ability to assist in EF development with the addition of protective factors if an otherwise typically developing individual is below average.

The limitations of previous research, as a whole, are significant with regards to allowing one to form a complete understanding of the typical development of EF skills. The most pressing of these effects regards our knowledge of the developmental trajectories of EF, especially that which could be formed from previous literature which has investigated EF in childhood and adolescence, certainly that produced in the 1990s and early 2000s. Perhaps the most influential account is that by Welsh, Pennington and Groisser (1991). Using the WCST, TOH and Matching Familiar Figures Test, both of which are physically administered, the authors investigated normative developmental performance. Comparing results between a child and an adult sample, the results suggested that adult level performance was achieved on some tasks at ages as young as 6 years old, with adult-level performance occurring on all tasks by age 12 (Welsh et al., 1991). The overarching suggestion was that such results indicate that most EF skills mature early in childhood and are able to be performed consistently throughout adolescence. Although not the first to produce such results, with Passler, Hynd & Issac (1985) and Schachar & Logan (1990) both finding that EF had matured fully by age 12, the work of Welsh et al. has proved phenomenally influential, still being used as reference in modern literature. Subsequently, these understandings, and the wider concept of EF skill maturation, provided the backbone of most EF research for the next decade. Although often with slight differences in results regarding the specific age of maturation of each EF domain and the exact domain which was named in measurement, numerous other studies influenced by that of Welsh et al. have since produced similar results by applying similar measures (Anderson et al., 2001, Klenberg, Korkman & Lahti-Nuutilla, 2001; Anderson, 2002; Luca et al., 2003; Brocki & Bohlin, 2004; Jonkman, 2006; Betts et al., 2006).

However, there are just as many contradictory accounts regarding the developmental sequencing of EF. A theory which has begun to gain traction in more recent years, following the widespread uptake in measures which are more appropriate for use within this population, instead suggests that EF development is far from complete in early childhood (Cartwright, 2012). Rather, behavioural evidence collected using computerised forms of EF tasks indicates instead that inhibition and attentional skills first undergo a rapid developmental spurt during early childhood (Grammer, Gehring & Morrison, 2018; Carlson, 2003; Best & Miller, 2010; Hughes, Ensor, Wilson & Graham, 2010). Following this spurt, a brief plateau is alleged to occurs between the ages of 8 and 11, wherein only minor task improvements are recorded, which precedes robust improvements to task performance on all domains throughout adolescence (Grammer et al., 2018; Cartwright, 2012; Best & Miller, 2010; Best et al., 2009; Crone, 2009; Blakemore & Choudhury, 2006; McKay, Schwarz & Sharma, 1994; Kelly, Borill & Maddell, 1996; Anderson, 1998; Anderson et al., 2001; Carrion et al., 2003; Blakemore & Choudhury, 2006; Davidson et al., 2006; Reuter et al., 2019).

The reasons for such vast changes in what is perceived to occur may indeed lie in the greater proliferation of computerised measures which followed the greater call to attention regarding the problematic nature of physically administered and largely unsuitable measures such as the WCST. Whilst the greater uptake of alternate tasks to measure EF initially occurred primarily to provide valid measurements, the more widespread availability of computers and thus computerized measures meant that EF research was no longer limited to assessing skill purely based on researcher-recorded task accuracy. Instead, computerised tasks facilitated the introduction of reaction time (RT) as a consideration in EF measurement, providing greater precision in measurement (Betts et al., 2006). Thus, it could be inferred that the main reason for the shift in understandings, specifically the significant uptake of opinion positing that a brief skill plateau rather than a concrete skill maturation occurs during the childhood development of EF, is largely due to modern methodologies having gained the ability to measure task performance more precisely. Much of the reported development after the initial spurt during early childhood is stated to occur as minute improvements only measurable using computerised versions of tasks such as the GNG (Best & Miller, 2010; Best et al., 2009). The greater opportunities for research into discrete changes to EF provided by computerized measurement have also allowed for some to investigate the interrelated nature of EF domains. Whilst some previous studies have asserted that development across the three core skills is likely to occur in parallel, subject to the development of the brain (Brydges, Fox, Reid & Anderson 2012; Willoughby, Blair, Worth & Greenberg, 2012) other studies have found that EF instead follows complicated, non-linear age patterns (Richardson et al., 2018; Crone, 2009). Specifically, WM is argued to develop ahead of attention and inhibition, with WM and inhibition both being required to have reached a certain developmental level before attentional switching can be utilized (Best & Miller, 2010), an argument which again has vast implications regarding past research which stated that some degree of skill maturation occurs. However, when assessing children's ability using novel computerized measures, additional considerations must now also be made regarding the earlier ages of exposure to information technologies, as most such studies employ the use of computerised tests and may indeed provide less of a challenge to those already familiarized with interacting with computers and some degree of performance may be related to computer-specific abilities (Best & Miller, 2010). Few studies have investigated the degree to which familiarity with ICT may affect scores on computerized measures, however one such report did find that inhibitory performance was reduced in individuals with internet addictions when presented with internet-related stimuli, suggesting that the application of a real-life context may affect performance on those familiar with the context provided (Nie, Zheng, Chen & Li, 2016).

Subsequently, the developmental overview provided by the past literature is unclear as to exactly what occurs to each skill, and at what age, in typically developing populations. Vastly different assertions on the developmental progression of EF can be found depending on the research assessed. This issue is compounded by the degree to which more modern research was influenced either by literature which implemented limited methodologies, or because studies attempted to enlighten developmental understandings of EF by relying on investigations of atypical populations such as ADHD or autism spectrum disorder (Best et al., 2009). Furthermore, specific to the individual factors which could have an influential effect on EF development, there is a suggestion that stress and anxiety (Raver & Blair, 2016) and issues with impulsivity and emotional and behavioural regulation (Crone, 2009) may affect the development of EF. However, the directionality of these effects is unknown and little research which has specifically investigated the effects of individual factors in typically developed children has been conducted.

To summarise, development in executive function may not be complete, or matured to adult levels, at the end of childhood as older research has suggested. EF development instead is argued to manifest as a gradual maturation over late childhood and adolescence, with task improvements primarily evident in speed, rather than accuracy, on measures of inhibition and attention. It is also unclear whether the addition of a real-life context may affect inhibitory performance, or whether an increased engagement with ICTs may have had a role in the difference between the results reported from the use of computerized measures when compared to that of physically administered measures.

Thus, if more modern research is correct, we would expect as reported to see consistent accuracy scores, but increases to speed on the measures applied, if this is the case. However, the effect of an individual's WM ability, behavioural regulation abilities and ICT exposure on EF scores obtained using computerized measures must also be investigated.

1.4 Aims

Given the mixed results of previous research, the first aim of this study was to investigate the development of EF in typically developed children by using computerized measures. In doing so, our limited and often contradictory understanding of both the developmental progression of each core domain of EF and of the ideal measures by which to measure them with can be enlightened, and the performance metrics which would be expected of individuals this age can be better understood. Such understandings are relevant to the educational context within which they often find themselves placed.

The second aim of this study is to investigate the external factors which may influence results on EF measures, specifically regarding exposure to ICT, WM ability and one's behavioural regulatory abilities. Gaining a greater understanding of the influence of these potential factors may allow us to make inferences regarding how EF develop can be fostered and will, at the very least, provide for the early identification of the precipitating factors of poor EF development in otherwise typically developed children.

CHAPTER 2: METHOD

2.1 Participants

Children aged between 7 and 12 years old were invited to take part in this study. Participants were ineligible for inclusion within this study if they had received a current diagnosis of any psychiatric, neurological or learning disorder, as this study aims to investigate the typical development of cognitive functions. Participants who were taking any medications which may affect neurological function, such as antidepressants, antipsychotics, stimulants or sedatives, were also excluded, as such medications may affect performance on the assessed tasks (Orriols et al., 2009, Vermeeren & Coenen, 2011, Strassels, 2008). Individuals with motor impairments which may affect their ability to interact with the tasks were also excluded from participation. Prior to the experiment, written consent was obtained from the parents or guardians of all participants, and they were informed that they could rescind their consent and end participation at any time. Included participants received a $40 voucher on completion of the protocol. All activities undertaken during the course of this study were approved by the University of Adelaide School of Psychology: Human Research Ethics Subcommittee (Approval Number: 2019-46). Participants were informed that all data recorded would remain anonymous, confidential and unidentifiable though the use of participant identification numbers. All individuals involved in conducting research for this study were required to obtain a child-related employment clearance check from the Australian Government Department of Community Supervision and Intervention. All research was conducted according to the 2018 NHMRC National Statement on Ethical Conduct in Human Research (Australian Government, 2018).

2.2 Demographics

Twenty-five children completed the study, aged 9.4 (SD = 0.33) years, with the sample consisting of 40% males and 60% females. Although this sex distribution did stray from the Australian population distribution of 51% female and 49% male (ABS, 2016), it is not severe enough to be a concern given that this study did not expect to see any significant differences in test scores as an effect of reported sex (Grammar et al, 2018).

2.3 Analysis of Statistical Power

An a priori power analysis was performed using the G*Power 3 power analysis software software (Faul, Erdfelder, Lang, & Buchner, 2007). In performing a repeated-measures ANOVA with two groups and three measurements, which was the case in the analyses performed relevant to the first hypothesis, with the alpha level was set at .05, a sample size of 26 was determined to be sufficient for this study to detect a moderate effect size (f = .25) with a power of .80. The estimates included in this power analysis were obtained from studies which applied similar methodologies to that of this study and reported no issues with power (Tarle et al., 2019; Jonkman, 2006; Betts et al., 2006), as confirmed by post-hoc power analysis. Twenty-five participants were recruited in total before data collection was stopped and thus no issues with the power of this study were anticipated.

2.4 Materials

Two questionnaires were used to collect social demographic data and typical behavioural quality data respectively. These questionnaires were completed by the participant's parents.

2.4.1 The Social Demographics and Pastimes Questionnaire (SDPQ)

The Social Demographics and Pastimes Questionnaire (SDPQ) (see Appendix A) was designed solely for the purposes of this study, and recorded the parent's responses regarding their child's age, gender, hobbies. A majority of the questions in this questionnaire also enquired as to the participant's technology use, with particular regard to the frequency of usage of smartphones, computers, video game consoles and televisions, as well as the age at which they first used each technology. The SDPQ recorded categorical responses for each question.

2.4.2 The Strengths and Difficulties Questionnaire (SDQ)

The behavioural qualities questionnaire used for this study was the Strengths and Difficulties Questionnaire (SDQ). This standardized form measured five scales in total over 25 items (Goodman, Meltzer & Bailey, 1998). These scales assessed total difficulties, emotional problems, conduct problems, hyperactivity, peer problems and prosocial behaviour, however the total difficulties score was the only subscale utilized within this study, as an in-depth overview of the issues specific to each participant was not required. The SDQ was previously found to possess acceptable internal consistency, test-retest reliability, inter-rater agreement and concurrent validity (Muris, Meesters & van den Berg, 2003, Stone, Otten, Rutger, Vermulst & Jansens, 2010). Two versions of this questionnaire were used depending on the age group of the participant (see Appendices B and C). The variant provided to the younger cohort is designed for use with participants aged 4-7, and the older cohort variant is designed for use with participants aged 11-17. These forms were largely similar and measured the same construct, with changes to the wording of several questions being the only difference. For example, whereas the younger cohort variant asked if the participant "shares […] toys, treats, pencils" with other children, the older cohort variant asked if the participant "shares […] books, games, food" with other youth. Responses were given a value between 0 and 2 on the accompanying scoring sheet. The sum of responses across the questionnaire, ranging from 0 to 40 indicated the severity of the behavioural difficulties experienced by the child. The severity was classed as being either normal, borderline or abnormal, with higher scores indicating greater severity. Scores between 0 and 13 were classed as normal, scores of 14 to 16 were classed as borderline and scores above 17 were classed as abnormal.

2.4.3 The Switching Attentional Demands Task (SwAD)

The SwAD investigated different attentional demands; namely selective demands on attention, dividing attentional demands, and switching attentional demands. In this task, participants were asked to monitor a stream of visual stimuli, with two shapes and two colours presented side-by-side, responding by pressing a key on a standard computer keyboard when a predefined stimulus was presented. Participants first completed a training trial wherein 20 stimuli, a variety of shapes and colours, were presented in sequence. Participants were first required to respond by pressing the L key when a predefined shape is shown, and then they were required to attend to a shape as well as a colour, pressing the S key when a predefined colour was presented. Participants received feedback during the training trial only. Following this, participants began four single demands trials, four divided demands trials and four switching demands trials. These trials presented 26 stimuli in total, with between five and eight of these stimuli being target stimuli. These stimuli were either a shape (bell, circle, flower, heart, moon or star) or a colour (red, blue, purple, yellow, black or green) (see Figure 1). All trials were otherwise identical in presentation, only differing in the instructions given and the order within which stimuli are presented as this is randomised. Within the selective attention condition, participants must only respond to one predefined target stimuli (e.g. only one colour or only one shape). In the divided attention condition, participants were instructed to attend to two predefined stimuli, both a shape and a colour. In the switching attentional demands condition, four trials of each attentional demand were presented alternatively. The order of presentation of the three conditions was also randomised to control for potential sequence effects, although the training condition was always presented first. There was a 2-minute break between each condition. Target stimuli, in all conditions, changed randomly after each trial. Each stimulus was presented for 250ms, with interstimulus interval occurring for a randomised time period between 500ms and 2,300ms. Participants must respond within 1,800ms of stimulus presentation for a response to be recorded. During the interstimulus period, a fixation-cross was presented in the middle of the screen and participants were instructed to focus on that cross throughout the trial. The results recorded consisted of the accuracy of responses and the reaction time taken to respond to a stimulus. Accuracy data consisted of either a hit or miss on a target stimulus, an incorrect response, whereby the incorrect key was pressed to respond to a target stimulus, or a false alarm on a nontarget stimulus. Reaction time was measured in Reaction time was measured in milliseconds from stimulus onset, with lower times signifying faster performance.

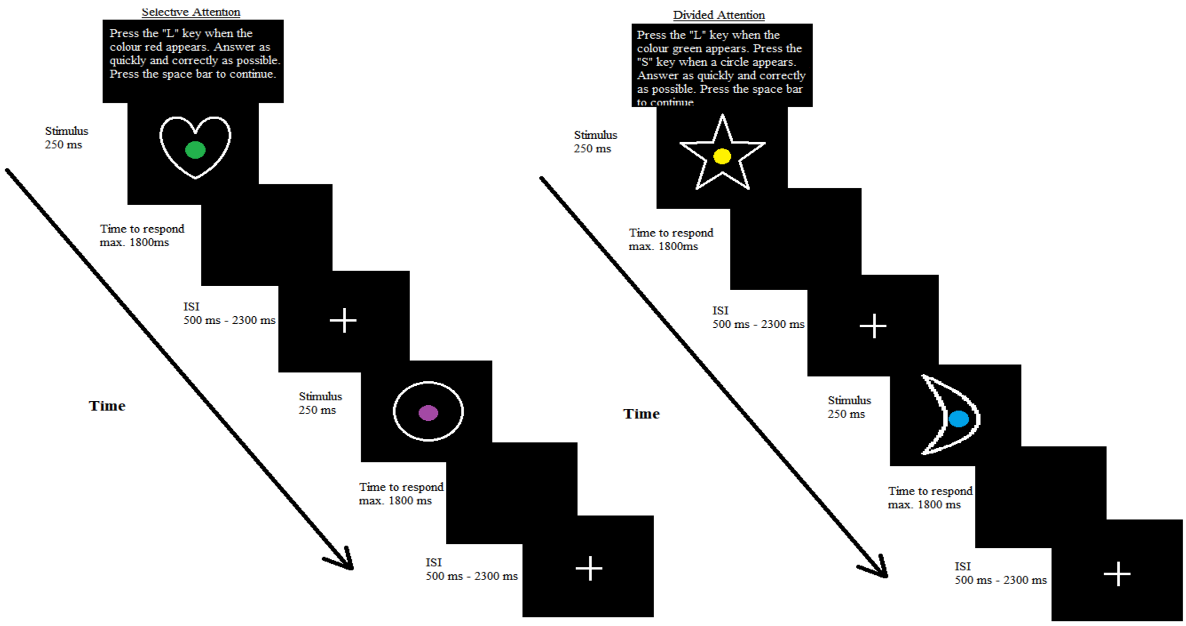

Figure 1. Schematic overview of the SwAD-task - Two trials in either selective or divided attention, depending on the instructions.

2.4.4 The Go/No-Go Task (GNG)

A computerised GNG task, designed to measure the participant's ability to inhibit a prepotent response, was implemented as a measure of inhibition within this study. This task required participants to differentiate between go and no-no stimuli, responding only to the more common go and inhibiting responses for no-go stimuli. This task utilises two paradigms. The first presented only audio stimuli and the second task combines audio stimuli with a video presentation as a distractor. The video played during the second task contained no audio and did not contain any stimuli which the participant was instructed to attend to. The video paradigm was instead designed to function as a test of inhibition in a real-life setting. Within the first paradigm, the go stimulus was a 700Hz tone and the no-go stimulus was a 600Hz tone. Within the second paradigm, the go stimulus was a 500Hz tone and the no-go was a 400Hz tone. All stimuli were presented for 200ms, and out of 120 presentations of stimuli, 90 were go stimuli and 30 were no-go stimuli. The interstimulus interval was randomised between 500ms and 1,000ms. The pitches of these tones and the pitch difference between tones were selected primarily to ensure that all participants would be easily able to hear them, as hearing ability screening was not performed on participants prior to their involvement in this study. These stimulus conditions have been stated to be optimum in the numerous studies which have utilized the similarly constructed auditory oddball tasks (Kim & McAuley, 2013, Fichtenholz et al., 2004). On detection of the go stimulus, the participant was instructed to press the space bar on a standard computer keyboard placed in front of them, and they must have done so within 2,000ms of the stimulus being presented to record a response. Their rate of "false alarm" responses to the no-go stimulus, and the accompanying reaction time between the presentation of the no-go stimulus and the response itself were used as metrics regarding inhibitory performance.

2.4.5 The Corsi Block-Tapping task (CBTT)

The CBTT is a measure of working memory, and has also been utilized as a control measure, as it is suitable for use as a general screening tool for typical development (Kessels et al., 2000). Participants used a 10.1” touch-screen android tablet to repeat a pattern shown to them at the start of each trial. This pattern was demonstrated by a pointer which briefly changed the colour of a number of onscreen “blocks”, which appeared as white squares. The length of the pattern, starting at two blocks and ending at a maximum of nine if the failure condition of mistakes on two successive trials had not occurred, increased by one on every second trial. The onscreen position of the blocks was randomized in each trial. with instructions regarding the performance of this task given on screen. Participants were shown a pattern at the start of each trial and were then required to remember and repeat that pattern by tapping the blocks which were highlighted during the demonstration of the pattern. The total number of trials completed has been used to assess working memory (Orsini et al., 2006). A demonstration video was administered prior to task completion; however, no training trial was utilised.

2.5 Procedure

Participants, accompanied by their parents or guardians, attended the Adelaide Brain and Cognitive Development laboratory at the University of Adelaide to complete the study. After obtaining written, informed third-party consent and ensuring both parent and child were suitably informed about the project by the participant information sheet (see Appendix D), the parents completed the SDPQ and SDQ forms.

The SDPQ asks of the participants gender, age and current grade in school before posing a series of questions designed to better understand their hobbies and pastimes, with a particular focus on the participants average time spent engaging with information and communication technologies (ICT) such as computer games and televisions. Participants are asked to mark the most appropriate response out of a provided selection of answers, with some questions, where applicable, having an option to provide a response which was not provided. Following the SDPQ, the participant's parents/guardians completed the SDQ, a questionnaire designed to obtain an overview of the participants behavioural qualities.

While these questionnaires were being completed by the participant's parents, the participants completed the battery of computer tasks in an adjacent room which was approximately 3^2 metres. The SwAD-Task and GNG tasks were presented on an LCD computer screen with a size of 24 inches, the position of which was marked to ensure equal conditions for all participants. Commercial headphones were used for the GNG tasks, which included an auditory component. The CBTT utilized a 10.1-inch Lenovo Android tablet. For the SwAD-task, all participants completed four trials within the three conditions, which were presented in a random order. A two-minute break was given after the completion of each condition. Following the completion of the SwAD-Task, participants were provided with a five-minute break before beginning the GNG tasks. The first paradigm consisted of the audio only task, followed by the audio + video task. Participants completed the CBTT last.

Participants were asked to complete three computerized tasks in the order in which they are listed above. Participants were required to attempt all of these tasks. Failure to complete any of the provided tasks resulted in the data for that task being excluded from statistical analyses.

2.6 Study Design

This study utilized a cross-sectional design for quantitative analysis. For the purposes of analyses, given that they are relevant to developmental progression, participants were grouped within either a "younger" or "older" group. The younger group consisted of participants aged 7 to 9, and the older group consisted of participants aged 10 to 12. Data analysis was performed using Statistical Package for Social Sciences Version 23.0 (SPSS Inc., 2015). The preliminary analyses, consisting of independent t-tests, were used to determine whether any statistically significant differences across age groups existed between the measures provided to participants. To investigate Aim 1, regarding the computerized assessment of the development of EF, repeated measures ANOVAs were used to compare the accuracy and RT results of the SwAD over the two age groups assessed. Repeated measures ANCOVAs were used to assess the rate of response to no-go stimuli and the accompanying RT, whilst also including covariates, thus addressing both the first aim and the second, which investigated the external factors which may have influenced EF development. Said covariate factors were identified through the individual t-tests performed during the preliminary analyses, with independent samples Mann-Whitney tests used to assess group differences between results which were found to be significant yet had failed Levene's test. Regression analyses were performed last to examine the relative progression of EF scores over the ages assessed.

2.7 Data Cleaning

Descriptive statistics, Q-Q Plots and boxplots were generated and examined to assess data distribution, normality and to assess the existence of outliers within all variables. Although some variables deviated slightly from a normal distribution, a visual examination of the Q-Q plots indicated that all distributions approached normal. The one exception was for participants' daily hours of ICT. This factor was heavily skewed and thus a log transformation was performed before this data was used in analyses. Taking the above into account, and given the robust nature of ANOVA regarding normally distributed data (Khan & Rayner, 2003), no data exclusions or other transformations were made.

CHAPTER 3: RESULTS

3.1 Data Screening

Only one entry within the data was removed, as one participant did not respond at all during the audio + video paradigm of the GNG task. However, that participant's responses in all other tasks were without issue and were thus included in the data used for other analyses. All responses were equal to or below the upper boundary of 8 (Cowan, 2001) and above the minimum children's cut-off score of 3.9 on the CBTT (Orsini et al., 2006), which functioned as a control measure for typical development. Scores ranged between 4.0 and 8.0 (M = 5.24, SD = 1.09) indicating that all participants can be considered typically developed. Results obtained from the SDQ were also within normal ranges, with scores ranging from 0 to 16, indicating that while some individuals scored "borderline" for general behavioural issues, most were within the normal category. Thus, the scores obtained can be said to reflect what would be expected of typically developed individuals without any underlying behavioural issues.

3.2 Descriptive Statistics

As shown in Table 1, the most significant differences reported were those regarding the accuracy on the switching condition of the SwAD test, the reaction times obtained for the SwAD test and those regarding the ICT use metrics of the participants. Scores on the CBTT, and SDQ, as mentioned above, were within the expected scores for typically developed individuals and no significant differences were found between age groups. Therefore, given these results, neither working memory nor behavioural regulatory abilities were assessed as covariates of EF development. In contrast, the significant differences between groups in the hours of daily ICT use, data obtained from the SDPQ, indicated that this variable was suitable for use as a covariate to investigate the second aim. However, Levene's test indicated unequal variances for this variable ($F = 6.74$, $p = .018$) and thus an independent samples Mann-Whitney test was conducted, which indicated that average daily ICT use was indeed greater for the older participants (*Mdn* = 7, range = 2 - 6) than the younger (*Mdn* = 4, range = 4 - 14), *U* = 125, *p* = .008.

Table 1.

Characteristics of the Sample and Scores on Each Measure by Age Group

			Independent samples t-test results	
	Younger M(SD)	Older M(SD)	*t*	*p*
Age – Years	7.92 (.79)	10.77 (.73)	-9.34	< .001
Gender – n (%)				
Male	4 (40.00%)	6 (60.00%)		
Female	8 (53.33%)	7 (46.67%)		
SwAD Singular Accuracy	.88 (.16)	.94 (.10)	-1.17	.25
SwAD Divided Accuracy	.71 (.19)	.77 (.17)	-.86	.40
SwAD Switching Accuracy	.79 (.14)	.89 (.10)	-2.18	.04
SwAD Singular Reaction Time	690.12 (124.40)	503.12 (61.03)	4.83	<.001
SwAD Divided Reaction Time	951.17 (145.03)	769.60 (128.72)	3.32	.003
SwAD Switching Reaction Time	780.70 (112.35)	657.67 (101.85)	2.87	.009
GNG Sound False Alarm Proportion	.27 (.19)	.26 (.28)	.08	.94
GNG Video False Alarm Proportion	.25 (.15)	.20 (.14)	.91	.37
GNG Audio Reaction Time	911.75 (229.14)	803.28 (438.58)	.73	.48
GNG Audio + Video Reaction Time	986.65 (247.81)	942.43 (259.75)	.42	.68
SDQ Score	7.92 (3.03)	6.62 (5.70)	.72	.48
First ICT Use Age Score	1.17 (.24)	1.50 (2.78)	-3.18	.004
Daily ICT Use (Hours)	3.92 (1.24)	7.15 (3.53)	-3.10	.007
CBTT Score	4.92 (.90)	5.54 (1.20)	-1.46	.16

3.3 Aim 1: To Investigate the Development of EF in Typically Developed Children by Using Computerized Measures

3.3.1: Attention

Table 2.

Means, Standard Deviations and ANOVA Results for Accuracy and Reaction Times Across Age Groups and SwAD Conditions.

	Younger			Older			F-values (η_p^2)		
	Singular	Divided	Switching	Singular	Divided	Switching	Age	SwAD	Age*SwAD
Accuracy	.88 (.16)	.71 (.19)	.79 (.14)	.94 (.10)	.77 (.17)	.89 (.10)	2.31 (.09)	20.79 (.48)***	.435 (.02)
Reaction Time	690.12 (124.40)	951.17 (145.03)	780.70 (112.35)	503.12 (61.03)	769.60 (128.72)	657.67 (101.85)	23.95 (.51)***	46.99 (.67)***	.85 (.04)

Note: * *p* = < .05, ** *p* = < .01, *** *p* = < .001.

To investigate the first aim specific to attention, a 2 x 3 repeated measures ANOVA was carried out to determine the difference across age groups in target accuracy over the three conditions of the SwAD; singular demands, divided demands and switching demands (see Table 2). Mauchly's test indicated that the data had violated the assumption of sphericity ($\chi2$ (2) = 7.13, p = .28) and thus degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = 0.78). An effect of condition was found, but no main effect of age was found and there was no interaction between age and SwAD condition. Post hoc pairwise comparisons indicated significant differences in accuracy proportions between the singular and divided conditions (p = <.001), the singular and switching conditions (p = .001) and the divided and switching conditions (p = .002). Refer to Figure 2 for mean accuracy scores on each of the three SwAD conditions across age groups. Regression analyses performed indicated that age had no concurrent predictive power on accuracy scores, with insignificant models found for the singular demands condition (F(1,23) = 2.19, p = .152, R^2 = .087) and the divided demands condition (F(1,23) = 3.37, p = .079, R^2 = .128). The overall regression model for the switching demands condition (F(1,23) = 4.69, p = .041, R^2 = .169) was significant, with the variables accounting for 16% of the variance.

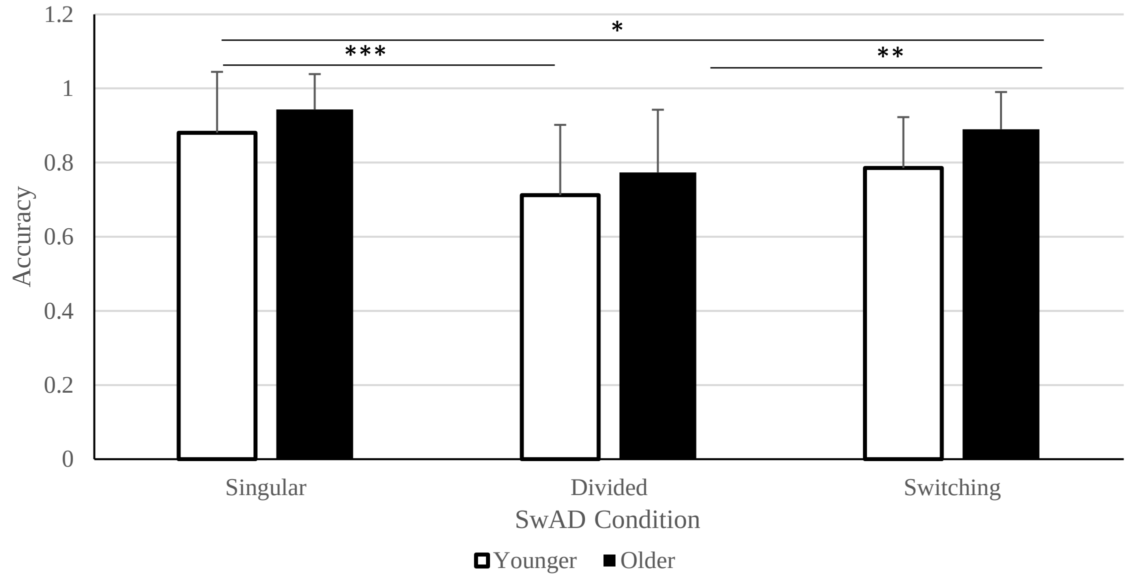

Figure 2. Mean SwAD accuracy scores across younger and older age groups by the three SwAD conditions with significance of differences indicated. Note: * p = < .05, ** p = < .01, *** p = < .001.

A 2 x 3 repeated measures ANOVA was then carried out to determine whether age had any effect on the reaction times recorded across the three conditions of the SwAD (see Table 2). Mauchly's test indicated that the data had violated the assumption of sphericity ($\chi 2$ (2) = 8.55, p = .014) and thus degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = 0.76). Significant main effects were found for both age and SwAD condition, but no interaction was found between age and condition. Post hoc pairwise comparisons indicated significant differences in reaction times across all three SwAD conditions and over both of the age groups assessed, with p values of <.001 in all cases. Refer to Figure 3 for mean RTs on each of the three SwAD conditions across age groups. Regression analyses performed indicated that age possessed predictive power for reaction times, with significant models found for the singular ($F(1,23) = 35.34$, $p = <.001$, $R^2 = .61$), divided ($F(1,23) = 16.09$, $p = .001$, $R^2 = .41$) and switching demands ($F(1,23) = 14.87$, $p = .001$, $R^2 = .39$) conditions of the SwAD. These models explained 60%, 41% and 39% of the variance within their respective models (Figure 4).

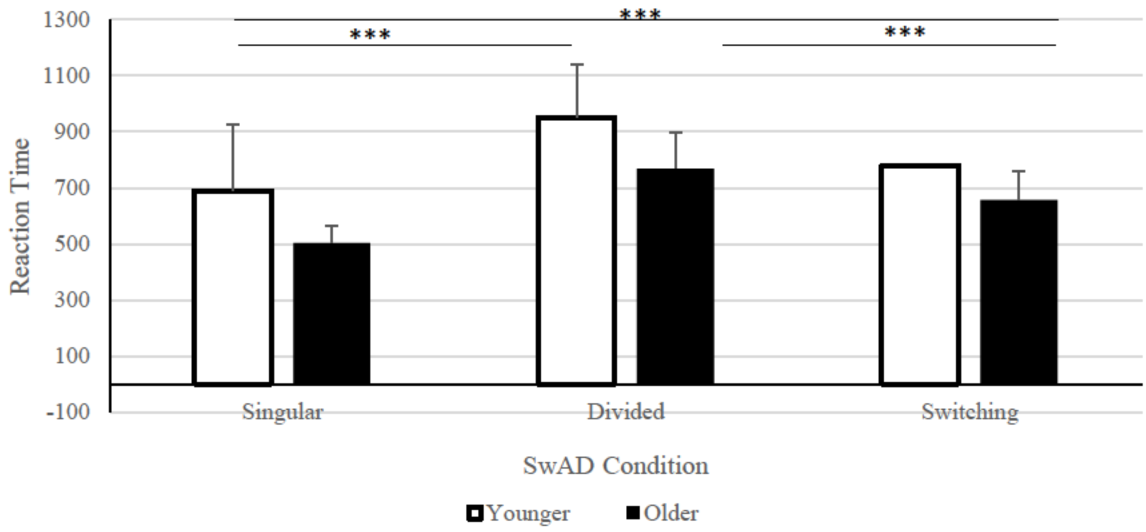

Figure 3. Mean SwAD reaction times across younger and older age groups by the three SwAD conditions with significance of differences indicated. Note: * $p = < .05$, ** $p = < .01$, *** $p = < .001$.

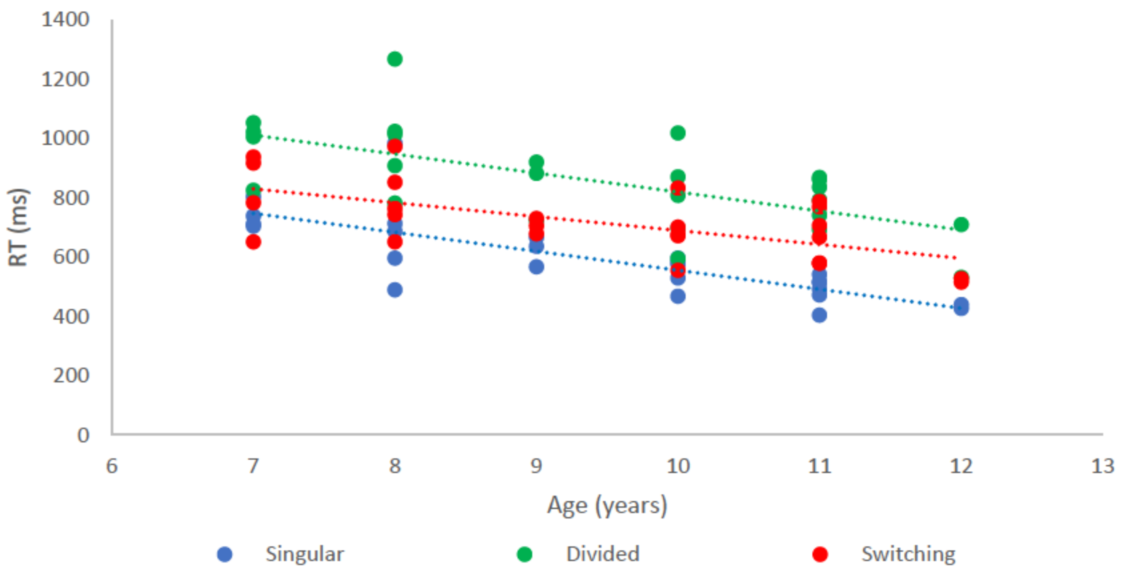

Figure 4. Reaction times across all three SwAD conditions by participant ages. Note: Singular condition $R^2 = .61$, divided condition $R^2 = .41$, switching condition $R^2 = .39$.

3.3.2 Inhibition

Table 3.

Means, Standard Deviations and ANOVA Results for Proportion of False Alarm Responses and Reaction Times Across Age Groups and GNG Paradigms

	Younger		Older		F-values (η_p^2)		
	Audio	Video	Audio	Video	Age	GNG	GNG*Age
Proportion of	.27	.25	.26	.20	1.99	.89	.33
False Alarms	(.19)	(.15)	(.21)	(.14)	(.01)	(.04)	(.01)
Reaction Time	911.75	986.64	803.28	942.43	.27	.83	.65
	(229.14)	(247.81)	(438.58)	(259.75)	(.02)	(.44)	(.04)

Note: * *p* = < .05, ** *p* = < .01, *** *p* = < .001

To investigate the first aim, specific to the development of inhibition, a 2 x 2 repeated measures ANOVA was conducted to determine the difference across age groups in the proportion of responses to no-go stimuli over the audio and audio + video paradigms of the GNG (see Table 3). No significant main effect of age or GNG paradigm was found and the interaction between age and paradigm was not significant either. Refer to Figure 5 for mean inaccuracy scores over the two GNG paradigms.

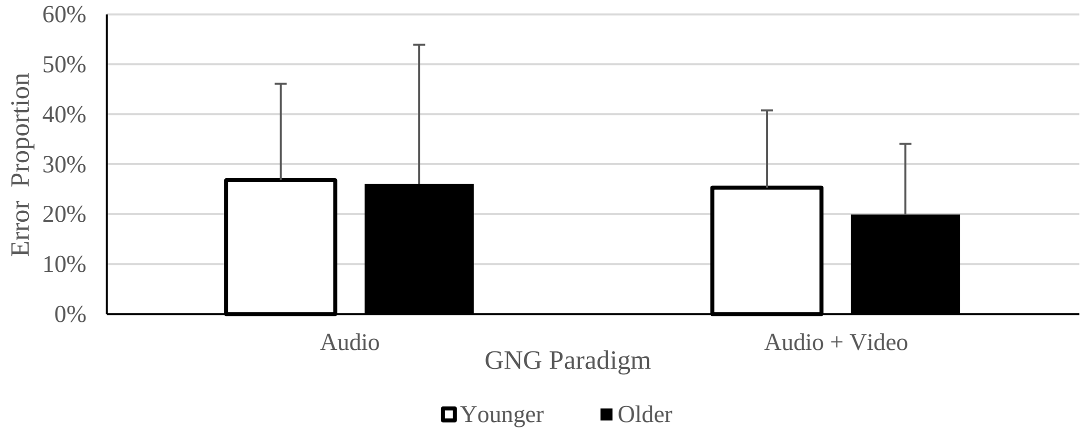

Figure 5. Mean proportion of no-go target responses across younger and older age groups by the two GNG paradigms.

A 2 x 2 repeated measures ANOVA was then conducted to determine the difference across age groups in the reaction times associated with responses to no-go stimuli over the audio and audio + video paradigms of the GNG (see Table 3). Again, no significant main effects or interactions were found. Refer to Figure 6 for mean RTs over the two GNG paradigms.

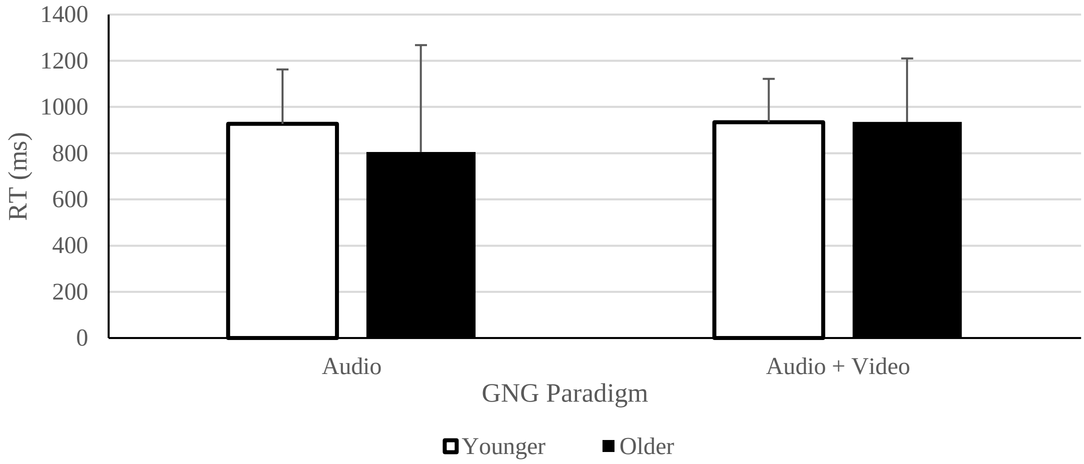

Figure 6. Mean no-go target response reaction times across younger and older age groups by the two GNG paradigms.

3.4 Aim 2: To Investigate the External Factors Which May Influence Results on EF Measures

3.4.1 Attention

	Younger			Older			F-values (η_p^2)		
	Singular	Divided	Switching	Singular	Divided	Switching	Age	SwAD	Age*SwAD
Accuracy	.88 (.16)	.71 (.19)	.79 (.14)	.94 (.10)	.77 (.17)	.89 (.10)	4.10 (.16)	1.87 (.78)	.27 (.01)
Reaction Time	690.12 (124.40)	951.17 (145.03)	780.70 (112.35)	503.12 (61.03)	769.60 (128.72)	657.67 (101.85)	15.03 (.41)**	7.19 (.25)**	.33 (.02)

Table 4.

Means, Standard Deviations and ANCOVA Results for Accuracy and Reaction Times Across Age Groups and SwAD Conditions Covaried for ICT use.

Note: * $p = < .05$, ** $p = < .01$, *** $p = < .001$

To address the second aim, which investigated the external factors which may have influenced EF scores, a 2 x 3 ANCOVA was conducted to determine the difference across age groups in target accuracy over the three conditions of the SwAD whilst controlling for average daily ICT use (see Table 4). Mauchly's test indicated that the data had violated the assumption of sphericity ($\chi 2$ (2) = 6.76, p = .034) and thus degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = 0.78). No significant main effects of condition or age were reported and no significant interaction between age and condition was found.

A 2 x 3 ANCOVA was then carried out to assess the effect of age grouping on RT over the three conditions of the SwAD (see Table 4). Mauchly's test indicated that the data had violated the assumption of sphericity ($\chi 2$ (2) = 8.23, p = .016) and degrees of freedom were thus corrected using Greenhouse-Geisser estimates of sphericity (ε = 0.76). Significant main effects were found for both age and condition. No significant interaction was found between age and condition. When controlling for daily ICT use, post-hoc pairwise comparisons indicate significant differences in reaction times between both the younger (p = .001) and older (p = .001) age groups assessed and the three SwAD conditions; singular demands (p = <.001), divided demands (p = <.001) and switching demands (p = <.001).

3.4.2 Inhibition

Table 5.

Means, Standard Deviations and ANCOVA Results for Proportion of False Alarm Responses and Reaction Times Across Age Groups and GNG Paradigms Covaried for ICT Use.

	Younger		Older		F-values (η_p^2)		
	Audio	Video	Audio	Video	Age	GNG	GNG*Age
Proportion of False	.27	.25	.26	.20	1.41	.93	.72
Alarm Responses	(.19)	(.15)	(.21)	(.14)	(.06)	(.04)	(.03)
Reaction Time	911.75	986.64	803.28	942.43	.24	4.94	.63
	(229.14)	(247.81)	(438.58)	(259.75)	(.00)	(.23)*	(.04)

Note: * p = < .05, ** p = < .01, *** p = < .001

A 2 x 2 ANCOVA revealed no significant effects of age, GNG paradigm or age by GNG paradigm interaction on the proportion of responses to no-go targets, even whilst controlling for average daily ICT use (see Table 5).

A 2 x 2 ANCOVA revealed a significant main effect of GNG paradigm on RT whilst controlling for average daily ICT use, with RT being greater for the video compared to audio task (see Table 5). No significant effect was reported for age and no significant interaction was reported for GNG paradigm by age.

CHAPTER 4: DISCUSSION

4.1 Summary of Overall Findings

The purpose of the present study was to gain a greater understanding of how EF develops in children; specifically, those who are typically developed and school aged. The first aim of this study was to investigate the development of EF in typically developed children by using computerized measures. The findings supported evidence that EF does continue to discretely develop past the age whereby some literature had suggested that maturation occurs, however this development is complex and may not follow a linear pattern across all domains measured. Such findings are unlikely to be replicated if physically administered measures were applied instead, as the significant age-related results found were only present in metrics which non-computerized tasks are inherently unable to measure with sufficient precision, such as reaction time.

The study further aimed to investigate the external factors which may influence results on computerized EF measures. The results suggested that while average daily ICT use may not significantly affect task performance as a function of age, it may affect task performance where the computerized context of the task itself is the focus, as was the case with the audio + video GNG paradigm. This would suggest that individuals who receive a greater exposure to ICTs may have a learned ability to split their attention between the ICT and their environment. However, no other variables assessed were suitable for use in investigating the effect which they may have had on EF development and the conclusions that can be made regarding this aim are limited.

4.2 Discussion of Findings

4.2.1 The Development of EF

Previous research has suggested that adult level performance would be expected on EF tasks at ages as young as 6 (Welsh et al., 1991), with similarly constructed studies finding that EF had matured fully by age 12 at the latest (Passler et al., 1985; Schachar & Logan, 1990). However, the results of the present study indicate that EF domains may possess a longer and far less straightforward developmental progression than first thought. Analyses conducted using the results of the SwAD indicated that significant differences in reaction times were present over all three conditions of the measure across both the younger and older age groups, with the older group demonstrating lower reaction times than the younger. A very large effect size was reported for this effect. No significant differences in accuracy were found though, suggesting that development over these ages consisted of discrete developments to the speed with which one could perform a task, which were not associated with improvements to one's task accuracy. These results are consistent with the suggestion from more recent research (Best & Miller, 2010), and plausibly evidence the developmental progression of attentional strategies, rather than attentional ability, which allow for change to the speed of response whilst holding accuracy constant. This finding is also consistent with what would be expected following the application of a computerized methodology and evidences the importance of doing so, as a manually administered test of attention would have been unable to record changes to RT (Betts et al., 2006). While inferences have been made regarding inhibition evidencing strategic development, rather than skill development during this age, no such claims have been made previously for attentional abilities. A significant effect of condition was found, however this merely evidences participants' different attentional abilities and the validity of each condition of the measure as expected.

Results regarding the development of inhibition were less consistent with previous research. Whilst some had suggested that inhibition would be expected to develop in much the same fashion as attention over the ages investigated (Reuter et al., 2019; Grammar et al., 2018; Cartwright, 2012) no significant changes to either accuracy or attention were found between the younger and older age groups. This may be due to the reported complexity of inhibition's developmental patterns (Richardson et al., 2018; Crone, 2009) or perhaps a result of a developmental plateau which is argued to occur during these ages (Best & Miller, 2010, Best et al., 2009). However, the results obtained during this study do not explicitly evidence this and thus such claims cannot be addressed.

4.2.2 The Factors which Influence EF Development

The results of analyses relevant to the second aim, although limited in scope, did produce significant and interesting findings. Although no significant effects or interactions were reported on SwAD accuracy scores or GNG no-go response proportions, and similarly for RTs on the SwAD, a significant effect of paradigm was found over age groups on the GNG for RTs. Individuals with greater exposure to ICTs perform faster on computerized tasks which contain distractor stimuli, without producing greater inhibitory errors. This effect can be inferred to evidence the development of strategies which function to allow an individual to divide their focus between an ICT and their environment as a result of likely having been required to do so frequently. For example, a child who regularly watches TV may learn to be able to both focus on the content of the show whilst also listening to their parents engaging in conversation with them. This ability is unlikely to be specific to inhibitory abilities as no significant effect was found on no-go stimuli response proportion rate, and is likely related to the reduced time required to process stimuli. While significant age and condition effects were found for RTs on the SwAD when controlling for ICT, these effects were present prior to the introduction of ICT use as a covariate, and the significance and effect sizes associated with these effects decreased. This would suggest that ICT use may not explicitly affect performance on all computerised tasks (Best & Miller, 2010).

4.3 Implications

This study identified three main issues arising as a result of limitations of previous research. The first being that the focus on atypical development, and the incomplete scope assessed in regard to age, limits our understanding of expected abilities of typically developed school aged children. This understanding having been applied in developing educational curriculum which accounts for an individual's skill level relevant to their age (Bassok et al., 2014) is highly problematic and may inaccurately capture the abilities which could be expected. Having obtained a generalizable sample, which was assessed on numerous control measures to ensure that all results are from typically developed individuals, the results obtained, and methodology applied, in the present study may be more suitable in determining age-dependant ability, or assessing EF ability in the future, than previous studies of a similar nature. Successfully identifying individual ability may provide for the construction of more appropriate curriculum which provides for the best EF skill outcomes, an important topic when considering the demonstrated link between EF ability and academic achievement (Blair & Razza, 2015).

The second issue concerns the methodologies applied in previous literature; specifically arguing that physically applied measures do not provide the precision necessary for describing functional trajectories in typically developed children. This study, having produced significant results on measures of RT serves as further evidence for the importance of computerized measures which are able to measure discrete changes separate to that of lower-order functions.

The third issue is that there remains a limited understanding of the external factors which may influence EF development. Although the results of the present study were largely inconclusive in this regard, they do evidence the need for further investigation into this topic as there may be factors not yet identified which could prove highly significant in fostering the development of EF. Similarly, new factors resulting from cohort changes such as technology development and use need to be considered in current research.

4.4 Limitations and Future Directions

Although post-hoc sensitivity power analysis indicated that the current study was suitably powered for the analyses performed, the division of age into only two groups may not have provided the resolution to demonstrate developmental trajectories across the age range investigated. A wider and larger age range would have allowed for a greater overall picture of the development of EF to be obtained, as the results of regression analyses conducted for this study would suggest that only the supposed developmental plateau has been captured, and that greater effects may lie on either side of the ages assessed. It would be wise of future research into this topic to attempt to address these issues, thus providing a more complete picture of EF development outside of the plateau. Previous studies have also evidenced the existence of other EF domains such as set-shifting and planning (Tibu et al., 2015; Ramey & Reiger, 2018), cognitive flexibility (Cartwright, 2012) and conflict monitoring (Jonkman, 2006), as well as numerous subsets of the EF domains previously identified (Klenberg et al., 2001; Brocki & Bohlin, 2004). The state of the current literature base is largely unknown in regard to these skills and the conclusion of this study should be considered in their assessment too.

4.5 Conclusions

Overall, the results of the present study suggest that modern research is correct in suggesting that skill maturation does not occur at the ages initially suggested, instead manifesting as discrete improvements to reaction times which evidence the development of new strategies. The use of more suitable measures in assessing EF have played a significant role in gaining this understanding. Thus, the accuracy of previous literature which has suggested otherwise must be called into question, and the conclusions of more recent studies which have gained an understanding of the topic from such results must too be considered carefully. The suggestions regarding the external factors which play a role in this development remain largely unexplored, however. Further research is needed both to clarify what these factors may be and how much influence they exert on an individual, and to produce metrics which can be used to better understand the age appropriate skill levels which could be expected of school-aged children. If these understandings were to be applied in developing educational curriculum to assist in fostering EF development, it is likely that individuals exposed to such programs would report greater academic success in the future.

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Appendix A: Social Demographics and Pastimes Questionnaire

Social Demographics and Pastimes Questionnaire

For each item, please indicate your answer by marking the circle next to your selected response. It would help us if you answered all items as best you can even if you are not absolutely certain.

Answer all questions in order, completing the questions in the left-hand column before answering the questions in the right-hand column.

Participant ID number: ___________

1. What is your child's **Gender**?
- o Male
- o Female
- o Other

2. **How old** is your child
They are _______ years old.

3. What **school year** is your child in?
My child is in Year _______.

4. Has your child ever repeated a year? If yes, which year?
- o No, they have not repeated a year.
- o Yes, they repeated Year _____.

5. Do you have additional **childcare**?
- o At-school care
- o Childcare
- o Family members provide care
- o Babysitter/Nanny/Au Pair
- o Other _____________________
- o No

6. What are your child's **hobbies**? (Multiple answers possible)
- o Reading
- o Playing video games
- o Spending time with friends/family
- o Participating in sports
- o Listening to music
- o Watching TV/YouTube/Netflix etc.
- o Surfing the internet
- o Other _____________________

7. How many **friends** does your child regularly meet outside of school?
___________ friends.

8. How many **books** has your child read over the last year in total?
- o 1 to <5 books
- o 5 to <10 books
- o 10 to <15 books
- o 15 to <20 books
- o 20 to 25 books
- o <25 books

8a. Which **book category** is your child most interested in?
- o adventure stories
- o comics
- o scary/horror stories
- o fairy tales
- o comedy
- o animal books
- o fantasy/fiction

9. Does your child have their own **mobile phone/smartphone**?
- o Yes
- o No

9a. If yes, at what age did your child get their first **mobile phone/smartphone**?
- o 6 years or younger
- o 7 to 9 years
- o 10 to 12 years
- o 13 years or older

9b. If yes, how long do they use their **mobile phone/smartphone** each day?
- o 0 to <1 hour a day

- 1 to <2 hours a day
- 2 to <3 hours a day
- 3 to <4 hours a day
- 4 to <5 hours a day
- >5 hours a day

10. Does your child regularly use a **computer/laptop**?
- Yes
- No

10a. If yes, how old was your child when they first used a **computer/laptop**?
- 6 years or younger
- 7 to 9 years
- 10 to 12 years
- 13 years or older

10b. How long do they use a **computer/laptop** a day?
- 0 to <1 hour a day
- 1 to <2 hours a day
- 2 to <3 hours a day
- 3 to <4 hours a day
- 4 to <5 hours a day
- 5 hours a day

11. Does your child regularly use a **tablet/iPad**?
- Yes
- No

11a. If yes, how old was your child when they first used a **tablet**?
- 6 years or younger
- 7 to 9 years
- 10 to 12 years
- 13 years or older

11b. How long do they use a **tablet** a day?
- 0 to <1 hour a day
- 1 to <2 hours a day
- 2 to <3 hours a day
- 3 to <4 hours a day
- 4 to <5 hours a day
- >5 hours a day

12. Does your child regularly use a **game console** (e.g. Playstation, Xbox, Nintendo etc.)?
- Yes
- No

12a. If yes, how old was your child when they first used a **game console**?
- 6 years or younger
- 7 to 9 years
- 10 to 12 years
- 13 years or older

12b. How long do they use a **game console** each day?
- 0 to <1 hour a day
- 1 to <2 hours a day
- 2 to <3 hours a day
- 3 to <4 hours a day
- 4 to <5 hours a day
- >5 hours a day

13. Does your child regularly watch **TV** (including streaming services such as Netflix/YouTube)?
- Yes
- No

13a. If yes, how old was your child when they **watched TV** for the first time?
- 6 years or younger
- 7 to 9 years
- 10 to 12 years
- 13 years or older

13b. How long does your child watch **TV** a day?
- 0 to <1 hour a day
- 1 to <2 hours a day
- 2 to <3 hours a day
- 3 to <4 hours a day
- 4 to <5 hours a day
- >5 hours a day

14. Which **social networks/messengers** does your child use? (multiple answers possible)
- WhatsApp
- Instagram
- Facebook
- Facebook Messenger
- Twitter
- Snapchat
- Other ___________________

Thank you for participating.

Appendix B: Strengths and Difficulties Questionnaire (Ages 4 – 10)

Strengths and Difficulties Questionnaire

P 4-10

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain. Please give your answers on the basis of your child's behaviour over the last six months.

Your child's name .... Male/Female

Date of birth...

	Not True	Somewhat True	Certainly True
Considerate of other people's feelings	☐	☐	☐
Restless, overactive, cannot stay still for long	☐	☐	☐
Often complains of headaches, stomach-aches or sickness	☐	☐	☐
Shares readily with other children, for example toys, treats, pencils	☐	☐	☐
Often loses temper	☐	☐	☐
Rather solitary, prefers to play alone	☐	☐	☐
Generally well behaved, usually does what adults request	☐	☐	☐
Many worries or often seems worried	☐	☐	☐
Helpful if someone is hurt, upset or feeling ill	☐	☐	☐
Constantly fidgeting or squirming	☐	☐	☐
Has at least one good friend	☐	☐	☐
Often fights with other children or bullies them	☐	☐	☐
Often unhappy, depressed or tearful	☐	☐	☐
Generally liked by other children	☐	☐	☐
Easily distracted, concentration wanders	☐	☐	☐
Nervous or clingy in new situations, easily loses confidence	☐	☐	☐
Kind to younger children	☐	☐	☐
Often lies or cheats	☐	☐	☐
Picked on or bullied by other children	☐	☐	☐
Often volunteers to help others (parents, teachers, other children)	☐	☐	☐
Thinks things out before acting	☐	☐	☐
Steals from home, school or elsewhere	☐	☐	☐
Gets along better with adults than with other children	☐	☐	☐
Many fears, easily scared	☐	☐	☐
Good attention span, sees chores or homework through to the end	☐	☐	☐

Do you have any other comments or concerns?

Please turn over - there are a few more questions on the other side

Appendix C: Strengths and Difficulties Questionnaire (Ages 11 – 17)

Strengths and Difficulties Questionnaire

P 11-17

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain. Please give your answers on the basis of your child's behaviour over the last six months.

Your child's name .... Male/Female

Date of birth..

	Not True	Somewhat True	Certainly True
Considerate of other people's feelings	☐	☐	☐
Restless, overactive, cannot stay still for long	☐	☐	☐
Often complains of headaches, stomach-aches or sickness	☐	☐	☐
Shares readily with other youth, for example CD's, games, food	☐	☐	☐
Often loses temper	☐	☐	☐
Would rather be alone than with other young people	☐	☐	☐
Generally well behaved, usually does what adults request	☐	☐	☐
Many worries or often seems worried	☐	☐	☐
Helpful if someone is hurt, upset or feeling ill	☐	☐	☐
Constantly fidgeting or squirming	☐	☐	☐
Has at least one good friend	☐	☐	☐
Often fights with other young people or bullies them	☐	☐	☐
Often unhappy, depressed or tearful	☐	☐	☐
Generally liked by other young people	☐	☐	☐
Easily distracted, concentration wanders	☐	☐	☐
Nervous in new situations, easily loses confidence	☐	☐	☐
Kind to younger children	☐	☐	☐
Often lies or cheats	☐	☐	☐
Picked on or bullied by other young people	☐	☐	☐
Often volunteers to help others (parents, teachers, children)	☐	☐	☐
Thinks things out before acting	☐	☐	☐
Steals from home, school or elsewhere	☐	☐	☐
Gets along better with adults than with other young people	☐	☐	☐
Many fears, easily scared	☐	☐	☐
Good attention span, sees chores or homework through to the end	☐	☐	☐

Do you have any other comments or concerns?

Please turn over - there are a few more questions on the other side

Appendix D: Participant Information Sheet

THE UNIVERSITY of ADELAIDE

PARTICIPANT INFORMATION SHEET

PROJECT TITLE: The Children's Inhibition and Attention Study
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: [redacted]
PRINCIPAL INVESTIGATOR: Dr. Mark Kohler
STUDENT RESEARCHER: Declan Shillabeer
STUDENT'S DEGREE: Honours Degree of Bachelor of Psychological Science

Dear parents/guardians,

Your child is invited to participate in the research project described below.

What is the project about?
The Children's Inhibition and Attention Study uses a series of computer-based tasks to investigate children's ability to switch between demands on their attention. Deficits in these skills, *which fall under the umbrella of "executive functioning"*, underpin numerous learning and behavioural issues. Better understanding of the mechanisms behind these abilities, how these abilities develop across childhood, and what other factors may interact with this development is crucial in gaining the knowledge needed to better address deficits in some children.

Who is undertaking the project?
This project is being conducted by the team at the Adelaide Brain and Cognitive Development laboratory (ABCD lab) at the University of Adelaide. Declan Shillabeer is the principal researcher, and this research will form the basis for his degree of Honours of Bachelor of Psychological Science. The work is being conducted under the supervision of Dr. Mark Kohler.

Why is my child being invited to participate?
Your child is invited to participate as they are over the age of 7 and under the age of 14 and they do not have a diagnosis of any psychiatric or learning condition, or a motor impairment which could restrict their ability to interact with the set tasks.

What am I being invited to do?
You are being invited to participate in research that will help develop a better understanding of executive functioning in children, how it develops and what influences that development. Participation will involve a face to face session with you and your child that will take place in the ABCD lab, located in the Hughes building of the University of Adelaide's North Terrace campus.

Firstly, you will be required to complete two questionnaires. These questionnaires will ask for background information about your child as well as information about media/technology use and daytime behaviour. These questionnaires should take approximately 10 minutes each to complete.

During this time, your child will complete 3 computerized tests in an adjacent room. Parents are free to be seated in the room if they or their child would prefer. The computer tasks require your child to be seated in front of a computer and instructed to press a specific key on a standard computer keyboard when a target appears on screen. Each task is slightly different and involves responding to a combination of visual, audio and video targets and distractors, and will require them to wear headphones.

No audio or video recordings will be made of your child during participation.

How much time will my involvement in the project take?
Participation in this study is expected to take no longer than two hours, although in many cases less time is likely. You'll be allowed to schedule a time which best suits you and your child.

On completion you'll be given an honorarium consisting of a $40 gift card. This honorarium will mitigate any expenses incurred such as travel and parking. Once all tasks have been attempted, you will be free to go and there are no follow-up visits required.

Are there any risks associated with participating in this project?
There are no foreseeable risks associated with taking part in this project.

What are the potential benefits of the research project?
While there are no specific benefits apart from the experience of participating in research, the findings of this study will be valuable for our understanding of typical cognitive development in children. This knowledge may help identify risk factors in the development of cognitive and/or learning deficits. You can request a summary of the results findings, which will be sent to you at completion of the study.

Can I withdraw from the project?
Participation in this project is completely voluntary. If you agree to participate, you or your child can withdraw from the study at any time if either of you wish to do so.

What will happen to my information?
This study is anonymous. No identifying information, such as names and school details, will be recorded. A participant identifier code will be used to enable us to link the information together, but your child will not be otherwise identified. The results published will only consist of whole group results, and no individual results will be reported separately. These results of this study will also be included in an Honours thesis and may be disseminated at conferences and submitted for publication in peer-reviewed journals.

The data recorded as part of this study will be stored electronically in a password protected University of Adelaide server and made accessible only to the research staff who are part of this study, in accordance with the Standard Operating Procedures of the University of Adelaide. All hard copies of participant information will be securely stored in a locked cabinet within the ABCD lab, accessible only to researchers who are part of this study. Data will be stored for a five-year period, before being securely destroyed and/or deleted.

If you consent, the data obtained from this study will be made available for use in studies conducted by either the researchers of this study for additional analyses following the approval of the University of Adelaide Human Research Ethics Committee.

Who do I contact if I have questions about the project?
All questions about this project should be directed to either:

[redacted]

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2019-46). This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research 2007 (Updated 2018). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 8 8313 6028
Email: hrec@adelaide.edu.au
Post: Level 4, Rundle Mall Plaza, 50 Rundle Mall, ADELAIDE SA 5000

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?

To organize a time to participate, ask any further questions you may have, and receive instructions on how to find the ABCD lab, contact the student researcher, Declan Shillabeer, at:

[redacted]

Yours sincerely,
Dr. Mark Kohler, principal investigator
&
Declan Shillabeer, student researcher.