The remediation of oculomotor and attentional deficits of children with ADHD: identifying and training control mechanisms based on ocular data

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Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy in the School of Medicine, September 2015

Abstract

This project set out to develop a cognitive training intervention for individuals with attention deficit hyperactivity disorder (ADHD). The thesis builds on research suggesting that reinforcement deficits in the ADHD population give rise to the underdevelopment of a number of cognitive abilities, in particular inhibitory control skills. Arguing that this skill is explicitly trainable and that training inhibitory gaze control is a means of training inhibitory control, this thesis set out to utilise eye-tracking technology to assess inhibitory gaze control performance in ADHD and to develop an engaging intervention in the form of a computer game capable of training the inhibitory gaze control system. Drawing on literature on inhibitory control in ADHD, the saccadic system, game development, and cognitive load theory a training intervention and battery of assessment tasks were developed iteratively across a number of pilot studies. The development process and resultant cognitive training interventions are described. The final proof-of-concept study was trialled for eight one-hour training sessions with an ADHD population (N = 8). Comparisons of pre- and post-training assessments produced strong effects for measures of gaze control, inhibitory control, timing, and attention. The results are interpreted and a number of limitations noted. The potential benefits of such interventions to aid clinicians to diagnose, to monitor, and to treat ADHD are considered. The relevance of cognitive interventions in contributing to research attempting to identify endophenotypes of ADHD is also discussed.

Declaration

I declare that this thesis is the result of my own work which has been undertaken during my period of registration for this degree at The University of Nottingham. I have complied with the word limit for my degree (as stated in the Quality Manual).

Acknowledgements

I would like to thank the Institute of Mental Health for funding this research. I am grateful to the Adult ADHD clinic at QMC, QbTech Ltd, the Eunethydis Network, and ESSEM for supporting this work. My sincere thanks also go to the many members of staff at the QMC and Institute of Mental Health for their support, in particular Dr Maddie Groom, Professor David Daly, Professor Chris Hollis, and my fellow PhD candidates. I am especially grateful to my supervisors Dr Elizabeth Liddle and Professor Georgina Jackson for their tireless patience, motivation, and immense knowledge. This project could not have been achieved without the support of the Nottingham ADHD Support Group, the Mellers and Portland primary schools, the Nottingham University's Summer Scientist Week, and especially not without all the participants who gave up their time to contribute to this project. I would like to thank friends and family, without their support it would not have been possible to conduct this research. Finally, I would like to thank my partner Christina for supporting me throughout writing this thesis and my life in general.

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Core thesis argument and structure

Sagvolden's Dynamic Developmental Theory proposes that the primary deficit in attention deficit hyperactivity disorder (ADHD) is an atypical dopamine system, which leads to reinforcement deficits (Chapter 1). The intervention developed as part of this thesis is based on the assumption that, at least for a sub-group of those with ADHD, a reinforcement deficit is a primary deficit. Due to this primary reinforcement deficit learning is impaired in individuals with ADHD and they fail to acquire a number of skills for which they have capacity, among them inhibitory control, and specifically inhibitory gaze control. Inhibitory gaze control is of particular interest in ADHD as it lies at the intersection of attentional, hyperactive, and impulsive symptoms. In light of research that suggests that children acquire inhibitory control skills, and that individuals with Tourette Syndrome and bilingual speakers demonstrate enhanced inhibitory control I argue that it is a trainable skill. With the correct performance contingent incentives inhibitory control may be trainable in ADHD. A targeted training intervention was designed to utilise the proposed latent capacity to remediate the inhibitory gaze control deficits seen in the ADHD population (Chapter 2).

Mixed results have been observed in the cognitive training literature generally and more specifically with ADHD (Chapter 3). In the development of the intervention I draw upon the anticipatory, feed-forward, and competitive integration models of the visual system, and review a number of saccade control paradigms and the associated deficits observed in ADHD populations (Chapter 4). Building on this work I argue that aspects of attention and timing are critically linked to inhibitory control and should therefore also be targeted. A brief review of the literature on timing and attention is provided (Chapter 5). Having identified the target of the intervention the literature on motivation, gaming, and exercise is reviewed to identify principles the training intervention can draw upon (Chapter 6).

I then outline the process by which the intervention was programmed. I discuss the equipment used, as well as the algorithms and methods utilised to identify saccades from the eye gaze data gathered (Chapter 7). A number of pilot studies conducted to inform the development of the training intervention and the pre- and post-training assessment tasks are reported. The process of task refinement and the changes made are discussed (Chapter 8). The main proof-of-concept study, including the methods and procedures, are described in full and a detailed description of the training intervention and assessment tasks are given (Chapter 9). A comparison of the pre- and post-training assessment tasks is presented and discussed (Chapter 10), followed by case studies of each of the participants (Chapter 11). The thesis concludes with a discussion of the findings, limitations, and consideration of the utility of cognitive interventions. A wider discussion of the potential use of cognitive interventions as an alternatives and compliments to medication is considered (Chapter 12).

1 Introduction

This project set out to develop a cognitive training intervention for individuals with ADHD. In chapter 1 I present the context for the development of the training intervention developed. I begin by providing an overview of ADHD; its classification, prevalence, and impact on the individual and society. I provide a sketch of the current state of the field, giving a summary of the cognitive deficits associated with ADHD and an outline of some prominent theories attempting to account for these deficits.

1.1 Overview of ADHD

Attention deficit hyperactivity disorder (ADHD) is a common highly heritable persistent disorder with a childhood onset. While commonly present to some degree in the general population, the diagnostic symptoms - impulsivity, hyperactivity and inattention - are considered as being excessively intense or frequent, and age inappropriate in cases of ADHD. Along with opposition defiance disorder, conduct disorder and antisocial personality disorder, ADHD is classified as a disruptive disorder (American Psychiatric Association, 2013). It is a highly heritable condition with genes accounting for an estimated 76-80% of an individual's susceptibility (Faraone & Doyle, 2001). ADHD as classified by the American Psychiatric Association's criteria (American Psychiatric Association, 2010) has a prevalence rate of 3% to 5% (Barkley et al., 2002). A diagnosis of Hyperkinetic Disorder is based on a very similar set of symptoms published by The World Health Organisation in the ICD-10. The ICD-10 diagnosis requires greater impairment than the DSM-5 and emphasises impulse-control problems, resulting in the lower prevalence rate of 1-2% (Banaschewski et al., 2009; Döpfner et al., 2008).

A diagnosis of ADHD is normally made by a clinician based on the presence of symptoms that map onto the diagnostic criteria of the DSM-5 or ICD-10. A diagnosis can be made primarily on the existence of attention problems, e.g. 'has problems maintaining focus on a task', on hyperactivity/impulsivity symptoms, e.g. 'often fidgets with hands or feet or squirms in seat' (American Psychiatric Association, 2013), or both. A diagnosis is a categorical decision based on a threshold number of symptoms exhibited. The clinician draws on multiple sources of information to make a diagnosis, as diagnostic symptoms typically must be observed in more than one context e.g. home and school. For example, behaviour observed by parents and teachers is communicated to the clinician. The clinician will typically conduct an interview and may also observe the child's behaviour. In some cases psychometric tests may also be completed in order to rule out alternative diagnoses (Bruchmüller, Margraf, & Schneider, 2012; Kooij et al., 2010). Cognitive impairments and biological or genetic markers are not diagnostic.

A diagnosis is 3 to 16 times more likely in boys (Nøvik et al., 2006). This may not reflect a gender imbalance in prevalence but in the nature of the symptoms girls display. Girls display more inattentive than hyperactive or impulsive symptoms, therefore they may not be disruptive to the same extent as boys and as a consequence may not be identified as needing an assessment for ADHD, and may be overlooked (Quinn, 2005). ADHD is typically diagnosed from around age 7 (Applegate et al. 1997). While it is a chronic disorder it has a purported 30% to 80% remittance rate in adults (Kessler et al. 2006; Fayyad et al. 2007), particularly for hyperactive and impulsive symptoms (Biederman, Mick, & Faraone, 2000). During young adulthood a reduction in the number of symptoms can lead to an individual no longer meeting the required 6 symptom criteria of a diagnosis (Wilens, Biederman, and Spencer, 2002). Whether they have truly remitted or developed coping strategies to manage their symptoms is an open question. To facilitate adult diagnosis of ADHD, in 2013, the DSM-5 (American Psychiatric Association, 2013) extended the age range for symptom onset from 7 to 12 years of age. While symptoms onset would be expected by age 7 or 8, this change provides adults who are uncertain of when they first displayed symptoms of ADHD greater opportunity of being correctly diagnosed than in the DSM IV. New adult criteria also include a reduced threshold of 5/9, rather than 6/9, symptoms in the two domains of inattention and hyperactivity/impulsivity. The co-existing diagnosis of autism has also been removed as an exclusion criterion for the diagnosis of ADHD.

ADHD is a complex heterogeneous condition. This leads to complications in its diagnosis and treatment, and to difficulties researching the condition. It is heterogeneous in its aetiology, neurophysiology, neurocognitive deficits, symptoms and prognosis. The large inter-individual variability in symptom profile led the DSM to create three subtypes, namely Combined Type, Predominantly Inattentive, and Predominantly Hyperactive/Impulsive. However, a growing awareness of the intra-individual instability in symptom profiles prompted the DSM 5 to now refer to presentations as opposed to subtypes. For example, an individual might display a predominantly hyperactive profile at an initial assessment but might subsequently meet the criteria for a combined type diagnosis (Lahey et al., 2005). Presentations, unlike the notion of stable subtypes, reflect the dynamic nature of the symptoms observed across assessments. A clear picture of ADHD is further occluded owing to the overlap of symptoms with a number of other conditions. Similar attention problems in particular are seen in a range of other conditions (Murphy and Tsuang, 1995). The issue is further complicated by the high prevalence of comorbidities, typically with conditions considered to be "externalising disorders". Comorbid conditions include: Oppositional Deviant Disorder, Conduct disorder, Tourette Syndrome, Autism, Sensory Integration Disorder, Depression, Anxiety, Bipolar Disorder, Learning Disorders, Early Speech/Communication problems, and in young adults and adults substance abuse (Deault, 2010; Larson, Russ, Kahn, & Halfon, 2011).

The condition has a large impact on both the individual and society. Having ADHD has a significant impact on academic and professional achievement and quality of life generally (Loe & Feldman, 2007). Individuals with ADHD have an elevated risk of peer rejection, accidental injury, antisocial behaviour, and subsequent substance misuse and imprisonment (Mordre, Groholt, Kjelsberg, Sandstad, & Myhre, 2011; Mrug et al., 2012). Relative to their peers, children with ADHD are often more intense, impulsive, and aggressive, and will often try to dominate play. Their inability to engage in class room work owing to their poor attention will often result in off task behaviour; this can disrupt and irritate peers (Abikoff, 2002). They also have difficulties with encoding and recalling social rules, hence they have trouble modulating their behaviour to suit the demands of a particular situation. This results in displays of inappropriate behaviour in a given context. Due to their decreased attention and ability to encode and recall social rules, as well as poor inhibitory control they tend to have problems with taking turns. This tendency to miss or act on social cues leads to them being regarded as different and strange and often results in social rejection (Kofler et al., 2011). Social rejection reduces the opportunity to learn through peer interactions. Learning and being motivated to interact appropriately with others is a critical aspect of development. Those with poor social skills are at higher risk of attaining poor academic performance and are more likely to leave the education system before completion (McEvoy & Welker, 2000; Welsh, Parke, Widaman, & O'Neil, 2001). Furthermore, friendships provide a critical buffer against stress and help protect against psychological and psychiatric problems (Deborah et al., 2000). For children with ADHD, peer relations are a predictor of adjustment as an adult and of the severity of behavioural symptoms (Karustis, Power, Rescorla, Eiraldi, & Gallagher, 2000). Those with ADHD are more likely to become involved in delinquency, to have higher rates of substance abuse, and affective disorder (Young, 2000; Green & Chee, 1997).

ADHD also represents a large societal burden. In addition to the social impact of drug misuse and antisocial behaviour there are financial consequences for the health care system owing to injuries caused to themselves and others resulting from their elevated risk for accidents and risky behaviour. The condition also represents a significant financial burden to the criminal justice system (Doshi et al., 2012). D'Amico et al. (2014) conducted a longitudinal study and observed that children with hyperactivity and conduct problems increase early adulthood costs by two or three times, driven mainly by criminal justice costs. Given the wide ranging impact ADHD has for the individual and society there is a need for timely diagnosis and effective management of the condition.

1.1.1 Cognitive deficits in ADHD

Many neuropsychological theories that attempt to account for the cognitive deficits frequently observed in ADHD posit that the proposed dysfunctions lie along the causal pathway that gives rise to ADHD symptoms or at least to problem behaviour associated with ADHD. For example, a child having poor self-regulation abilities will demonstrate difficulties in paying attention at school, organising tasks, making and retaining friends, moderating emotional displays, and controlling impulsive behaviours (Clark, Prior, & Kinsella, 2002; Miller, 2004).

Cognitive deficits associated with ADHD can be grouped into:

1. Motivation factors, such as delay aversion and decision making, (potentially due to impaired reinforcement learning) (Bitsakou, Psychogiou, Thompson, & Sonuga-Barke, 2009; Ernst et al., 2003).
2. Executive functioning deficits, including response inhibition; working memory; attentional set shifting and planning (Martinussen et al., 2005; Alderson, Rapport, & Kofler, 2007; Rohlf et al., 2012).
3. Non-executive functioning deficits, such as basic storage aspects of memory, timing, reaction time and reaction time variability (Noreika, Falter, & Rubia, 2013; Rhodes, Park, Seth, & Coghill, 2012; Tamm et al., 2012).

A multitude of tasks are used to assess cognitive deficits associated with ADHD. The stop-signal task is a measure of response inhibition and error monitoring (Logan, 1994; Schachar et al., 2004) for which children with ADHD have an impaired performance compared to typically developing children (Barkley, 1997). Inhibitory control deficits are similarly seen in the stroop and go/no-go tasks (Castellanos et al. 2006). Task-Switching tasks, the Attentional Network Task (Fan et al., 2002), and Choice Delay Task (Mischel, Shoda, and Rodriguez,1989) measure a number of control processes such as attentional disengagement, selection, conflict monitoring, and motivational style and also produces impaired performance scores (see Gupta & Kar, 2010 for a review). Impaired performance scores also are seen for the Attentional Blink task (Khetrapal, 2007). Khetrapal (2007) suggests that this is due to the misallocation of resources to target one at the expense of target two, and in turn suggests that this is due to faulty top-down control of attention. Flory et al. (2006) suggests that the observed difficulty children with ADHD can have in understanding causal connections and plans within stories is attributable to problems with sustained attention. In tasks that examine children's ability to wait for a reward in order to obtain a more sizable reward children with ADHD more often select a smaller more immediate over a larger more delayed reward. Sonuga-Barke (2002) suggests this reflects a delay aversion, i.e., motivation to escape or avoid delay. While young children are also poor at this task typically developing children improve between the ages of 6-9, whereas children with ADHD do not (Gupta et al., 2006, for review).

However, caution is needed when interpreting findings of apparent cognitive impairment in ADHD.

- There will be a degree of natural variability within the general population and ADHD population which needs to be taken into account when interpreting results. Investigators cannot assume homogeneity in either population. A study by Fair et al. (2012) examined a sample of 213 typically developing and 285 children and adolescents with ADHD. The study investigated the neuropsychological heterogeneity of these groups using a data driven graph theory approach. They identified subgroups within both populations and the results suggested that some of the heterogeneity in the ADHD population was nested in the normal variation seen in the typically developing group.

- Owing to aetiological heterogeneity the identification of sub-groups within the ADHD population may be necessary to produce reliable results (Nigg, Goldsmith, and Sachek, 2004). A failure to take account of this confound may in part account for the lack of consistency when examining cognitive deficits in the ADHD population.

- Consideration must be given to whether the deficit observed is primary or secondary, that is, is it a cognitive deficit that relates in a causal way to ADHD or is it a deficit that results from a primary deficit? For example, if there is poor reinforcement learning due to an abnormal dopamine system, this could impact on the learning of other cognitive functions such as inhibitory control. In this case inhibitory control is a secondary deficit (this is further discussed in the succeeding section).

- The interpretation of neuropsychological test data is complicated by the fact that the tasks are not “process pure”. While a task may claim to evaluate inhibitory control it will also draw on a multitude of other functions. One solution is to attempt to triangulate a function of interest with multiple tasks, each using a different constellation of functions, while all utilise the function of interest.

- An impaired performance on a particular task could result from dysfunction in a number of systems. For example, both impaired inhibitory control abilities and low motivation may independently lead to impaired performance on an inhibitory control task.

- Many of the tasks used are programmed in the testing lab of the researchers involved, and are therefore not standardised; this can result in differences in the implementation of the paradigms. This is not a trivial matter as a slight difference can result in different motivational states, different strategies being adopted by the participant, different rates of task fatigue etc. which will all impact on performance.

1.1.2 Inhibitory control

Poor inhibitory control has been proposed as a neuropsychological 'core deficit' that may underlie ADHD symptoms, accounting especially for impulsivity and distractibility (Aron and Poldrack, 2005; Nigg, 1999). Numerous papers have discussed and examined inhibitory control in an ADHD population (Band and Scheres, 2005; Barkley, 1997; Nigg, 1999; Schachar et al. 2000). Inhibitory control refers to the suppression of activity (neural responses or actions) that is pre-potent, inappropriate or no longer required. Inhibitory control is essential to everyday functioning. It is a function that is acquired and naturally improves over the course of typical development (Schachar and Logan, 1990; Williams et al., 1999). ADHD is often referred to as an inhibitory control disorder (Barkley, 199; Schachar, Tannock, and Logan, 1993), even though a diagnosis can be made on the basis of inattentive symptoms alone.

Major developments in response inhibition seem to occur between 6 and 8 years of age in typically developing children (Leon-Carrion et al., 2004). Becker et al. (1987) also reported a developmental transition in inhibitory control between 6 and 8 years of age. Other developmental studies examining inhibitory control have also shown significant development between 7.5 and 9.5 years of age (Brocki and Bohlin, 2004). Active development of response inhibition between 7 and 8 years of age is consistent with the maturational patterns of the frontal cortex thought to mediate inhibitory control (Hudspeth and Pribram, 1992).

An age-related improvement in inhibitory control of the same degree is not observed in children with ADHD between 6 and 9 years of age. A worse performance was observed for the stop-signal task (Oosterlaan et al., 1998). Rubia and colleagues found that during successful inhibition ADHD children between 9 and 16 years of age showed reduced activation in the left dorsolateral/inferior prefrontal cortex. Immature inhibitory control in young ADHD children is also supported by EEG studies. Spronk et al. (2008) investigated ERP measures of conflict monitoring and inhibition (Nogo-N2 and Nogo-P3), cue orientation and pre-stimulus target expectation (Cue-P2 and Cue-P3) for 5 – 7 years old children with and without ADHD. They found that children with ADHD between 5 and 7 years of age detected fewer targets and had higher inattention scores accompanied by reduced centro-parietal Cue- and Go-P3 activity and reduced Nogo-P3 at fronto-central leads. These findings may indicate early signs of delayed attention development and immature inhibitory processing in ADHD children. Booth et al. (2005) observed reduced activation of fronto-striatal regions in children with ADHD completing an inhibitory control task. Structural and functional deficits were observed in the inferior frontal cortex (IFC) of ADHD participants (Rubia et al., 2008), a brain region implicated as having a critical role in inhibiting an already initiated response (Aron and Poldrack, 2005).

The global term inhibitory control is vague. Nigg (2001) proposed a need to distinguish between inhibition that is under executive control and inhibition that is under motivational control (anxiety or fear). While Douglas (1988) suggested that motivational components gives rise to (i) poor investment and maintenance of effort, (ii) poor modulation of arousal to meet situational demands, (iii) a strong tendency to seek immediate reinforcement, and (iv) deficits in impulse control, Nigg (2001) argues that ADHD is unlikely to stem from a motivational inhibitory control deficit and more likely to be an executive inhibitory control deficit.

Executive inhibitory control can be broken down further into separate functions; for example:

1. Pre-potent response inhibition, the ability to choose a less frequently activated response over a more frequently activated response, commonly assessed with the Go/No-go task

2. Inhibiting on-going responses, the ability to stop the execution of a behaviour the programming for which has already been initiated, commonly examined with the stop signal task (SST)

3. Resistance to interference distraction, the ability to ignore or down regulate information that interferes with the efficient execution of a task, commonly examined with the Stroop, flanker, or Simon tasks,

4. Resistance to proactive interference, preventing previously relevant but now irrelevant information from intruding (Friedman & Miyake, 2004).

For individuals with ADHD, inhibitory control deficits are apparent for pre-potent response inhibition, inhibiting ongoing responses, and the withholding of a premature response on tasks requiring estimates of time duration. A poorer performance is seen for the Go/No-go tasks (Bezdjian et al., 2009). Vaidya et al. (1998) report that ADHD participants commit more errors of commission. For the SST, ADHD groups typically produce poorer performance (Barkley, 1997; Schachar & Logan, 1990; Schachar et al., 2004). Performance is impaired for motor inhibition as measured by the delayed response tasks (Sonuga-Barke et al. 1992). Deficits are seen for resistance to interference as measured by the Stroop task (King at al., 2007) and Wisconsin Card Sorting Test (Grodzinsky, & DuPaul, 1992).

The importance of inhibitory control impairments in ADHD is underscored by the observation that the delivery of methylphenidate, the primary drug of treatment of ADHD which produces a robust reduction of ADHD symptoms, improves inhibition of a pre-potent response and inhibition of an ongoing response (Scheres et al., 2003). Further, deficits in inhibitory control are also observed in those at risk of ADHD (Crosbie & Schachar, 2014) suggesting that the trait may be a causal factor.

1.1.3 Primary versus secondary cognitive deficits

When trying to understand cognitive deficits, it may be useful to demarcate between primary deficits and secondary deficits. In this thesis, I define a primary deficit as a deficit that is relatively far back in the causal chain; while I define a secondary deficit as one that is further down the causal chain and is the consequence of a more primary deficit. A primary deficit is not necessarily at the head of a causal chain and a secondary deficit is not necessarily the final point on a causal chain. It should be noted that what is defined as a primary deficit is simply a convenient label attributed to a deficit identified that is hypothesised to lead like a falling domino to a consequential deficit; the consequential deficit is labelled as secondary. Both are relative terms. For example, an impaired reinforcement system can be labelled as a primary deficit, while the impaired development or acquisitions of cognitive functions due to an impaired reinforcement system are secondary deficits. In this example impaired reinforcement learning may lead to impaired inhibitory control. Note however that impaired inhibitory control can similarly be classed as a primary deficit and the consequential impairments it originates are secondary. I propose that a primary deficit is more likely to serve as a useful diagnostic endophenotype, whereas a secondary deficit is likely to be less useful, since the further down a deficit is in a causal chain the more noise and variability that is likely to be introduced. However, while secondary deficits are less useful for identifying causal factors they are worth identifying and addressing, as they may prove worthwhile targets of remediation.

In considering secondary deficits, it may also be useful to draw a further distinction between those secondary deficits that cannot be remediated (possibly due to the nature of the primary deficits or the passing of a critical developmental window) and those for which there is latent capacity and the potential for remediation. In the latter case, a secondary deficit that does not reflect a lack of capacity but a lack of opportunity to develop the cognitive function offers a prime target for remediation through the delivery of a targeted intervention. Ideally, primary deficits would be identified early in a child's development in order that medication, environmental supports, or other interventions minimise the emergence of secondary deficits, particularly for those functions for which there is a critical window. In this way the negative impact of the primary deficits could be minimised. However, even in cases were secondary deficits have already been established those deficits for which there is latent capacity can be seen as the low hanging fruit, that is, a prime target for an intervention seeking to activate the latent capacity. This point has particular relevance for this thesis, in which I report the development of an intervention developed specifically to remediate cognitive deficits that are hypothesised as secondary deficits with latent capacity. This issue will be expanded upon in the succeeding chapter.

1.2 Progress in the field

There has been progress and emerging consensus in the field of ADHD research. Lange et al. (2010) provide a summary of development of academic accounts of ADHD. Since early studies around the turn of the 20th century, hyperactive impulsive children with a poor attention span have been described with a succession of names, such as Defect of Moral Control, Mild Mental Deficiency, Hyperactivity Disorder, Mild Brain Dysfunction, Hyperkinetic Syndrome and ADHD. Initially there was a moral interpretation of ADHD. Those with ADHD were considered "bad" and judged to be weak, immoral, or lazy. An encephalitis epidemic in 1917-1918 gave rise to the concept of a "brain-injured child syndrome" mirroring a shift to a biomedical model. In the 1940s and 1950s it was proposed that ADHD was the result of "minimal brain damage". Today subtle brain abnormalities are now accepted as a common feature of the condition (Goodman, 2009). Heritability studies subsequently highlighted the importance of genes as conveying susceptibility (with environment providing experiential activators). Proposed core deficit cognitive models (e.g. Barkley, 1997) have shifted over the last few decade from suggesting initially hyperactivity, later attention, later delay aversion and then inhibitory control as the key deficit (Sonuga-Barke, 2005). This has been followed by a shift from single to multi-deficits models (Sonuga-Barke, 2002; Sonuga-Barke, Bitsakou, & Thompson, 2010).

1.2.1 Models of ADHD

Various models attempt to account for the deficits associated with ADHD. Douglas (1988) suggested that a central impairment in self-regulation in ADHD gives rise to (i) poor investment and maintenance of effort; (ii) poor modulation of arousal to meet situational demands; (iii) a strong tendency to seek immediate reinforcement and (iv) deficits in impulse control.

Nigg (2010) describes two potential control systems that may account of ADHD symptoms - reactivity and regulation - both critical for controlling one's behaviour.

1. Reactivity control systems are driven by immediate affective incentive, potentially bottom-up involving the activation of subcortical or posterior brain regions which are involved in incentives.

2. The regulation control systems involve the evaluation of new information that is goal relevant. A top-down process informed by prefrontal brain regions involved in activation and corresponding suppression of behaviour. At the level of personality this could be broadly conceived as regulatory ability. Difficulty in regulating and effortful control behaviour could lead to attentional problems.

Barkley (1997) proposed an account of the development of executive functions and regulatory control involving a range of interrelated abilities served by regions of the prefrontal cortex and associated connections in the thalamus and basal ganglia. Behavioural inhibition is typically considered to be one of the "executive functions", however in Barkley's theory inhibition is a separate function that works in conjunction with executive functions. Its function is to inhibit a response to stimuli to provide a delay between stimulus and action. Executive functions then control behaviour. Inhibitory control is the primary deficit in ADHD and impairments in executive functions are a consequence of this failure to delay. The function of the executive system when given enough time is to implement deliberate planned actions.

Based on observed neurological abnormalities in frontal and parietal regions associated with executive function in individuals with ADHD, Barkley and others suggested that the key deficit relates to executive function impairments leading to either (i) problems with the cognitive regulation of behaviour, i.e., planning, attention, inhibition, WM, or (ii) impaired higher order functions such as strategic goal planning (Barkley, 1997; Krain and Castellanos, 2006).

Another body of research indicates that cerebellar dysfunction may be critical to understanding ADHD (Nicolson and Fawcett, 2005). Executive functions purportedly build on more simple functions such as motor control. A critical function is served by the cerebellum in this respect, which is implicated in the acquisition and automatisation of motor control. The cerebellum may also have a function in the development of cognitive control, for example, in the development of internal models of prediction and error detection / error correction (feedback loops), and assessing feedback in the light of predictions made. Bellebaum & Daum (2007) suggested that control shifts between cortical and cerebellar regions. Some evidence does suggest that motor control in early childhood predicts subsequent executive function control (Kochanska, Murray, & Harlan, 2000). If this understanding of the cerebellum is correct and it does have a foundational function necessary for executive functions and other processes, then its dysfunction will have a broad impact on cognitive and behavioural functioning, and may give rise to heterogeneous executive function deficits. It is common for children with ADHD to exhibit poor coordination skills (e.g. trouble learning to tie their shoe laces) and they are often described as clumsy. One proposal is that a critical component of ADHD dysfunction relates to the abnormal functioning of the cerebellum (Berquin et al., 1998; Durston, van Belle, & de Zeeuw, 2011).

Sergeant, Oosterlaan, & Meere (1999) proposed a state regulation or energetic model of ADHD that emphasises physiologic and performance data. Key features of the model are

- low cortical arousal relating to a right lateralised noradrenergic neural system
- low "activation", that is on-going response readiness related to the left lateralised dopaminergic networks.
- poor effort, relating to motivation

Sagvolden et al. (2005) proposed a "dynamic developmental" theory of ADHD that gives a pivotal role to altered dopamine function. It provides a comprehensive account of ADHD spanning the underlying neurology, individual behaviour and cognition, and the environmental context. This model is discussed in more detail in the succeeding section.

The brief summaries above highlight the multitude of approaches that have been taken to developing a coherent model of ADHD. Multi-deficit models may go some way to explaining the heterogeneity of the condition; however, given the emerging consensus that ADHD is aetiologically heterogeneous no single model will likely provide a fully comprehensive account of ADHD. This may suggest that there is a need for the identification of aetiological sub-groups (Fair et al., 2012; Roberts, Martel, & Nigg, 2013) (This point is further discussed in the discussion). For example, for one sub-population of individuals with ADHD, symptoms may arise via impaired reinforcement learning, for another via executive function deficits, and for another via congenital cerebellar damage.

1.3 Dynamic Developmental Theory of ADHD

The "dynamic developmental" theory of ADHD proposed by Sagvolden and colleagues suggests that the reinforcement system is disrupted due to an abnormal dopamine system, and that the symptoms of ADHD and other cognitive deficits observed are the result (Sagvolden et al., 2005). The symptoms associated with ADHD are the result of altered dopaminergic function which fails to appropriately modulate nondopaminergic signal transmission. In the dynamic developmental theory, response disinhibition, typically seen as a central deficit of ADHD, is proposed to result from the slower acquisition of long sequences of behaviour, combined with deficient extinction of previously reinforced behaviour. The theory proposes that:

- The hypofunctioning mesolimbic dopamine branch produces atypical behavioural reinforcement as well as deficient extinction of previously reinforced behaviour. This is observed as delay aversion, development of hyperactivity in novel situations, impulsiveness, deficient sustained attention, increased behavioural variability, and disinhibition of behaviour.
- The hypofunctioning mesocortical dopamine branch is associated with deficient attention and poor behavioural organisation, specifically deficient orienting responses, impaired saccadic eye movements, poorer attention responses towards a target, and poor behavioural planning and executive functions.
- A hypofunctioning nigrostriatal dopamine branch is associated with impairing motor functions due to impaired modulation of motor functions and poor nondeclarative habit learning.

These impairments give rise to apparent developmental delay, clumsiness, and a "failure to inhibit" responses when quick reactions are required. The altered reinforcement of novel behaviour and deficient extinction of previously reinforced behaviour impacts on how behaviour and its consequences are associated.

These impairments are proposed to impair learning in a number of ways; more repetition is needed to establish associations, more noise present in the system makes it hard to prioritise pertinent associations, closer temporal proximity between an event and its consequence is needed to establish the causal relationship (abnormally steep reinforcement gradient) (Johansen et al., 2009). In effect, they propose that the period of time that exists between behaviour and its consequences must be shorter compared to typically developing children in order that they are associated. This fundamental difference to a critical system that lies at the centre of how we perceive and learn about the world would have numerous consequences. A narrower reinforcement time window would restrict the stimuli that shape behaviour thus impacting on attention. It would also bias the reinforcement of short sequences of behaviour thus resulting in motor impulsivity. Altered behaviour extinction processes would result in hyperactivity and increased behavioural variability.

If, as suggested by Sagvolden's model, individuals with ADHD have an abnormal dopamine reinforcement system, impacting on learning in a number of ways, this is likely to also impact on an individual's motivation to learn those skills for which their reinforcement system is poorly adapted. Additionally compounding the impaired ability to learn may be a lack of opportunity to learn in a manner appropriate to their learning style. The education system, and more broadly the socialisation process that a society establishes, primarily cater for typically developing children. As a result those with an altered reinforcement system may be trebly disadvantaged when it comes to learning or developing a host of cognitive functions and socially communicated skills, some of which may present as behaviours diagnostic of ADHD. If viewed in this way many of the presenting diagnostic symptoms of ADHD may be secondary to the learning deficit, and further exacerbated by environmental factors.

2 Rationale for the current intervention

2.1 Argument for training inhibitory control

Inhibitory control is a skill that develops and is learnt across childhood and adolescence. It follows from the Dynamic Developmental Theory that individuals with ADHD may fail to develop inhibitory control due to abnormal learning or reinforcement, rather than due to a lack of capacity. A number of other studies have similarly brought into question the primacy of inhibitory deficits in ADHD (for example, Castellanos et al., 2006 and Willicutt et al., 2005; see Sonuga-Barke, 2005 for a discussion on this), that is, proposing that the impairments observed in inhibitory control are secondary to more primary impairment.

In addition to the impaired modulation of motor functions and poor nondeclarative habit learning resulting from a hypofunctioning nigrostraital dopamine branch as suggested by Dynamic Developmental Theory, an impairment in inhibitory control may compound the motor control deficits observed and thus may contribute to hyperactivity symptoms in ADHD. Specifically, given that eye movement control is intimately related to control of attention (where we are looking is often where we are paying attention), a lack of motor control in the ocular-motor system is likely to impact on attentional systems. Failure to exert control over gaze direction or to maintain gaze stability may account in part for attentional impairments observed in this population. While a degree of the impairment seen with respect to attentional control, hyperactivity, and impulsivity are proposed to be attributable to an abnormal dopamine system as delineated in the Dynamic Developmental Theory, a failure to acquire inhibitory control as a result is suggested to additionally exacerbate these cognitive impairments and symptoms observed. Training in inhibitory motor control may contribute to the remediation of both hyperactive and attentional symptoms in ADHD.

Might it be possible to train inhibitory control? Support for the notion that inhibitory control is a trainable skill comes from work showing that children with Tourette Syndrome demonstrate enhanced motor control in tasks requiring overt suppression of pre-potent responses (Jackson et al., 2011). It has therefore been suggested that constantly suppressing or delaying tics results in enhanced inhibitory control skill which transfers to other motor control tasks; for example, they exhibit better than normal gaze control during an anti-saccade task, as well as manual suppression control (Jackson et al., 2011). This suggests that inhibitory motor control can be learned and potentially overtly trained. In support of this hypothesis, Bialystok and colleagues found enhanced inhibitory control, including gaze control as measured by performance on an anti-saccade task, in bilingual children (Bialystok, 2006). They propose that the strengthening of their inhibitory control mechanisms is the product of the demands they place on their system to inhibit the lexical access or production when using one language or the other. Interestingly, this language-related improvement in inhibitory control also generalizes to an enhanced ability to resolve response conflict (Bialystok, 2006; Bialystok & Ryan, 2006). They outperform monolinguals on tasks with high inhibitory control demands; for example, ignore a misleading perceptual cue. This research suggests that inhibitory motor control is a trainable skill, but the question remains, can we train inhibitory control in a controlled setting, and specifically with an ADHD population.

Evidence suggests that inhibitory control is a function that develops in the natural course of development (Mangina & Sokolov, 2006). In a study examining the development of inhibitory control in pre-schoolers, Dowsett & Livesey (2000) suggest that the development of inhibitory control improves with age as a result of the development of the ability to develop complex rule structures, and that exposure to relevant tasks will aid the development of task relevant rule structures. Thus, it may be the case that the acquisition of inhibitory control can be accelerated with training. In addition, ADHD performance on inhibitory control tasks does approach that of typically developing controls when incentives are provided or if the task is novel or interesting (Borger & van der Meere, 2000; Luman, Oosterlaan, & Sergeant, 2005; Slusarek et al., 2001), supporting the hypothesis that motivational deficits may be primary to inhibitory deficits. This hypothesis is also supported by the finding that both, incentives and treatment with the dopamine agonist, methylphenidate, were found to normalise event-related default mode network suppression (Liddle at al., 2011) during a Go/No-go task. This evidence suggests that reinforcement mechanisms underlie performance on such tasks. More generally, numerous studies demonstrate the plasticity of the brain; for example, the widely cited enlarged hippocampus of London taxi drivers presumed to result from their extensive navigation experience (Maguire et al., 2000), musical training producing measureable neural changes (Herholz & Zatorre, 2012), and an intervention for dyslexia targeting the ability to convert visual letters to sound demonstrating the normalisation of neural activation (Eden et al., 2004). Considering the highly adaptive plastic nature of the brain it is reasonable to expect that neural networks within the brain can respond adaptively to a targeted training intervention that makes use of reinforcement. However, to produce long-term changes that transfer to real-life tasks through reinforcement-based training may be a challenge.

Individuals with Tourette syndrome and bilinguals can be thought of as models for such training. By virtue of their condition, they undergo extensive training in inhibitory control that is intense and of prolonged durations, and show inhibitory control performance that is, above the typical performance level. One of the major challenges of this project will be to develop an inhibitory control specific training intervention that can produce improvement in inhibitory motor control but at a practical level of intensity and duration.

Moreover, in developing such a training for people with ADHD, we are working with a population with a performance below that of the typically developing population. However, while inhibitory control deficits are observed in ADHD, this does not necessarily suggest a lack of capacity to develop inhibitory control functions, therefore easier gains may be possible as we are normalising an underdeveloped function. On the other hand, if their impaired inhibitory control is a result of a reinforcement deficit that has obstructed the learning of inhibitory functions in ADHD over the natural course of development, providing an appropriate level of motivational incentive may be key to developing a suitable training environment.

To summarise, a failure to develop inhibitory control may be a consequence of impaired reinforcement learning resulting from abnormalities of the dopaminergic system, as suggested by the Dynamic Developmental Theory of ADHD. If true, there may be latent capacity to develop better inhibitory control, including the inhibitory control over gaze direction that underlies visual attention, if given a training system that employs appropriate motivational incentives. Research suggests that inhibitory control is a skill that is acquired over the course of development. Work with individuals with Tourette syndrome and bilinguals suggest that inhibitory control is a trainable skill that transfers to untrained inhibitory modalities including gaze-control. Individuals with ADHD demonstrate ability for improved inhibitory control performance under the correct conditions, and we know that the neural system is adaptive and plastic. Impaired inhibitory control is likely to impact on a range of other functions; likewise improved inhibitory control will likely contribute to the remediation of a number of impairments.

2.2 Training Gaze Control

The eye-movement system lies at the interface between perception, cognition and behaviour (input, processing, and output). Eye-movement measures provide information about many processes that may be disturbed in disorders of attention and motor-control. As will be discussed in detail in chapter 4, a particular ocular-motor profile is associated with ADHD which may provide an endophenotype for the condition. In time this may provide a useful early diagnostic tool and method for monitoring treatment effects.

Vision is intimately related to the attention system. Aspects of attention are intimately related to inhibitory control and attention deficits are a diagnostic symptom of ADHD. A major assumption of the eye gaze literature is that gaze-direction is a proxy measure for visual attention. Generally, where we are looking is where we are attending. Findlay and Gilchrist (2003) provide an excellent overview of the visual system. The eye processes a non-homogeneous visual field. The foveal pit is the area responsible for central vision. It corresponds to a visual angle of 5 degrees. Preferential processing is given to the information that falls on the fovea. The "eye-mind hypothesis" suggests that by recording eye movement we can trace a person's visual attention (Just and Carpenter, 1984). Cognitive psychology has identified bottom-up mechanisms relating eye-movements to visual attention, e.g. saliency maps of the visual field (Koch and Ullman, 1985), as well as top-down mechanisms relating attention to the visual system, e.g., strategic decisions (Najemnik and Geisler, 2005), and specific interests (Birmingham, Bischof, and Kingstone, 2009). Imaging studies have also demonstrated the overlap of attention and eye-movement networks (Corbetta et al., 1998).

In addition to the direction of gaze being a proxy for attention, the degree of gaze stability may also be a measure of hyperactivity as gaze direction is determined by muscular movements. Also, gaze shifts in the face of exogenous stimulations may be a proxy for impulsivity. Control over eye movement may therefore be relevant to both the diagnostic symptoms of ADHD, namely attentional deficits, and the deficits of inhibitory motor control that may underlie at least some of the symptoms of hyperactivity/impulsivity. Given the evidence summarised from the Tourette's and bilingual literature that the trainable features of gaze-control are also those that underlie other forms of inhibitory control, training in inhibitory gaze control might remediate both inhibitory control and attentional symptoms in ADHD, sometimes collectively referred to as "cognitive control" deficits.

For the researcher, eye-movement studies lie conveniently at the boundary of the neural and behavioural level, being highly automated and reflexive responses to external stimuli, yet directly measurable as overt behaviours. They thus provide one of the most direct behavioural measures of neural activity bypassing manual motor or verbal response systems. In addition, and of particular use for the examination of inhibitory control, the eye-movements lie at the boundary of automatic and conscious control. They are fast and automatic, but can also be programmed and withheld. In this way eye-movement provides a direct measure of inhibitory control; we can observe participants' attempts to engage in conscious control over unwanted, pre-potent, and reflexive gaze behaviour.

Data on the visual system is readily collected with a video eye-tracker. Data collection is relatively straight forward and the equipment is quickly set up for collection. This is a direct non-invasive means by which to study the visual system. It provides a continuous stream of precise temporal and spatial measurements of gaze position. In addition to providing information on inhibitory control and attention, the provision of high temporal resolution data provides a means of accurately assessing and training the timing of motor responses. As an added benefit, because the eye-tracker algorithm requires pupil delineation and measurement, the eye-tracker can also output pupillary dilation data. Some debate exists regarding the interpretation of pupil dilations but there is a degree of consensus that it provides a measure of arousal or an index of cognitive resource recruitment in response to the demands being placed on the system (Pass et al., 2003; Granholm et al., 1996). Both tonic and phasic pupillary dilations can be measured. Tonic changes reflect more general factors such as emotional arousal and anxiety; phasic changes reflect task-evoked changes. Lastly, the number of blinks can also be calculated. Research has linked the number of spontaneous eye-blinks to levels of dopamine (Dreisbach et al., 2005).

Additional benefits of eye-tracking tasks are that, if well designed and programmed, they have a degree of naturalness. The tasks require no response devices (button boxes, joysticks, no language output) and lend themselves to clear instructions (Rommelse et al., 2008).

To summarise, as eye-movements are at the boundary of automatic and controlled actions, they provide a direct measure of both attentional focus and of inhibitory motor control. In line with this, gaze control deficits are observed in ADHD. The direction of gaze, and potentially the degree of engagement as measured by pupil dilations, provides a proxy for attention. As gaze direction is determined by muscular movements the degree of gaze stability may also be a measure of hyperactivity.

3 Cognitive Training

Increasingly attempts have been made to intervene at the cognitive level, attempting to enhance cognitive functioning or remediate cognitive deficits. Within the literature the label "cognitive training" is used to refer to strategy training, problem solving training, or the training of a specific function (such as working memory or attention switching, or inhibitory control). Cognitive training interventions may be designed to strengthen cognitive mechanisms that are thought to be weakened or underdeveloped, or to strengthen mechanisms that would allow the individual to more successfully compensate for cognitive deficits.

A major challenge in the development of training interventions is "transfer". If a particular function is trained do we see improvements in the performance of tasks involving different stimuli, or contexts, or response modalities, or in real life tasks? In other words does the improvement generalise? We might expect to see this if we trained a function that is upstream from another function. For example, if we a training intervention successfully targeted "cognitive control" this could have a broad impact on the performance of many tasks. Taking the example of bilingualism, fluency in a second language is proposed to result in improvement in inhibitory control that generalises to an enhanced ability to resolve response conflict. Bilinguals outperform monolinguals on tasks with high inhibitory control demands; for example, ignore a misleading perceptual cue (Bialystok, 2006; Bialystok & Ryan, 2006). In addition to this top-down notion of transfer we might also see improvements in parallel functions reliant on the coordinated activation with the trained function, for example, an improvement in a timing task performance when sustained attention is improved. Oberauer (2006) suggests that attention and WM processes draw upon a shared pool of resources, thus greater efficiency in one results in greater availability of resources for the other. However, it is worth noting that the labels and functional hierarchies we use do not necessarily map onto useful categorisations of cognitive functions. Cognitive science is rife with vague ill-defined terms.

3.1 Training General Intelligence

Many attempts have been made to improve general intelligence, often referred to as G. G is principally composed of crystalline intelligence (Gc), acquired knowledge, and fluid intelligence (Gf), ability to reason and problem solving based on the information available in the environment and on Gc. Gf is a strong predictor of academic and career success. Training interventions attempting to target Gf have resulted in task specific effects, that is, those trained demonstrate improved performance on measures of fluid intelligence with no transfer effects observed. Studies that do report transfer effects typically use testing tasks that bear a close similarity to the tasks participants have been trained on, raising questions of whether transfer has truly been demonstrated (Cassidy, Roche, and Hayes, 2011; Bergman Nutley et al., 2011).

Some of the most robust findings of the beneficial effects of cognitive training have been demonstrated for elderly participants (Willis et al., 2006). The effect may be specific to this group due to the protective effects of neural stimulations against the cognitive and neural decline associated with old age. Additionally, these effects may also be the result of the reengagement of underutilised neural mechanisms or simple reflect an up-regulation in activity levels generally. Importantly, these training effects are reported to have a positive impact on the performance of daily activities. Training improvements reported in the literature include processing speed, working memory, selective attention, and composite measures of cognitive functioning and executive function (see Kueider, et al., 2012, and Kelly et al., 2014 for a review).

A range of training interventions target a broad array of cognitive functions; e.g. sustained attention, selective attention, task switching and inhibition. Wass, Porayska-Pomsta, and Johnson (2011) used an eye-tracker administered battery of training tasks using a gaze-contingent interface targeting attentional control in typically developing infants. They report that training for one hour and a quarter led to improved cognitive flexibility, sustained attention, and to a reduction in saccadic reaction time latencies. Rueda et al. (2005) trained 4 and 6 year olds for 5 days over a 2 to 3 week period with tasks targeting object tracking, anticipation, stimulus discrimination, conflict resolution and inhibitory control. They report some transfer to reasoning tasks but no performance improvements on the Attention Network Test (Fan et al., 2002) or temperament scale ratings. They note changes to the anterior cingulate EEG activity associated with improvements. Those participants who were initially the poorest at attention tasks showed the most benefits, which suggests that this effect may reflect regression to the mean. Studies using adapted computerised versions of dimensional card sorting tasks compare the effects of training children, young adults and older adults. They report transfer to fluid intelligence and other executive tasks across all age groups (Karbach and Kray, 2009, Kerns et al., 1999 and Kloo and Perner, 2003).

Recently there have been studies attempting to train working memory (WM). A number of studies report improved WM after a period of training (Jaeggi et al., 2008; Klingberg et al. 2002; Oberauer, 2006; Olesen, Westerberg, & Klingberg, 2004; Salminen, Strobach, & Schubert, 2012). There is some debate as to whether this training is improving WM capacity or speeding up attentional processes within WM. An exciting aspect of this research is that WM improvements have been reported to transfer to executive function abilities. It has been proposed that WM and attentional processes share a capacity system, a shared resource pool. Thus, increased WM efficiency leads to a greater availability of resources for other cognitive functions. Oberauer (2006) suggests that WM training specifically on the n-back task leads to a speed up in attentional processes within WM, rather than to a pure increase in WM capacity.

Salminen, Strobach, & Schubert (2012) conducted a similar WM intervention study using a dual N-back training task with a typically developing university sample. The aim of the study was to identify transfer effects from WM training to different aspects of executive functioning, namely WM updating, coordination of dual discrimination task performance, task switching, and attention switching. No control intervention was used. 9 of the 18 controls completed the post test, while 13 of the 20 participants who took part in the training completed the post-test After the dual N-back training improvements were seen for visual spatial WM updating, and task switching and attentional processing. There was no transfer seen for the dual-task situation or to reasoning skills. While suggestive this is a small sample with a high attrition rate.

A study by Jaeggi and colleagues (2008) examined the impact of WM training (N-back) on fluid general intelligence (Gf). They propose that WM and Gf share a common capacity constrain referred to as binding, that is, the maintenance of a number of items or interrelations in the cognitive system. Participants were assessed on a matrix reasoning task, then received training for 8 days (N=16), 12 days (N – 22), 17 days (N = 16), or 19 days (N=15) on a dual N back task, before repeating the assessment on the matrix reasoning assessment task. After controlling for individual differences and improvements in WM with a digit span task they found Gf improvements. Importantly Gf improvements were dose dependent, that is, more training resulted in greater improvements. Irrespective of whether the dual N-back task can be classed as a WM task, these results are promising and suggestive of the potential to make cognitive gains with training. Replication, controlling for participant-experimenter interactions, and experimenter blinding are needed. Thompson et al. (2013) and others subsequently failed to reproduce this result. A recent meta-analysis of 20 studies examining the effects of N-back training on Gf suggested a small but significant positive effect (Au et al., 2014).

An intervention delivered to adults with dyslexia targeting the ability to convert visual letters to sound demonstrated an improvement in reading performance but also a normalisation of activity in regions associated with reading, the boundary between temporal and parietal lobes (Eden et al, 2004). A meta-analysis by Barquero, Davis, and Cutting (2014) examining reading interventions and neural activation concludes that performance can be improved as a result of interventions and that improvements are accompanied by neural activation changes in regions associated with reading.

Chapman and Mudar (2014) discuss an intervention targeting top-down cognition. The 'Gist' reasoning training purportedly targets strategic attention, integrated reasoning, and innovation. This training targets the acquisition of strategies to 'facilitate cognitive control and depth of encoding to facilitate knowledge acquisition and creation' (Chapman and Mudar, 2014). In contrast to interventions attempting to enhance cognitive functions, this training holds intuitive appeal as it seeks to enhance the utilisation of the cognitive functions already in place. While the results thus far are promising well controlled independent replication is needed with demonstrable functional improvements in everyday activities.

Numerous cognitive training programmes have been marketed in recent years directly to the public, in some cases, making grandiose claims about the benefits of cognitive training. A consensus statement was recently released by leading academics in the field in reaction to the claims by advertisers (Kooij et al., 2010). The statement rebuts claims that there is scientific support that such cognitive training programmes, or "brain games" as they are known enhance neural functioning such that cognitive performance in everyday life improves, or that cognitive decline, slowing, or disease in old age are reduced. It goes on to say advertisers frequently exaggerate and at times mislead the public with the claims made. While it is possible that cognitive training may lead to improvements in everyday functioning at present more research is needed. The effects thus far are small, narrow, and fleeting, and due to a publication bias positive effects are likely to be overrepresented.

3.2 ADHD and cognitive training

Many different types of cognitive training have been implemented with individuals with ADHD. Different interventions target deficits at different levels, for example, training in social skills, or strategies for controlling impulsive behaviours. Training interventions also attempt to teach the use of modelling, self-verbalisation, self-reinforcement techniques, and training in problem solving. Cognitive training interventions attempt to train more fundamental processes such as attentional skills, or WM (Abikoff, 1991; Halperin, Marks, et al., 2012; Halperin, Bédard, et al., 2012; Toplak, Connors, Shuster, Knezevic, and Parks, 2008, Wass, Scerif, and Johnson, 2012).

Cortese et al. (2015) conducted a meta-analysis of randomized controlled trials examining the effects of cognitive training on ADHD symptoms in children and adolescents with ADHD. A combined analysis of all types of training (N = 16) revealed significant effect for total ADHD and inattentive symptoms in cases were the raters were proximal to the treatment setting. However, these effects diminished and were not significant when the raters were "probably blinded". Laboratory testing did reveal gains for working memory performance but these gains did not translate into improvement on ADHD symptoms. Similarly Sonuga-Barke et al. (2013) conducted a systematic review and meta-analysis of non-pharmacological interventions, including psychological treatments, for ADHD. The psychological treatments examined included cognitive training, neurofeedback, and behavioural interventions. The significant effects seen for all cognitive treatments (standardized mean differences=0.40-0.64) when the outcome measure was based on ADHD assessments by raters closest to the therapeutic setting. However, the effects where again attenuated and not significant for the best probably blinded assessments.

Working memory (WM) capacity has been linked to performance on a number of tasks, including simple attention tasks, reading comprehension, reasoning and problem solving, and executive functioning in everyday life. Training WM may have an impact on several other functions (Salaminen, Strobach, Schubert, 2012). Klingberg et al. (2002) implemented a WM training intervention; they report a transfer effect to other WM tasks of a different modality. They additionally report a reduction in the number of head movements made during task completion after the training interventions. In a subsequent study the same research group conducted a pre, post and follow-up assessment for a WM training intervention versus a control intervention on 42 ADHD participants aged 7 to 12 years old. Those completing the training intervention demonstrated improvements in WM, response inhibition and reasoning, and a reduction in parent-rated inattentive symptoms (Klingberg et al., 2005). It is worth noting the control intervention for the WM tasks was a non-adaptive version of the task. This suggests that the adaptiveness of the training intervention is an important feature. In a study by Olesen, Westerberg, & Klingberg (2004) a sample of 8 participants underwent a fMRI scanning to examine neural activity during a WM task and a control task. Working memory training was found to increase activity in the dorsolateral prefrontal and parietal cortices suggestive of training inducted plasticity. These areas partly overlap with the prefrontal regions implicated in ADHD pathology.

Shalev, Tsal, & Mevorach (2007) trialled the Computerised Progressive attentional training (CPAT) programme developed for children with ADHD. Twenty children with ADHD and sixteen age matched controls aged 6 to 13 years old received the training composed of sustained attention, selective attention, orienting of attention, and executive attention tasks. Feedback on performance, a point structure, and a levelling of difficulty were used. Two sessions per week over an 8 week period were completed. Improvements were observed for a number of non-trained measures, including reading comprehension, passage copying, and a reduction in parents' reports of inattentiveness. No improvements were seen for the control group. While the authors conclude that they could not exclude the possibility that the improvements seen may be due to extraneous variability derived from pre-existing individual differences, the results are suggestive. Of particular interest is that the improvements observed relate to tasks with a direct relevance to daily academic function.

Kerns et al. (1999) trained 7–11 year-olds on dimensional card sorting; they report reductions in the severity of a number of ADHD symptoms as measured by teacher and parent behavioural ratings, and improved maths performance. Rabiner et al. (2010) trained 6–7 year-olds with an attention training programme. They report significant improvements in teacher rated behaviour and in academic performance for those children identified as having attention difficulties by their teachers.

An examination of the cognitive training literature suggests that gains are possible, that training may transfer to other domains and may have an impact at the behavioural or symptom level. However, there is a need for the above effects to be replicated. These arguments provide a context for the cognitive training intervention developed in this thesis. The thesis intervention aims to identify and remediate cognitive deficits associated with ADHD. In the proceeding chapter I provide a rationale for the intervention developed suggesting that cognitive control has latent capacity in ADHD that can be utilised by training inhibitory gaze control. In the succeeding chapter I will outline a framework for the visual system and review the inhibitory gaze control deficits observed in ADHD populations.

4 Gaze control in ADHD

Having argued that inhibitory gaze control affords a viable and appealing target through which the latent potential of the cognitive control system in ADHD can be activated, this chapter first provides an overview of the visual system drawing upon the anticipatory, feed-forward, and competitive integration models, and then reviews a number of saccade control paradigms and the associated deficits observed in ADHD populations.

4.1 The visual system

Before considering deficits in the visual system associated with ADHD it will be useful to first provide an overview of the visual system. Much of this review of the visual system is informed by Findlay and Gilchrist (2003). The study of the visual system is often broken down into a number of subsystems. The pursuit system (smooth pursuit) allows the maintenance of gaze on a target when either the target or the observer is in motion. The vergence system maintains the alignment of both eyes on a target that moves in depth or adjusts for a new target. Of most relevance to the training intervention are the fixation and saccade systems. The saccade systems' function is to bring selected targets to the fovea. The fixation system maintains the direction of gaze at a single target.

The fovea is the high resolution area of retina and covers just 0.1% of the visual field. This area of high acuity continuously scans the visual scene, the eyes alternating between periods of relative fixation and saccadic shifts. This behaviour creates the subjective illusion of a whole visual field with high detail. Within the visual system sensory experience and motion cannot be viewed separately. Eye movements help to stabilise gaze in response to head movement and other large image motion, but image motion can also benefit vision (Rucci et al., 2007). In the absence of image motion on the retina visual perception fades (Martinez-Conde et al., 2004; Tulunay-Keesey, 1982).

Saccades are typically only a few degrees in magnitude, though during an active task they can be as great as 18- 20 degrees. Saccades are ballistic, that is, they cannot be intentionally modified once initiated, though their trajectory can be influenced by bottom-up processes in advance, e.g. distractors. Information arriving less than 70 ms prior to the start of a saccade cannot modify the movement (Quaia, Lefévre, and Optican, 1999). Post saccadic drifts (slow irregular movements) are typically seen. In simple experimental saccade tasks (e.g. pro-saccade task) a bimodal distribution for saccade latencies is often seen. This occurs because there are two mechanisms by which saccades can be generated; a reflexive mechanism which generates "express saccades" in the latency range of 100 to 130ms in humans and a more overt control mechanism that produces saccades of greater latencies. Eye movements to more distal targets typically require two saccades due to a degree of noise in the system. The initial saccade covers the majority of the distance, approximately 90% of the distance (Walker & McSorley, 2006). It has been suggested that consistently falling short of the target location reduces the computational load and processing speed of the second smaller saccade as its direction can be pre-programmed. An attempt to shift to a distal location in a single saccade would in the majority of attempts lead to over- or under-shooting the target and require the system to fully orientate before determining the direction of the secondary saccade (Harris, 1995).

Fixation is a dynamic state: during a period of fixation drift movements will occur a few times per second, tremors (rapid irregular movements) and micro saccades (small jump-like movements) will occur up to 2 to 3 times a second. Fixation eye movements drive vision during fixation. Rucci et al. (2007) demonstrated that image motion can benefit vision, further it has been shown that in the absence of image motion on the retina visual perception fades (Martinez-Conde et al., 2004). The nature of the stimuli and the processes involved influence fixation. Oral reading has been found to produce longer fixations than silent reading, fixations are also longer for scene perception than for silent reading, and a greater range in duration is seen for visual search tasks compared to other tasks (Rayner, 2009).

Micro saccades are usually around 15 min arc magnitude but are as large as half a degree. Micro-saccades are increasingly seen as a scaled down version of saccades as opposed to a special class of movement. Saccades and micro saccades appear to have a common neural generator (Van Gisbergen et al., 1981; Hafed et al., 2009; Brien et al, 2009; Van Horn & Cullen, 2012), have a comparable distribution in time

(Heikkenen, 1965; Rolfs et al., 2006; Otero-Millan et al., 2008), and are comparably affected by covert attention and distracters (Hafed & Clark, 2002; Engbert & Kliegl 2003).

4.1.1 Anticipatory and feed-forward models of vision

Are stimuli passively perceived or is perception active? Some theories posit a passive, serial process such that the generation of an internal representation of the world is achieved through processing of the retinal image. Information enters the system, is processed, decoded, and then manipulated by the executive and higher cognitive functions, and overt behaviour is subsequently produced (McLeod, 2008; Neisser, 1967; Treisman, 1964). Such linear flow chart models are increasingly untenable given their limited utility in explaining the data gathered. An examination of the visual system highlights the high inter-dependence of processes which are often investigated in isolation, such as action and perception (Schütz, Braun, and Gegenfurtner, 2011), ignoring the processes of interpretation and assignment of meaning (involving expectations, knowledge, motivation, and emotions). Evidence suggests that by drawing on our pre-existing knowledge, our expectations, and the visual input to the retina we generate a representation of our visual world, this representation in turn guides (or biases) our visual exploration of the world and our processing of the sensory input (Findlay and Gilchrist, 2003, Summerfield and Egner, 2009).

Support for this view of vision is found in the examination of covert attention (a shift in the focus of attention that is not accompanied by eye or head movements). Around the fovea is an area of high spatial acuity called the conspicuity area. This area is extended in the direction of covert attention and receives preferential processing. Covert attention is a necessary precursor to a saccade; it is the peripheral preview for the next fixation location providing the appropriate information for the subsequent orienting movement and foveal recognition. Research demonstrated that neural activation of retinoscopic maps shift in anticipation of the movement to come, that is, the firing pattern is not simply reactive to stimulation but anticipates the stimulation that will result from the upcoming saccade (Colby, 1992). In addition, Hoffman and Subramaniamm (1995) demonstrate that it is not possible to orient attention to one location whilst moving the eyes to another thus indicating the correspondence of these systems. This research demonstrates that sensory input is preceded by activation in expectation of input. Further, research suggests that top-down expectations bias the sensory processing of visual information at the early stages of processing in the visual cortex (Kok et al., 2013).

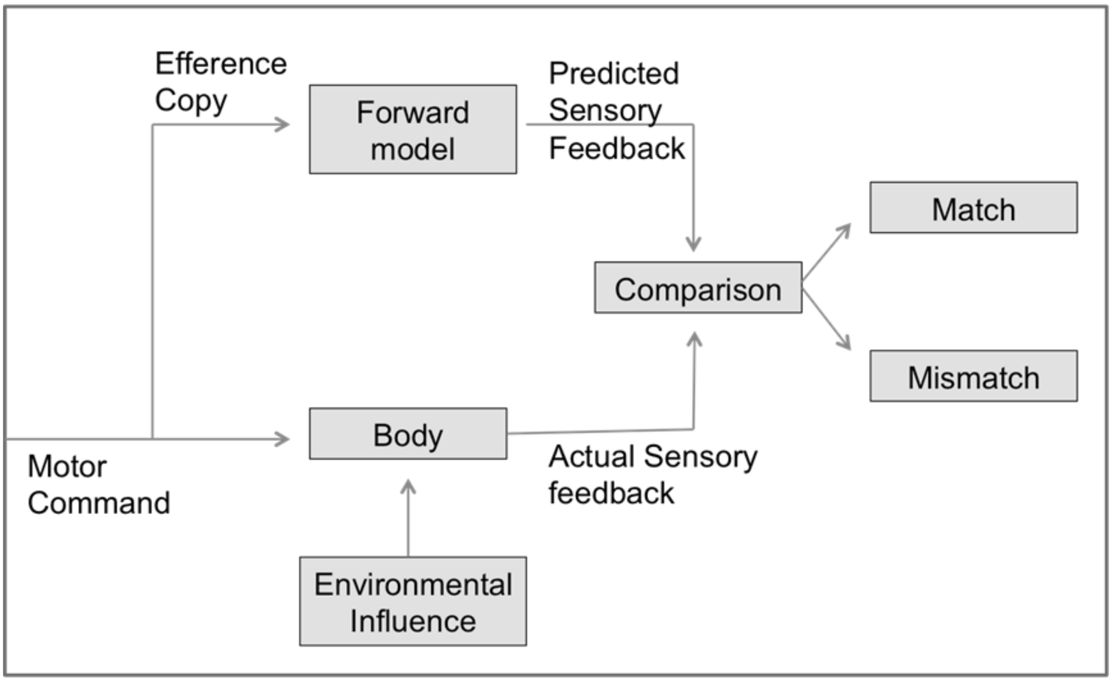


Figure 1 Prediction model of motor control (adapted from Bubic et al., 2010).

Figure 1 is an illustration of a feed-forward model. Such models do not question the importance of the feed-forward information flow, but also emphasise the relevance of feedback and recurrent processing. The feed-forward model of vision and motor control additionally posit that an efferent copy of motor commands are used to generate a "forward model", that is, an anticipation of predicted sensory feedback based on a representation of the environment and the motor commands issues. The representation is then compared to the actual sensory feedback and any error observed is used to refine future predictions. Based on the efference copy of the motor command, the idea is that a forward model is formulated and used for predicting the consequences of one's own actions. These predictions are compared with the incoming sensory input which can result either in a "match" in case predictions were correctly formulated, or a "mismatch", signalling an error in prediction.

We do not process the visual world as it exists; networks of heterogeneous cells anticipate and signal motivationally relevant targets, signal novelty, process reward values associated with phenomena, and influence motor responses. Our goals and mental state provide the context within which feedback is processed. Attention and cognition integrating feedback from various sources modulates executive activity which in turn produces motor responses. It is the generation of expectations and the utilisation of pre-existing patterns that produces the illusionary subjective impression of seeing a complete world (Bush, 2009, Noë, 2002).

Given the levels of noise and ambiguity which are always present both in the neural system and environment this approach highlights the importance of introducing bias for facilitating and optimising current processing. The implicit assumption of bottom-up serial processing models is that we react once all relevant information has been presented and fully processed. But by taking into account the current context and previous experiences integrated across different timescales predictive models allow us to act, as opposed to simply react. Anticipation allows for more pertinent reactions in the immediate situation.

4.1.2 Competitive Integration Model

A fine-grained account of saccade generation and the role of top-down attentional control are provided by the Competitive Integration Model (Godijn and Theeuwes, 2002). This model assumes that the programming of saccades is based on the competitive integration of endogenous (top-down goal directed) and exogenous (bottom-up stimulus driven) activity. It explains many phenomena observed in the saccadic system (e.g. global effect, centre-of-gravity effect, curvi-linear saccade paths) while providing an account of how goals and conscious control are combined with the input from the visual environment when deciding where to direct gaze. With respect to understanding inhibitory control it provides an account of how the eyes can be captured by the onset of an exogenous stimuli even though we know the stimulus to be irrelevant, and also how top-down control of the system ensures the direction of gaze is not wholly determined by the visual salience of phenomena in the environment.

The Competitive Integration Model posits the existence of a retinotopic saccade map located in the superior colliculus upon which endogenous (internally) and exogenous (external) activation is integrated. A saccade target location is based on the mean vector of activity on the saccade map. A lateral interaction structure is present, whereby activation at a particular location on the saccade map spreads to neighbouring locations and inhibits distant locations. Two distant location activations are mutually inhibitory and two nearby locations will produce combinatory activations. Top-down inhibitory mechanisms can act directly on exogenous activation to reduce activation and thus ensure a saccade is not made to this location. Such location specific inhibition can pre-empt the arrival of a distractor and can cause a sub-baseline level of activation at this location. A saccade is triggered when activation at a particular location reaches a set threshold. Our experience and expectations lead to both the activation and inhibition of regions of the saccade generation map. One way of interpreting the top-down influence is as a bias signal with the potential to improve the computational processing with respect to achieving goals. This model draws together a number of processes of interest and offers a framework by which to analyse ocular-motor behaviour on tasks assessing inhibitory gaze control.

4.1.3 The neural activity of saccade generation

A number of brain areas are involved in the control of visual fixation and saccade production. Two important nodes of activity are the frontal eye fields (FEF) located in the frontal lobes, and the superior colliculus (SC) (Munoz and Schall 2004). Both of these regions contain fixation and saccade neurons. The fixation neurons are active and the saccade neuron inactive during visual fixation, and vice versa during saccades (Munoz and Fecteau 2002; Munoz and Schall 2003; Munoz et al. 2000). Reduced fixation and increased saccade neuron activity is seen with the removal of an exogenous fixation target (Dias and Bruce 1994; Dorris and Munoz 1995; Dorris et al. 1997; Everling and Munoz 2000; Everling et al. 1999). Top-down endogenous activity to suppress unwanted saccades is seen during the anti-saccade task. Relative to the prosaccade task, during an antisaccade trial increased fixation and decreased saccade neuron activity is seen before the arrival of the distractor stimulus, that is, in anticipation of the distractor's arrival (Everling and Munoz 2000;

Everling et al. 1999). Once successful suppression of the reflective saccade is achieved a saccade to the target location can be programmed.

Two likely structures involved in endogenous control of signals in the FEF and SC are the dorsolateral prefrontal cortex (DLPFC) and the substantis nigre pars reticulate (SNr). These areas provide inhibitory input to the SCc (Hikosaka and Wurtz 1983; Munoz and Istvan 1998; Munoz and Wurtz 1993), and possibly to the FEF via a thalamus relay (Lynch et al. 1994). Areas critical for the programming of muscle commands are the cerebellum and the premotor brainstem circuitry. Motor neurons in the brain stem innervate the extraocular muscles (Leigh and Zee, 1991). Cerebellar input to the premotor circuitry carries information on the motor programming of saccades and is critical for saccadic accuracy. Munoz and colleagues attribute poor inhibitory control in ADHD to a weakened endogenous suppression signal due to a frontostriatal deficit (Munoz, Armstrong, Hampton, & Moore, 2003; Munoz, 2002).

4.2 Saccade control in ADHD

In light of the complex attentional and motor control systems that underlie gaze control, as reviewed above, it is perhaps unsurprising that gaze-control deficits are seen in ADHD. In this section I will review evidence for gaze control deficits in ADHD. Of particular interest are the inhibitory gaze control tasks: the antisaccade task and the stop-signal task. These tasks are subsequently used in the development of the training intervention.

4.2.1 Prosaccade

Two classic saccade tasks used in the gaze-control literature are the prosaccade and antisaccade tasks, or variants on these basic paradigms. In the prosaccade task participants simply shift their gaze from a centrally located fixation point to the target as soon as it appears. The target will typically appear at a set distance of between 10 to 15 degrees to the left or right. Typical reaction time (RT) latency for a prosaccade is 150 - 250ms.

Figure 2 illustrates the time course of activation in the saccade map for a prosaccade task according to the competitive integration model. In panel A the only exogenous activation is generated from the fixation point stimulus. We can see that no saccade will be triggered because at no point on the saccade map is activation above the threshold point. Note that the activation at the fixation point laterally inhibits activation at all other points on the saccade map reducing activation to below the baseline level. In panel B the target to which a prosaccade should be made appears; this results in activation at the target location exceeding the threshold level of activity leading to the initiation of a saccade to this target location. Note also the dip in activation seen at the fixation location. This dip facilitates the speed at which activation at the target location can reach the required level of threshold activation and thus facilitates a faster RT.

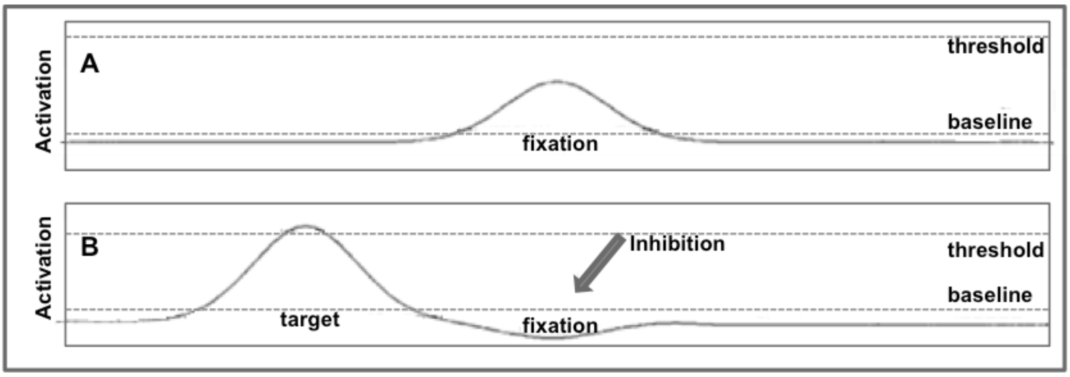


Figure 2 Time course of activation in the saccade map for a prosaccade task according to the competitive integration model (source: Modified from Godijn & Theeuwes, 2002).

4.2.1.1 Prosaccade performance in ADHD

A number of studies have examined the performance of ADHD participants on the prosaccade task. This task is a good assessment of the general function of the visual system. Mostofsky et al. (2001) found no latency difference between children with ADHD and controls, however children with ADHD who were off medication (methylphenidate) had greater variability. Karatekin et al. (2009) examining children and adolescents found an increase in RT variability for the ADHD group. In a larger study (114 ADHD participants) Munoz et al. (2003) found that ADHD was associated with longer reaction times, greater intra-subject variability, and reduced peak velocity and duration. These findings have not always been replicated and often the effect sizes are small (Hanisch, 2006; Karatekin, Bingham, & White, 2010;

Mostofsky, Lasker, Cutting, Denckla, & Zee, 2001). The consensus is that the ADHD population have an intact ocular-motor system for the generation of saccades. It has been suggested that the observed behavioural effects may reflect a failure of sustained attention, but these studies do not clarify whether the deficits of ADHD pertain to motivation, attention, or other cognitive functions such as executive function.

4.2.2 Antisaccade

The stimuli used in the antisaccade task are the same as those in the prosaccade task except that instead of shifting to the target participants must shift to the mirror opposite location of the target. This requires inhibitory control, sustained attention, and reprogramming. The reaction time is typically 100 – 200ms longer than for the prosaccade task. Improvements in antisaccade performance are seen between the ages of 6 to 16 years. Task improvements correlate with maturation within the network of brain areas that includes the frontal cortex and basal ganglia (Klein & Foerster, 2001; Luna et al., 2001). Older children exhibit faster saccades and less erroneous prosaccades, as well as less erroneous express saccades. Everling and Fischer (1998) report an error rate of 60% in children below the age of 10 years and 20% at the age of 20 years.

The time course of activation for a successful antisaccade task is illustrated in Figure 3. In panel A activation is only seen at the fixation point and other activity is below the baseline. The arrival of the exogenous stimulus, the onset distractor (the cue to make an anti-saccade in the opposite direction), has the effect of increasing activation at this location. Note the level of activity does not reach the threshold level of activation needed to trigger a saccade to the distractor location. The arrival of the distractor also reduces activity at the fixation location via lateral inhibition and further depresses activity at all distal locations. In panel C endogenous control is exerted. Top-down processes inhibit activation at the fixation and onset distractor locations. Elsewhere in the brain a location transformation is computed on the onset distractor location to determine its mirror location, that is, the saccade target location. Note that there is no exogenous stimulus present at the saccade target location. This information is used to endogenously generate activity at the saccade target location. In panel D activation at the target location reaches the threshold level of activity triggering a saccade to this location. Inhibition at the fixation and onset distractor locations creates a sub-baseline dip in activation.

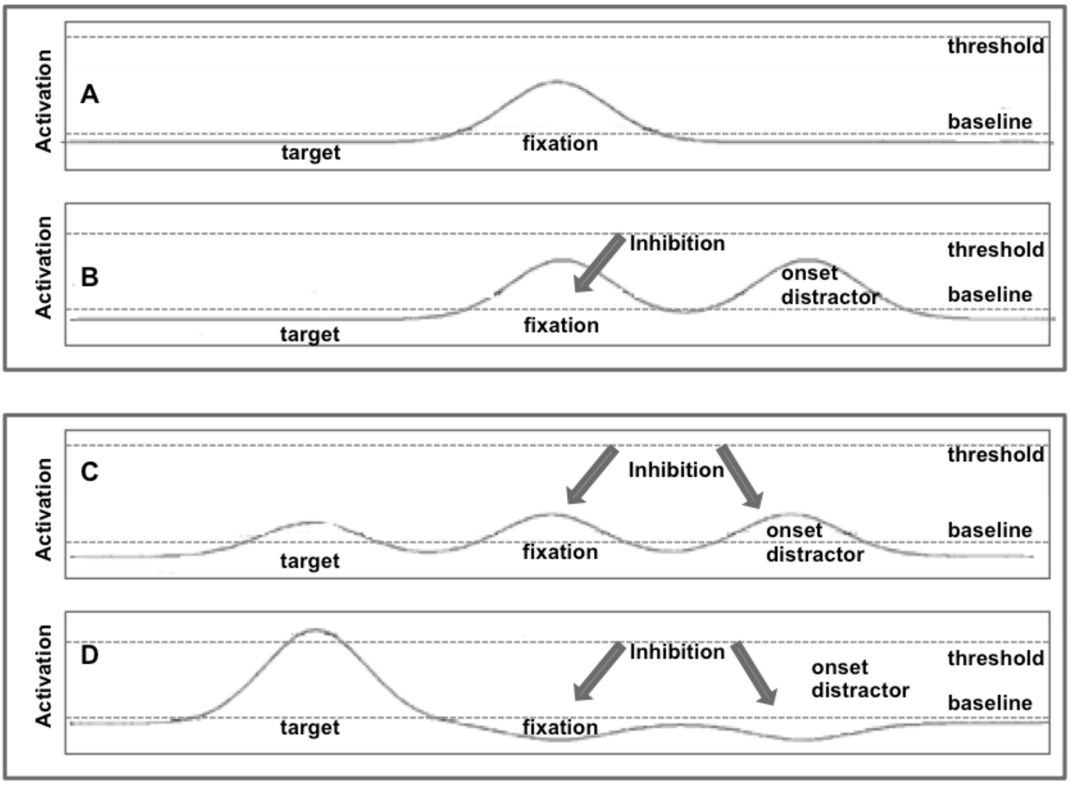


Figure 3 Time course of activation in the saccade map for a successful antisaccade task according to the competitive integration model (source: Modified from Godijn & Theeuwes, 2002).

4.2.2.1 Antisaccade performance in ADHD

Mixed reports for ADHD deficits are seen for the anti-saccade task, but the effects are more robust than those seen for the prosaccade task. This task is proposed to tap into inhibitory control mechanisms among others. Reflexive errors, fast automatic saccades to the location of newly presented stimuli, are a common error made during the antisaccade task, particularly for gap conditions. Children, adolescents, and adults with ADHD (Karatekin et al., 2009), on and off medication (Mostofsky et al., 2001), have been found to perform more poorly on this task. Compared to controls they make more reflexive saccades, a longer latency for reflexive saccades, directionally errors (Mostofsky et al. 2001), have increased RT on correct trials and more RT variability (Karatekin et al., 2009; Munoz et al., 2003), thought these results are less robust for adults (Karatekin et al., 2009) and have not always been found (Hanisch et al. 2006). An increased number of directional errors would suggest a deficit in response inhibition or goal neglect. The increase in RT variability may suggest attentional fluctuations. Karatekin et al, (2009) also reported significant accuracy and RT effect for the first but not the second block, and suggested that this may indicate a problem with the regulation of arousal for a novel task. They further reported fewer corrective saccades once an error had been made which may reflect difficulties with self-monitoring or goal neglect.

4.2.3 Stop-Signal Task

Less used in the eye-gaze literature is the countermanding task also referred to as the stop-signal task. The task has go trials in which the participants must make a saccade to a target location, and stop trials in which the go signal is followed by a stop signal, the signal to withhold the planned saccade to the target location and to maintain fixation at the central fixation cross. The stop signal is typically a centrally located visual stimuli or an auditory tone. For stop trials the delay between the go and subsequent stop signal is referred to as the stop signal delay (SSD). The length of the SSD is typically varied based on the participant's success or failure to inhibit responses on stop trial. The SSD thus tracks performance and is typically set to produce a 50% success rate. The stop-signal task is a paradigmatic inhibitory control task. The antisaccade task requires that a reflexive saccade be withheld, but the stop signal task measures how quickly an individual can inhibit (cancel) the execution of a planned saccade movement (Logan, 1994; Schachar et al., 2004). The action is considered "planned" because the majority of trials are go trials (typically 66% to 75% go trials) and because the participants have insufficient time to plan a saccade if they wait to see if a stop signal will arrive. Successful performance on both go trials and stop trials entails the programming of a go response which must be cancelled if a stop-signal is given.

The horse race model posits that there are two independent processes; a go (the overt RT to the stimulus to act) and a countermanding stop process (covert RT to the stop signal that cancels the go process, referred to as the stop signal reaction time, or SSRT). Both processes take a variable amount of time to complete. The go process has a head start but the stop process is faster. The stop process must catch-up before the motor command is initiated, the ballistic point of no return. The covert stop process is widely referred to as the Stop Signal Reaction Time (SSRT). The SSRT is inferred by examining the RT distributions for "go trials" and failed "stop trials".

4.2.3.1 Stop-signal performance in ADHD

Longer SSRT's are observed in children with ADHD (Jennings et al., 1997; Logan et al., 1997; Nigg, 1999; Schachar, Tannock, and Logan, 1993) using manual versions of the task. Similarly, when performing a saccadic version of the stop-signal task adults with ADHD inhibited fewer saccades than controls, especially when there was a longer delay before presenting the stop signal, but they also tended to respond slightly quicker so there is most likely a trade-off between commitment to respond and speed (Hanisch et al. 2006; Armstrong and Munoz, 2003). While the Stop Signal Task purportedly measures inhibitory ability as indexed by the SSRT other contributing factors must be entertained, for example, reduced vigilance due to attentional fluctuations, or poor timing in the execution of attentional or inhibitory functions (Liddle et al., 2009). There is a need to also consider motivational factors such as perceived value. Motivational incentives affect the efficiency of inhibition in cognitive control tasks. In tasks with a trade-off between speed and accuracy the valuation of the likely outcomes modulates the balance between inhibition and activation. Motivational incentives normalises performance in children with ADHD (Liddle, 2011; Slusarek et al., 2001).

4.2.4 Fixation task

Tasks assessing visual fixation are a good measure of gaze stability and gaze stability in the face of distractions. For fixation tasks, in which participants must fix their gaze on a point in the absence or presence of distracter stimuli, individuals with ADHD produce a larger number of intrusive saccades (Munoz et al., 2003). Munoz (2003) suggests that ADHD participants have a reduced ability to suppress unwanted saccades and control their fixation behaviour voluntarily, a finding that is consistent with a fronto-striatal pathophysiology. Hanisch et al. (2006) reported more intrusive saccades at the beginning of the task which may suggest they were exploratory saccades. In a task requiring fixation for 21 seconds where no exogenous distracters were presented Gould et al. (2001) reported impaired fixation in ADHD children. They suggest that ADHD children have a problem with their fixation system as opposed to a failure to inhibit an unintended response to external stimuli.

4.2.5 Pupillometry

Pupillometric data is often gathered concurrently during ocular-motor tasks. Pupillary dilations are sensitive to task difficulty, and are particularly sensitive to memory load. For a digit span task pupil diameter increases can be tracked as additional digits are added until the participant repeats the sequence. Dilations will also level off or decrease if the load exceeds memory span. Tonic pupillary data is used as an index of physiological arousal, whereas phasic pupillary data is a measure of cognitive load. Pupillary waveforms are found to be different for erroneous trials. A higher rate of errors in the anti-saccade task is associated with smaller dilations in controls. Pupil dilations are larger for the antisaccade task compared to the prosaccade task in controls, but not in ADHD. This may indicate a deficit in the regulations of tonic levels of arousal (Karatekin et al., 2009). For an n-back task we see larger dilations for 1-back versus 0-back. There were however smaller dilations across conditions for the ADHD group; in addition the size of dilations correlated with d’ scores for the task (Karatekin, 2009). This data may indicate the ADHD deficits are in part due to problems in regulating physiological arousal on a moment to moment basis in accordance with task demand, fluctuations in maintaining a readiness to respond quickly, and that this deficit is exaggerated under conditions requiring greater attentional control.

5 What to train

In this chapter I draw on the feed-forward model of cognitive function and argue timing and attention are critically linked to inhibitory control. Training inhibitory control therefore necessitates that aspects of timing and attention be considered in the development of the training intervention. A brief review of the literature on timing and attention is provided.

5.1 Inhibitory control cannot be viewed in isolation

The training intervention reported in this thesis targets inhibitory control of gaze. It is however difficult to disentangle cognitive functions. As with most functions, inhibitory control cannot be assessed in isolation. A number of dominant approaches attempting to delineate cognitive processes imply a passive, bottom-up, serial process: such models start with the sensory input, continues with executive and higher cognitive functions, and ends with overt behaviour. Such thinking is exemplified in the original behaviourist and early information-processing theories. While this linear stimulus – leading to processing - leading to response view of human behaviour is now less pronounced, cognitive processes are still predominantly studied in isolation. More realistic are models that see the cognitive system as being in a constant state of flux, processing information in both serial and parallel modes simultaneously and holding biased expectations that contextualise the processing of stimuli. Mostly likely cognitive functions cannot be conveniently boxed off in a manner often seen in models of cognitive processes, and when trying to assess or train inhibitory control, we must be aware that a host of related and supporting functions are also likely to be activated, and that sub-functions utilised operate in the context of the broader system. This is however problematic: psychology and neuroscience as scientific disciplines have not matured to the degree that a basic unit or an agreed upon framework of cognitive and neural processing has been identified. The field of cognitive science is rife with alternative models of brain function, and these are often a fragmented mosaic picture of cognitive functions which do not readily produce a coherent global picture, but instead often contradict. The lack of clarity is problematic when we draft an operational definition of inhibitory control and identify related or supportive functions. Inhibitory control cannot be viewed in isolation; the interdependence of processes must be appreciated. Exercising inhibitory control inevitable involves the deployment of other functions, for example, components of attention and timing. In addition, in training inhibitory control (as opposed to the use of the currently level of inhibitory control ability) the process of training will also draw on additional cognitive processes.

Attention is critically deployed in multiple ways when exercising inhibitory control. For example, children with ADHD fail to slow their responses to the same degree as typically developing children following a failed inhibitory control response (Schachar et al., 2004). This may reflect a performance monitoring impairment which hinders the execution and learning of inhibitory control. Critical to the execution of inhibitory control, attention, and learning, is the accurate temporal deployment of cognitive resource, that is, a precision in when a function is deployed. Multiple aspects of timing have been reported as impaired in ADHD (Hart et al., 2012). In addition to targeting inhibitory control the training intervention will additionally target attention and timing deficits. The involvement of timing and attention with respect to inhibitory gaze control will be further discussed below.

5.1.1 Attention and timing in inhibitory gaze control

The anti-saccade task can illustrate the involvement of attention and timing in execution of a successful inhibitory control performance. When completing a block or multiple blocks of a trial a participant will develop an anticipatory model to optimise performance. While the tasks utilised may have unpredictable elements, for example the location on screen at which a distractor will appear, there are other task elements that can be anticipated to increase the efficiency of cognitive resource expenditure. For example, time estimations of the inter-trial interval and the time window within which a distractor will appear, anticipating the need to strengthen fixation to guard against ocular capture by the imminent arrival of a distractor, and preparing to compare a self-evaluation of performance against the task feedback given.

The successful execution of an anti-saccade requires the attentive regulation of activity on the saccade map. Keeping the task instructions in mind the participant must anticipate the need to initially maintain fixation in the face of the sudden onset of a distractor. Generating a fast RT to the target location also entails exercising just the right amount of endogenous activation of the fixation location; too little will result in ocular capture by the distractor cue, but too much will increase the time required to generate a saccade to the target location. Maintaining a preparedness to respond is required for initially computing the transformed sensorimotor coordinates and then exercising endogenous saccade map regulation to initiate an antisaccade to the correct location.

An anti-saccade RT is faster when there is a set inter-trial interval, that is, when the temporal arrival of the distractor can be anticipated (Karatekin, 2006). Greater temporal precision implementing endogenous regulation over saccade map activation and inhibition will result in greater efficiency, that is, greater economy of cognitive capacity expenditure to produce the same performance outcome. Effective timing has knock on effects for the efficiency with which numerous functions are utilised. A highly inefficient sense of timing may not impact directly on inhibitory control, but it will require the expenditure of an excessive amount of cognitive capacity by extending the period of time within which a readiness to implement inhibitory control must be maintained. Expert performance is the result of efficient use of resources and an accurate sense of timing is instrumental for efficiency.

Given this, what are some of the attention and timing deficits we see in ADHD? Below I provide a brief summary of timing and attention, and the deficits in these function associated with ADHD.

5.1.2 Timing

A critical aspect of attention, inhibitory control and a range of other functions are their deployment at critical junctures (see Maniadakis & Trahanias, 2014 for a discussion on the role of time in cognition). Using the attentional system to monitoring the external world does not bear a similarity to a switch that is either on or off but instead its activity ebbs and flows based on our expectation of significant relevant events. The more accurate our temporal perceptions of when events occur and how long they last the greater the temporal accuracy of the representation we create. The more accurate our representations and the greater the temporal precision with which we deploy our cognitive resources the more efficient we are in the use of our cognitive resources. If we are deficient in our ability to form accurate expectations of when to deploy attention, or in the controlled deployment of attention, we are likely to use greater amounts of cognitive resources or glean less pertinent information from a situation; the system will be inefficient and deplete resources more readily, learning and perceptions will be impaired.

Time-dependent function is ubiquitous and fundamental to the efficient operation of all organisms. All animals and plants have a need to respond to the cyclical rhythms that result from the passing of time. The duration varies from fractions of a lifetime to milliseconds. We have no obvious sense organ by which to perceive time, time cannot be directly observed, instead only its effects can be observed and the passing of time itself inferred. Derived from internal processes time is reconstructed by the brain. Our perception of duration is subjective and can vary. Different mechanisms are used for supra and sub second intervals.

Our perception of time can be based on exogenous stimuli, either rhythmic or constant temporal dynamics within the external environment, or it can be derived from endogenous internal activity, potentially an internal clock or regularities within the neural system. A prominent model of time estimation is Gibben's pacemaker-accumulator model (Gibben et al, 1984). When triggered an accumulator begins to count pulses emitted by an internal pacemaker. The pulse tally can be passed to WM for comparison with previously stored tallies. An attention gate or switch determines whether all pulses are counted or not, this accounts for how paying attention to time can impact on estimations and the subjective experience of duration. Less attention means fewer pulses counted and an underestimation of the interval.

A degree of experimental support has been found for this model but its neurological plausibility is debated. An alternative to dedicated neurological timing mechanisms is the suggestion that timing perception is an emergent property derived from the patterns of neural firing within various distributed regions. Instead of a centralised timing system with an accumulator, regularities within neural systems (which may be modality specific) are opportunistically utilised for time estimation. For example, estimating the time at which two objects are going to impact may be based on emergent regularities within the visual system. Support for modality specific estimations have been found for durations of less than a second long. For longer durations there do appear to be some centralised structures, and imaging reveals that different aspects of timing and time perception appear to engage different neural regions. While there may not be a specific sensory system responsible for time research suggests that there is a neurological system governing our perception of time, a highly distributed system incorporating the cerebral cortex, basal ganglia, and cerebellum.

A number of studies have identified timing and time perception deficits in ADHD, however, as with all cognitive deficits observed it is difficult given the current methodologies employed to determine if these deficits are primary or secondary. Time perception at the scale of minutes, seconds, and fractions of a second are of particular interest to research in ADHD. The specious 'present' refers to the time duration wherein one's perceptions are considered to be in the present. Sagvolden et al. (2005) suggested that individuals with ADHD have a shorter present moment, that is, a sense of perceiving events as occurring within a meaningful moment. As with the inhibitory control deficits seen in ADHD, altered temporal parameters may be the result of an abnormal dopamine reinforcement system. A reinforcement system that fails to correctly link events due to greater temporal distance will impact on cognition, for example, on the perceptual chaining of events leading to a greater level of segregation of temporal events in time for individuals with ADHD. This in turn may contribute to hyperactivity or an apparent lack of attention. In an experiment participants synchronised drum tapping to a metronome and then continue without the metronome for 3 minutes at speeds of 60, 40 and 30 beats per second (bps). Those with ADHD have a rhythm cut-off that is faster in tempo. At 40 bps ADHD participants begin to lose the rhythm of the beat, that is increased variability around the beat, compared to 30 bps for controls (Sagvolden et al., 2005). This is suggestive of the notion of a shorter perceptual moment in individuals with ADHD. Shortened time scales for reward based learning as a result of dopamine dysfunction may lay the basis for a shorter perceptual moment. Berkley et al. (2001) observed greater discounting of delayed hypothetical monetary rewards compared to immediate rewards in ADHD participants (12-19 years old) compared to control participants.

An altered perceptual moment would fundamentally effect how an individual perceives the world. Indeed, an altered sense of time is a commonly reported effect of mind altering drugs. Our perception of the world is filtered through our perception of the causal relationships and the reinforcement contingencies we perceive. Weaker causal links between events due to an altered perceptual moment may explain the delay aversion seen in individuals with ADHD.

Within the literature time is examined as:

- time reproduction (e.g. a presented time interval must be reproduced with button presses)
- estimation of a duration (e.g. for how long did a buzzer sound),
- temporal order judgments (e.g. which of two stimuli appeared first)

On a time reproduction task Barkley, Koplowitz, Anderson, and McMurray (1997) reported that both a control and ADHD sample became more inaccurate as durations were increased but that controls were significantly more accurate at intervals of 12, 24, 36, 48, and 60 seconds and unlike children with ADHD were not affected by the distractions. Meaux and Chelonis (2003) report similar temporal reproduction task deficits for an ADHD population for 3, 6, 12, and 24 second durations. A methylphenidate dose manipulation was found to have no effect on duration reproduction. Kerns et al. (2001) similarly reported time reproduction deficits in addition to WM and attention deficits. Smith (2002) observed no significant difference but a trend for the ADHD population to respond earlier. Berkley (2001) observed impaired time reproduction but no deficit in time estimation. A study by Smith et al. (2002) also found no time estimation deficits for 10 second verbal estimation. Smith and colleagues assessing the minimum threshold at which time intervals of approximately 300 ms could be discriminated found that ADHD participants required the difference between intervals to be 50 ms longer compared to the control group for successful discrimination.

An accurate sense of timing is critical for the efficient execution of numerous other cognitive operations. A keen temporal ability will support an individual to generate accurate internal models of events. This in turn will guide predictions of when events will occur and when the deployment of various cognitive skills will be required.

5.1.3 Attention

Attentional control provides top-down influences that allow task-relevant stimuli and response to be processed preferentially. Because attention involves specific brain networks that influence the operation of other brain networks both enhanced and deficient attentional processes may have a generalizable effect for many functions. There are numerous examples of the wide ranging impact of attention functioning. Differences in attention have been related to emotional and behavioural control (Rothbart and Ruela, 2005). Attention is involved in (i) the anticipation or planning of actions (Fagioli, Hommel, & Schubotz, 2007); (ii) target selection (Deubel & Schneider, 1996), (iii) filtering distracting information (Ungerleider & G, 2000); (iv) WM (Kane & Engle, 2002); (v) response selection and / or inhibition (Pliszka et al, 2000); (vi) novelty detection (Tiitinen, 1994); (vii) error signalling (Schlagenhauf, et al 2013); (viii) reward evaluation (Peck et al, 2009). Attentional skills can help attenuate negative affect (Thompson, Cowan, & Rosenhan, 1980). Given the ubiquitous nature of attention it is apparent that attention is intimately involved in aspects of inhibitory control.

Attention is often segregated into:

- Reflexive (transient, automatic); engaged by an abrupt sensory event, has a short latency
- Voluntary (controlled, sustained); required conscious mental effort, takes slightly longer to activate than reflexive, is controlled by cognitive demand.

The two are functionally related and mediated by overlapping areas, primarily the frontal and parietal areas.

Posner & Petersen (1989) refer to three attention operations, namely alerting, orienting, and executive attention.

- Alerting – activate and maintaining a state of high sensitivity to incoming stimuli, potentially in response to a warning signal or cues. The brain regions purportedly involved include the thalamus region, frontal region and parental region.
- Orienting – the selection of information from sensory input, this can involve covert or overt eye movements. The brain regions purportedly involved include

superior parietal lobe, temporal parietal lobe, frontal eye field, and superior colliculus.

- Executive control of attention – involved in resolving conflict e.g. the stoop task. The brain regions purportedly involved include midline frontal areas, anterior cingulated and lateral prefrontal cortex.

A number of attention and attention related deficits are reported in ADHD. Individuals with ADHD demonstrate diminished sensitivity to reinforcement, or deficient rule-governed behaviour (Barkley1989; Haenlein & Caul, 1987).

It has been proposed that impairments in self-regulation lead to poor sustained attention and impulse control and preference for immediate reinforcers. Flory et al. (2006) suggest that the observed difficulty children with ADHD have in understanding causal connections and plans within stories is attributable to problems with sustained attention. Khetrapal (2007) suggests that a poor performance by ADHD participants on the attentional blink task is due to the misallocation of resources due to faulty top-down control of attention. Impaired performance scores are also observed for the task-switching task, attentional network task, and choice delay task. These tasks all measure a number of control processes including: attentional disengagement, selection, conflict monitoring, and motivational style (Gupta et al., 2006, for review).

As suggested in the proceeding section, altered perception of temporal proximity will lead to an altered perception of salience and will thus impact on attention. If only feedback presented in close temporal proximity to the event results in reinforcement, it will be difficult to learn certain abilities, as some skills may require that more distal events are associated. Thus temporal attentional span and learning are intimately related, and reduced attentional span may result in attenuated reinforcement and thus result in delayed learning of inhibitory control. The training intervention must factor in these considerations. To do this the targeted skills of the training intervention are presented in closer temporal proximity and the reinforcement of desired behaviour is consistent and immediate.

6 How to train

I have argued that due to an impaired reinforcement system individuals with ADHD fail to develop inhibitory control skills for which they have latent capacity. Further, I suggested that inhibitory gaze control draws on aspects of attention and timing, and that therefore training that targets inhibitory gaze control may result in transfer to other aspects of cognitive control, including attention and timing, as well as to other stimuli, contexts and modalities. In this chapter I review the literature on how the training intervention can train the targeted function. The literature on motivation, gaming, and exercise is reviewed to identify principles the training intervention can draw upon.

6.1 Principles and Design

A number of concepts and design principles have been explored in the literature to guide the development of training programmes. They outline what the goal of training should be as well as suggesting how these goals can be achieved.

Two attributes of the skill or function acquired should be -

- Flexibility - it should be transferable. It should be possible to apply the newly acquired ability to new tasks or in new situations, performance improvements should be seen in novel tasks, not just in the tasks that were trained. The early behaviourist work by Thorndike and others viewed the elements of knowledge to be stimulus response associations; if true the transfer of acquired knowledge is not expected. Bransford et al. (2000) proposes that we will see transfer between tasks to the degree they share common cognitive elements (theory of identical elements). The cognitive approach views the elements of knowledge to be abstract knowledge structures that are readily transferable (Anderson, 2005, p.306).
- Sustainability - the acquired skill should be trained to such an extent that the trainee is able to regulate their own learning and maintain their skill levels after the training. This suggests a need to develop the ability to the extent that it is used and can be integrated into everyday function.

6.1.1 Complexity versus specificity

A major consideration when developing a training intervention is deciding how targeted it should be, that is, what level of complexity should the training task contain, how general or specific should the tasks be with regards to the function identified? In their review paper on improving intelligence Buschkuehl & Jaeggi (2010) stipulate three criteria for successful training: (1) the task should minimise the development of task specific strategies; (2) the training must be adaptive, that is, utilise some form of algorithm that adjusts difficulty in the light of current performance, and (3) the task should be complex enough to train several different processes at once in order to maximise process overlap with other tasks, and thus facilitate transfer.

The alternate view is that training programs will typically need to avoid complex tasks, for instance most real-life tasks. Success on complex tasks requires integrated knowledge, and appropriate skills and attitude (Merrill, 2002). Training by completing complex tasks, while more ecologically valid, places a high load on the trainee's cognitive system and typically takes individuals who are committed (for instance learning a sport or musical instrument) out of genuine interest years to master (ten year rule, Simon & Chase, 1973). A well-designed training program will encourage deliberate practice in a specific domain critical to the success of the complex or real-life task; this is referred to as high fidelity (Van Merrienboer, 1997). Bilinguals and individuals with Tourette syndrome display enhanced inhibitory control, but in both cases we provisionally attribute this to the prolonged intense exercising of the cognitive systems involved. It should be noted that Buschkuehl, and Jaeggi recommendations pertain to the development of intelligence generally. Perhaps this is the critical distinction to be made; are we seeking to train the cognitive system generally or are we focused on developing a specific function? In this instance we are focused specifically on training-up an underdeveloped cognitive ability with latent capacity.

Buschkuehl & Jaeggi (2010) suggest that complexity may be a critical aspect of encouraging transfer of the learned skill. However, the more complex the task the more likely that there are multiple solutions and solutions that are less reliant on the target of the training. If there is a weakened function and multiple solutions are possible, we might expect the selection of a solution that avoids the use of the weakened function. A better performance does not necessarily mean they are learning the intended target. For example, improved performance may be dependent on a limited strategy reliant on compensatory skills that are sub optimally using cognitive resources. Bad technique can often lead to improved performance but with little chance of progression beyond a certain point. We can liken this to the training of a weakened muscle. It may be possible to compensate for a weakened muscle with the recruitment of the surrounding muscles and to improve on outcome measures such as speed or load bearing, but this is not optimal in the long term. Instead there is a need to strengthen the weakened muscle with specific isolation exercise, as seen with physiotherapy. Beyond the rehabilitation exercise there is also a need for the trainee's genuine interest in strengthening the weakened muscle and understanding that simply compensating for this weakness will be limiting in the long-term. Tasks that are less specific that utilise multiple functions simultaneously will more readily lend themselves to successful completion with the use of compensatory mechanisms, thereby circumventing the target of the training. In addition, in complex tasks with multiple solutions it is likely to be more difficult to identify reliable indices pertaining to the intended target. With a focused training task we can curtail the number of possible solutions and encourage the identification of more optimal or efficient solutions.

If the decision is made that isolating a particular function is a more reasonable approach, then what level of detail should be sought? Inhibitory control itself may be broken down into sub functions. A study by Hanisch, (2006) suggests that children with ADHD had an inhibitory deficit with regards to exploratory saccades and inhibiting an already initiated response. They were not impaired at inhibiting a pre-potent response. This result has not been consistently replicated but does highlight the potential need to deconstruct and separate different types of inhibitory control. However, this approach, attempting to isolate and strengthen a particular cognitive function or sub function, may not be viable.

There is a number of problems with too specific a focus:

- It may not be practical, given that even the most basic tasks draw on multiple cognitive skills. The level of detail that can be reliably isolated will reflect the sensitivity of the measurement techniques used. For the current intervention this will be the ocular indices extracted.
- It makes the assumption that the impairment relates to a specific function as opposed to the coordination of multiple functions.
- It places a higher demand on identifying with a high level of precision the deficit to be targeted.
- The more specific the target of the training the more specific the population it will benefit. This may not be desirable given the heterogeneity of the ADHD population. For the purposes of the current training intervention we are not seeking to train a specific sub-population of the ADHD population.

Expanding on this final point, it may be possible and beneficial to develop specific inhibitory control interventions for ADHD sub-populations, for example, in an anti-saccade task predominantly inattentive and combined subtypes were found to have different response patterns (Loe et al., 2009). Children with ADHD combined type had increased anticipatory movements and increased fixation time. However, this intervention in the first instance aims to develop a one size fits all intervention. If this proves to be unachievable due to heterogeneity then specific interventions targeting sub populations within the ADHD population may be necessary. The reasonable approach is to first attempt to reliably identify a specific inhibitory deficit in the general ADHD population.

With regards to achieving a balance between complexity and specificity in the training intervention, the ideal solution might be to initially isolate the targeted skill early on to prevent the use of compensatory mechanisms, and later increase complexity and similarity of the task to real life to encourage its integration with other functions and transfer (as a side point, there may be additional tangential skills that need to be strengthened in order to support transfer). This approach would help ensure the intended target is strengthened early while avoiding the use of compensatory strategies, but subsequently securing the flexibility and sustainability of the function by ensuring it can be used in conjunction with other functions and that there is a potential functional utility to its use. Such an advanced approach is beyond the scope of the current project. The focus of the intervention will be to strengthen the intended target, inhibitory control and aspects of timing and attention, but it is beyond the scope of the intervention at present to seek to integrate these targeted functions into everyday functioning.

To summarise, the use of complex tasks may offer trainees an opportunity to complete tasks using compensatory mechanisms and thus bypass the target of the training. Due to the discounting of delay rewards associated with ADHD this may in particular be a problem with this population, that is, they may focus on the short-term aim of completing the task successfully by any means as opposed to focusing on the longer-term benefits of developing an underdeveloped skill. By using a training intervention with simplified tasks it may be possible to curtail the degree to which the intended target can be bypassed with compensatory strategies and it will be easier to highlight the potential benefits of investing in the underdeveloped function. Additionally, it may be difficult to identify reliable indices of specific functions when complex tasks are used. The training intervention will avoid complex tasks that offer the potential to avoid the use of inhibitory control. Conversely, if the tasks used are overly specific they may only be beneficial for a sub-group of the ADHD population. The intervention will also not target a specific component of inhibitory control, e.g. reflective component; it will target multiple aspects of inhibitory control with a number of tasks. In this way the targeted function will be used in conjunction with different constellations of functions for different tasks. This approach if successfully will balance the issues around complexity and specificity.

6.1.2 Cognitive Load Theory

In addition to the question of complexity the difficulty of the task must also be considered. Deliberate practice entails focused practice on a specific aspect of performance but also at an appropriate level of difficulty. It affords the trainee an opportunity to successively refine their skill through repetition, gives them room to make and correct errors, and provides informative feedback (Ericsson, et al., 1993, Ericsson and Lehmann, 1996). Buschkuehl & Jaeggi's second recommendation, that the training should be adaptive, is echoed by Paas & Van Gog who highlight the need for a training program to be sensitive to the individual's changing needs.

Ideally the training should adapt dynamically to ensure that the trainees are continually challenged within what Vygotsky termed their zone of proximal development (Vygotsky, 1978). Tracking algorithms that vary the difficulty of the task dependent on performance are typically used for this purpose. Tracking algorithms typically maintain success at a set level. A broad distinction can be drawn between tracking algorithms that record success and overtly tell the student that they are about to "level up" and continually adaptive algorithms that maintain success at a given level. While the latter is more efficient at ensuring the trainee is challenged within the zone of proximal development it can be demotivating if the increases in parameter difficulty is not obvious, that is, if improved performance is not translated into greater apparent success.

Cognitive load theory provides a means of assessing the level of task difficulty but also highlights the importance of the nature of the difficulty. It details the components of a task that will determine the performance level achieved and how specific knowledge and skills can be targeted. Cognitive load is a multidimensional construct. It is the load imposed on the trainee's cognitive system when completing a particular task (Paas & Van Merriënboer, 1994). It is comprised of a number of components; the characteristics of the trainee (their cognitive abilities) and the mental load. The mental load is further broken down into the environment (e.g. peripheral noise levels), and the task (e.g. the task complexity).

The characteristics of the trainee determine how the requirements imposed by the mental load are met. To meet the mental load requirements the trainee will deploy some automatic processing and also engage in controlled processing to tackle the demands for which automatic processing is not available. Mental effort is necessary for the engagement of control processing, that is, effortful processing. The mental effort will determine the degree to which the trainee utilises his or her characteristics to meet the demands of the mental load not met by automatic processing. Figure 4 summarises these processes.

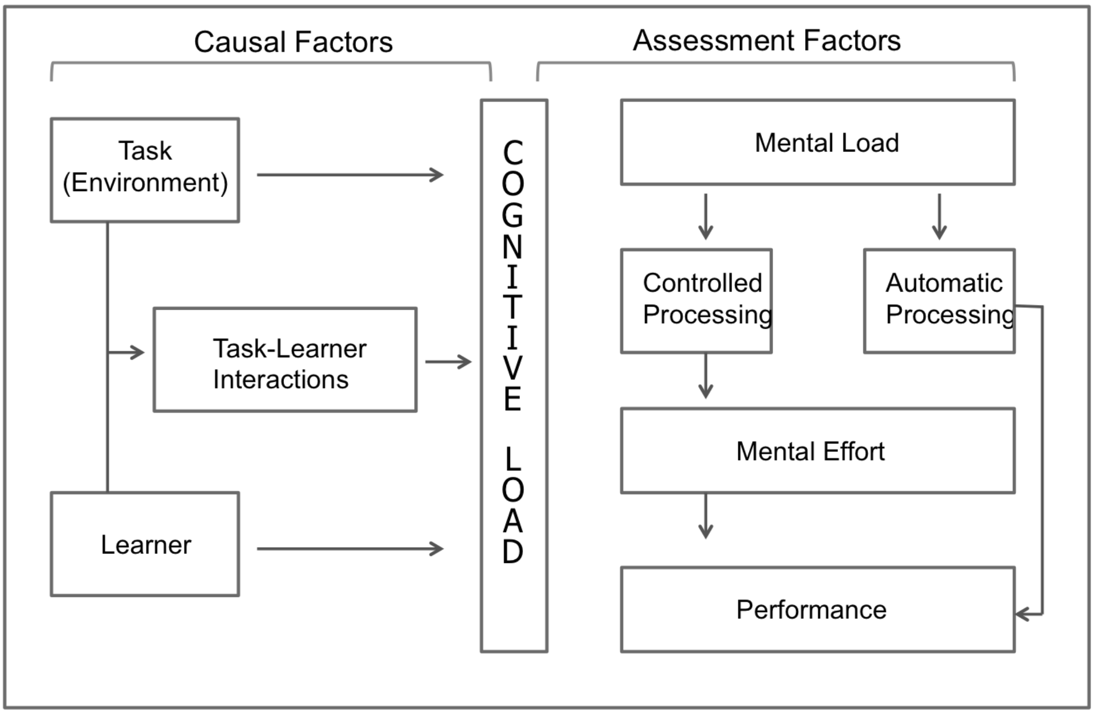


Figure 4 A representation of Cognitive Load (source: Paas and Van Merrendboer, 1994).

An efficient training program is one that optimises the nature of the cognitive load. Cognitive load can be divided into three components; intrinsic load, extrinsic load, and germane load. Intrinsic load is the inherent immutable cognitive load of the task (Sweller et al., 1998). Extraneous cognitive load is additionally unnecessary cognitive load that is not relevant to the learning being targeted, for example noise distractions in the environment not pertinent to the target of the training. The goal of a good training program is to have a germane load. A germane load is the effort required by the trainee to construct schemas, cognitive structures and processes that improve performance (Sweller et al., 1998). These three loads are independent and additive; the load imposed by non-task relevant elements (extrinsic), plus the load imposed by the inherent complexity of the task (intrinsic), plus the load imposed by the construction of schemas that will increase the efficiency with which the intrinsic load is processed in the future (germane).

To process the germane load is to construct cognitive schemas. Cognitive load theory posits that the construction of schemas increases expertise. Cognitive schemas are used to store and organise knowledge. A schema incorporates multiple elements of information into a single element with a specific function. To become highly skilled is to build useful schemas and to combine lower-level schemas into high level schemata. Compiling information in this way reduces the number of elements that must be processes in WM when meeting the demands of an intrinsic load. With practice the use of a schema will be automated, further reducing the mental effort needed to meet the demands of an intrinsic load.

The cognitive load of an efficient training program will minimise the extraneous load and optimise the amount of intrinsic load to match the personal characteristic of the trainee. It will require that mental effort be exerted to process the intrinsic load; however it should not place too high a demand, and the nature of the load should be such that a germane load can be processed, that is, cognitive capacity should be available for the development of schemas that will increase the efficiency of processing over time. This corresponds with the principles of deliberate practice discussed above. Enough room should be afforded to allow the trainee an opportunity to successively refine their skill through repetition, i.e. it should give them room to make and correct errors. In such instances reducing the difficult may be useful, it may free up resources or allow more flexibility thus affording the trainee more scope to, for example find alternative solutions, perfect subtle sub-functions, integrate constituent components or a function. Lower demand may allow the trainee space to develop neglected or underdeveloped skills that will eventually lead to a more efficient strategy. However, progress will also be dependent on the trainee's sincere engagement and desire to improve, and their creativity and playfulness in optimising their cognitive system.

If the task demand is below the level of what the trainee is capable of achieving they have capacity available to devote to the processing of the germane load, but they could likewise simply choose not to invest the cognitive energy. The decision is in part dependent on motivational factors which are discussed in section 6.2 below. A partial solution to this problem would be to making apparent to trainees the utility of investing in the germane load by firstly identifying their maximum capacity and then varying the task difficulty close to but below this point. By having the task difficulty set close to their maximum capacity communicates the need to increase the level of skill, that is the need to process the germane load, and when the difficult is reduced below the level of their maximum capacity they are afforded a degree of latitude to process the germane load.

The above solution is dependent on identifying the trainee’s maximum capacity with respect to the task being completed; further, as the trainee improves (by developing schemas) the intrinsic load must be increased. As suggested earlier this can be achieved with a performance tracking algorithm. Research suggests that adaptive training programs are an effective and more efficient way to train than fixed training programs (Camp, pass, Rikers, and Van Merrienboer, 2001, Corbalan, Kester and Van Merrienboer, 2008). Note, it is important that the adaptive training parameters add intrinsic load that necessitates the development of increasingly sophisticated schemas, and not extraneous load.

It is difficult to determine the amount of intrinsic load to introduce, the decision should reflect the amount of mental effort being exerted as well as the schemas in place and the automatic processing being utilised. For instance, an excellent performance on an objectively difficult chess problem will not necessarily be difficult for a chess grandmaster. They will have numerous automated schemas upon which to draw. When increasing the mental load and evaluating performance it is essential to have knowledge about the effort being expended by trainees, this information is not necessarily reflected in the mental load or performance. Quantitative neurophysiological measures such as heart rate-blood pressure product (RPP) (Fredericks et al., 2005) and pupil dilation and eye-movements (Buettner, 2013) can give some indication of cognitive load. Also, the best achieved performance provides an indication of the trainee's current level of ability when a high level of mental effort is exerted. Tracking algorithms do provide a partial solution by increasing the difficulty of a task to the extent that further improvements require the exertion of mental effort. Ideally a trainee is motivated and the performance level achieved when a tracking algorithm is used reflects a sufficient degree of mental effort.

Optimising the cognitive load is dependent on the expenditure of a sufficient degree of mental effort. Therefore, if we have developed a training program that targets the function of interest with an adaptive intrinsic load we must next ensure that mental effort is exerted by ensuring the trainee is motivated.

6.2 Motivation

Motivation, learning, reinforcement and attention are inter-related concepts. I have suggested that the central impairment in ADHD is an abnormal dopamine reinforcement system. One of the consequences of this is the impaired reinforcement of causal connection and association between specific events, stimuli, and behaviours, particularly those with greater temporal distance. This biased weighting towards proximal events will impact on what is learnt but will also impact on what stimuli and events within the environment are most salient to the individual and thus where their attention is directed. An individual's motivation to behave in a certain way will reflect what appears to them to be salient and those behaviours that have been reinforced in the past. For example, we will prioritise short-term goals, and those stimuli in our environment related to short-term goals will appear most salient, when in the past these goals and stimuli have tended to be reinforced. With respect to inhibitory control tasks the role of valuation of likely outcomes has been shown to modulate the balance between activation and inhibitory processes (Liddle et al., 2009; Montague, King-Casa and Cohen, 2006; Schultz, Dayan, and Montague, 1997). Motivational incentives bring performance of children with ADHD up to the level of typically developing children (Slusarek et al., 2001)

A major challenge for this intervention is ensuring that trainees are sufficiently motivated to engage in the remediation of inhibitory control deficits despite the fact that they failed to acquire this function in the past. I have suggested that individuals with ADHD have failed to learn inhibitory control due to an impaired reinforcement system. It is important that attempts to remediate this deficit acknowledge and work within the parameters of the altered reinforcement system. A failure to do so will undermine motivation. This requires that the salience or the importance of their inhibitory control system is highlighted, that the trainee's expenditure of mental effort to improve inhibitory control functions is reinforced, and that a sufficient number of repetitions are presented to consolidate learning while ensuring a sufficient degree of variety is present to sustain attention.

Motivation will result in the expenditure of mental effort and will maximise the learning efficiency of the trainees (Schunk, 2008). Motivated trainees will utilise their cognitive capacity to produce their best performance. But the nature of the motivation that is brought to bear is also important. The nature of the motivation driving the trainee will impact on their goals and their mental state when engaging with the task.

A common distinction made in the literature is between intrinsic and extrinsic motivation. An intrinsic motivated act is its own reward, that is, it is not completed to receive a reward. The activity itself brings pleasure or results in learning deemed important. Intrinsically motivated behaviour is typically exploratory, playful, and curiosity-driven. Extrinsic motivation results from a force external to the individual that compels them to act; the classic examples of extrinsic motivators are money and good school grades. Intrinsic motivation is most apparent in young children who are driven to explore and understand the world for its own sake without thinking of the beneficial consequences this might bring. Intrinsic motivation has been shown to diminish as a child progresses through the school grades (Harter, 1981). Intrinsic motivation, as opposed to extrinsic motivation, is proposed to result in greater learning gains as a result of a deeper connection and engagement with the learning content; it also results in a greater amount of time on task. Flow experiences, or "being in the zone" are also associated with intrinsic motivation. Similar to the idea of developing schemas Sandberg & Barnard (1997) describe "Deep Learning". Deep learning is characterised by insight and an understanding of the underlying principles and rules as opposed to memorisation of the content. Work by Bigg (1987) links deep learning to intrinsic motivation. Intrinsically motivated students read more widely and integrated newly acquired knowledge with previous knowledge. In contrast, extrinsically motivated students focused on rote learning and sought to meet the minimum requirements.

The deployment of intrinsic motivation resolves a number of issues related to training weakened cognitive function. One of the greatest challenges identified is ensuring that trainees do not rely on their habitual cognitive solution when completing the training task. Encouraging intrinsic motivation may provide a means of encouraging trainees not to use compensatory strategies and encouraging investment in processing the germane load to develop the targeted function. The trainee should not be trying to find a way to work around their weakened function (a short-sighted solution), but instead should invest effort in the short-term to develop a range of component functions that support the system's optimal functioning and potential for growth in the long-term. Due to the discounting of delay reward associated with ADHD this may in particular be a problem with this population.

The utility of the training intervention will be dependent on the trainee's sincere engagement and their genuine interest in improving the weakened function. While completing the training tasks they should be willing to experiment, and should not be overly invested in always producing correct responses or attempting to minimise the energy they invest. Finding solutions that can optimise cognitive functioning requires creativity, insight and an understanding of the underlying principles. Intrinsically motivated trainees are more likely to engage in a curiosity-driven search for effective solutions to the task challenges, and therefore increasing the chances they will activate the weakened function we are attempting to target.

Deci (1971) proposed that the delivery of external rewards for completing an action that is intrinsically motivated will reduce the intrinsic motivation by shifting the person's perceived locus of control to an external source, referred to as the "overjustification effect". However, this is an oversimplification, intrinsic and extrinsic rewards can be used effectively in conjunction. Research suggests that unexpected external rewards do not necessarily decrease intrinsic motivation, that praise and feedback can help increase intrinsic motivation, but that excess external rewards for completing a specific or simple task can reduce intrinsic motivation (Plotnik & Kouyoumjian, 2011).

Theories of motivation identify a number of task features that encourage intrinsic motivation. Ryan & Deci (2000) propose that intrinsically motivated behaviours satisfy innate psychological needs, namely competence, autonomy, and relatedness. Competence or challenge means an opportunity to develop mastery and a feeling of achievement. Autonomy refers to a sense of being responsible for one's own learning and experience. Relatedness means an understanding of the purpose of the task and how it ties into something bigger than oneself, and forges a connection with and acceptance from others. Vallerand & Ratelle (2002) decompose intrinsic motivation into three basic types: (i) intrinsic motivation to know - drives our curiosity to know and explore new phenomena; (ii) intrinsic motivation to accomplish - drives us to improve and surpass our accomplishments and (iii) intrinsic motivation to experience - drives our desire for new stimulating experiences.

There is a cost associated with the development of new skills or strategies; cognitive load theory refers to this as the germane load. Motivation to act can be thought of as an appraisal of where to invest our energy. The decision to invest in the germane load in part depends on weighing up the long-term benefits versus the short-term costs. By expending cognitive capacity in the short-term we will increase the efficiency or performance level achievable in the long-term. In ADHD the balance of this evaluation may be affected by an altered reinforcement system. ADHD is associated with the discounting of delayed rewards, hence a potential bias to fail to expend cognitive capacity on the germane load. Due to an altered reinforcement system the delayed benefits are not deemed worth the investment and the skill is not developed. For the trainees to be motivated they need to believe that gains can be made and that the gains are worth making.

As suggested above there is potentially a need to initially incentivise individuals with ADHD to invest in the development of inhibitory control. In the training intervention they are extrinsically incentivised to focus on the core mechanics with inviting game graphics, a points reward system and performance feedback screens. Extrinsic reinforcement is used to focus their interest on the inhibitory control mechanisms that constitute the core of the game mechanics. In the training intervention the core mechanic of the tasks are the target of the training intervention, this is referred to as intrinsic integration and will be discussed in detail in section 6.3 below. Incentivising the use of the targeted function and highlighting the gains made will identify the target of training as an ability they can improve on. The extrinsic reinforcement is the initial hook; it is however intrinsically rewarding to see improvement and experience a sense of mastery and this is especially true if there is a favourable trade off between the energy invested and the size of the gains seen. While the evaluation of the gains made are subjective and partly dependent on the perceived utility of the ability acquired, in this case the utilisation of the latent capacity (hypothesised latent inhibitory control capacity) will result in large gains being made for the energy invested. It is hoped that once the focus of the trainees is directed to the targeted function that they find the increased sense of mastery intrinsically motivating.

However there is a need to consider the amount of extrinsic reward delivered. It should be sufficient to ensure they are sufficiently motivated to be invested in producing a good performance, and therefore focusing on the game mechanics, but not overly invested in getting all trials correct as a better performance does not necessarily mean they are investing in the germane load. The size of the extrinsic rewards should be just enough to direct their focus on the core mechanics of the game and to then allow intrinsic motivation to subsequently dominate. The function of the point reward system is to initially guide their interest to the core mechanic of the tasks but in addition it also acts as feedback on the functionality of the targeted ability and thus facilitates the development of greater mastery, hence feeding intrinsic motivation.

As a side note, under the stress of everyday life we are likely to rely on our habitual strategies, therefore if the training intervention is successful and if the acquired skills are to be maintained and integrated into daily function it may be necessary to highlight to trainees the utility of inhibitory control with respect to daily function in an effort to encourage them to invest in integrating their new skills into daily functions. This is especially true in cases where compensatory strategies are in place and have been extensively used; an additional intervention for this purpose may be beneficial.

A successful training intervention will provide a platform for learning while minimising any obstructions. An awareness of how altered reinforcement parameters (e.g. requirement for temporal proximity between events, an increased number of repetitions to ensure consolidation of learning) will impact on learning, stimuli salience, and where attention will be directed, will aid the engagement and maintenance of motivation. However, the training environment can only provide a context, it can only put the pieces in place and it is the trainee’s drive and creativity that will ultimately determine whether learning occurs. It must however be remembered that each trainee will also have their own idiosyncratic strengths and weakness that will facilitate or hinder the training process, for example, deficits in other cognitive functions, or more broadly dispositional or personality traits. A history of adverse learning experiences and an avoidance of prescriptive learning environments may manifest as poor motivation and high levels of frustration during training.

6.3 Games

Game playing is strongly associated with intrinsic motivation. Unlike assessments or training tasks which are outcome focused, games are enjoyed in themselves. The purpose of playing a game can simply be to engage with the game, it is its own reward. This shift in focus has implications for the degree of engagement and perhaps more importantly the nature of engagement. Games can encourage a creative mind set towards achieving an objective; they afford space within which to playfully combine functions. Within games a degree of failure is often seen as part of the process, we are typically expected to produce a poorer performance when we first play a game, and unlike tests and assessments, that are one off assessments of our ability, games are seen as an on-going activity which can be repeated and can refine our skills. In games failure and experimentation are more acceptable and feedback becomes a tool to refine skills and strategies as opposed to being simply an evaluation of performance. They also offer a means of contextualising the content to be learnt, contextualising information has been shown to increase intrinsic motivation (Cordova & Lepper, 1995).

Given both the time and intrinsic motivation invested in game playing they may constitute a major resource to be tapped by trainers and educationalists. Computer games additionally offer a means of creating an artificial environment within which a particular function of interest can be targeted and trained. By making an intervention feel like a convincing game we also draw on the trainees' pre-existing associations of games being fun and thus increase the likelihood they are intrinsically motivated and in a receptive state. They also offer a means of introducing familiar concepts to aid communication of the structure of the training intervention, e.g. levelling up to increase the difficulty, processing feedback to refine performance etc.

Prins and colleagues examined whether game elements enhanced motivation and game performance in a WM training program with children with ADHD. They found both greater motivation (more time playing the game) and better training performances. Braingame Brian used an extensive game-like world which contains embedded executive functioning sub-games (WM, inhibition, and set shifting) to train children with ADHD (Prins et al., 2013). While not controlling for expectation effects, improved parent rated EF and ADHD behaviour are promising. Basak and colleagues (2008) found enhanced executive control and visuospatial skills after 23.5 hours of training on a strategy game. Glass, Maddox, & Love (2013) also conducted training with a strategy game and observed enhanced cognitive flexibility. Salminen et al. (2012) and Shawn Green and colleagues (2012) demonstrated cognitive improvements resulting from training on action games. Habgood & Ainsworth (2011) demonstrate that playing games as a means of training, in this case mathematics, results in more time spent learning but also greater learning per time spent playing.

Challenge, curiosity, control, and imagination have been proposed as the characteristics of games that are motivating (Mouaheb, Fahli, Moussetad, & Eljamali, 2012). Similarly Lepper and Malone (1987) describe four individual motivation factors, namely challenge, curiosity, control, and fantasy, and additionally three interpersonal motivating factors, namely cooperating, competition and recognition that can be utilised in game design to encourage intrinsic motivation. The individual factors are of most relevance here.

6.3.1.1 Challenge

Challenge refers to the need for the difficulty of the task to be sufficient to challenge the individual but without being unachievable. The experience of a flow state is commonly reported for video games. It is associated with total concentration, a distorted sense of time, and an extension of the self. The work of Csikszentmihalyi links a sufficiently challenging problem with the inducement of a flow state. To encourage a flow state the challenge should be achievable, have clear goals, and accurate feedback should be provided (Csikszentmihalyi, 1988; Habgood & Ainsworth, 2011).

Having achievable goals relates to optimising the intrinsic load as discussed earlier. If the trainee is sufficiently motivated a correctly adjusted tracking algorithms will ensure the task is both challenging but achievable. Also important is the nature of the intrinsic load. It should be possible to develop schemas to simplify processing of the intrinsic load over time. Accurate feedback is essential. The feedback will direct the focus of the trainee completing the task. It signposts the germane load, that is the components of the task that can be simplified with the use of schemas. The feedback needs to continue to serve this role when the task difficulty is altered. Also if the feedback received does not reflect task performance it stands to undermine trust in the feedback and the effectiveness of the intervention, and as a result can lead to frustration and impose a extraneous load.

6.3.1.2 Curiosity

The gaming world should be a place that draws forth the interest. The world presented should be one that we seek to explore and understand. This reflects the drive to explore and accommodate new information as detailed in Piagetian theories of learning (Carlson, Martin, & Buskist, 2003). Being presented with novelty, an incongruity between the information presented and our current understanding and puzzles to be resolved all help to fuel curious engagement (Berylne, Craw, Salapatek, & Lewis, 1963).

6.3.1.3 Control and self-determination

The trainees' behaviour should matter and should have consequences. Winning and losing should not be random, but should reflect their actions. It is similarly motivating to have options dependent on choices made. These choices should be meaningful and significant with respect to the learning content of the game. It is however important not to overwhelm the trainee with too many choices. An excessive amount of choices and particularly those not pertinent to the target of the training will increase the extraneous load of the game. One method to further enhance the sense of self-determination is to firstly explicitly describe to the trainee the functions they are training when they engage with the tasks, and secondly, by encouraging them to actively reflect on and refine the means by which they succeed on the tasks they complete.

6.3.1.4 Fantasy

The creation of a fantasy is proposed to promote a richer learning experience by facilitating learners to link new learning with existing knowledge through the narrative structure of the fantasy. Fantasies also provide an opportunity to introduce emotional content. The game fantasy can provide an engaging metaphor to aid understanding the learning content. By drawing on pre-existing associations it can simplify the understanding of the rules and objectives of the game world. Habgood & Ainsworth (2011) suggest that while the choice of fantasy is important for engagement of emotional interest, the primary importance of visual representations is to aid an understanding of the core mechanic of the game.

6.3.2 Intrinsic integration

It is not enough to call something a game and attach conventional game elements in order to derive the benefits associated with games. Dressing a training intervention up by adding cartoon graphics, introducing a reward points system, having fun games interleaved between the learning content are all examples of introducing gaming elements but failing to embed the learning content in the game. The term 'chocolate covered broccoli' is sometimes used to refer to the practice of superficially disguising dull learning or training with appealing game elements. This subterfuge will be readily apparent to trainees after a short period. Habgood & Ainsworth (2011) discuss in detail the importance of intrinsically integrating game goals with content to be trained, an approach they refer to as "intrinsic integration". To implement intrinsic integration the skills or functions being targeted should comprise the core mechanics of the game (Kafai, 2001). The core mechanics are the mechanisms by which the trainee engages with the world to achieve the game objectives (Habgood & Overmars, 2006). This relates to the removal of extraneous load and ensuring that the intrinsic load of the task specifically relates to the intended target of training. Once the intended target of the training comprises the core mechanics of the game, a flow experience can be encouraged by overtly tying the key components of the flow experience as defined by Csikszentmihalyi - clear goals, achievable challenges, and accurate feedback - to the core mechanics. The use of visual representation of the core mechanics will help communicate clear goals.

The core mechanics are what should be manipulated to ensure game challenges are achievable. And the feedback should reflect the trainee's adherence to the rules governing the core mechanic. Habgood's two recommendations for enhancing the intrinsic integration of learning content are:

1. "Deliver learning material through the parts of the game that are the most fun to play, riding on the back of the flow experience produced by the game, and not interrupting or diminishing its impact."
2. "Embody the learning material within the structure of the gaming world and the player's interactions with it, providing an external representation of the learning content that is explored through the core mechanics of the game play." (Habgood, Ainsworth, & Benford, 2005).

The principle of "intrinsic integration" was central to the game's development. It is particularly relevant to those with ADHD given the importance of maximising their motivation. This entailed integrating the game goal with the content to be learned. If we want the participants to learn to control their direction of eye-gaze then success in the game, the behaviour we reward with points or provide feedback about, should be gaze control. While this sounds obvious it is often not implemented in training games. It can be challenging to make the content that we want people to learn into a believable game that is enjoyable. Further, evaluating whether the game has succeeded in linking game success with the proposed target of training will never be straight forward. Success will instead always be partial, and will be achieved to a greater or lesser degree, and the degree of this success can only be inferred. A multitude of minute decisions will impact on this success. Subtle difference in the programming can have unforeseen consequences.

Of primary importance is to firstly ensure that the game mechanics reflect the aspect of the system targeted, and secondly, that success in the game (game points, awards, and progression to new levels) map onto the game mechanics. The successful implementation of intrinsic integration principles will deliver maximum learning for time spent playing the game, but additionally it is shown to motivate people to spend a greater amount of time playing the game.

6.4 Exercise

One of the difficult aspects of training the cognitive system is that the effects must be inferred, the results of the training are not readily observable. Physical exercise and the best practice for improving physical strength, endurance, and resolving muscular imbalance have been extensively studied. The effects of training the physical system can be readily observed and validate the principles of training derived. The biological constrains that govern the principles of good physical training may also have some relevance for training the cognitive system. Examining the principles of how to increase capacity in the physical system may provide some useful guidance on increasing the capacity of the cognitive functions we are attempting to train. Caution is however needed in the application of such principle to the cognitive system.

There are some general principles of exercise that are common sense, e.g. it is important to ensure adequate sleep and to eat properly in order to operate at peak capacity during training, and this is similarly applicable for cognitive training. The U.S. Army Fitness Training Handbook proposes seven principles for increasing the capacity of the physical system through physical exercise, namely progression, regularity, overload, variety, recovery, balance and specificity. These are summarised in table 1.

The utilisation of principles similar to these is apparent and obvious in many forms of training, e.g. motivation is aided by introducing some variety and there is a need to gradually increase intensity and/or duration, but these principles do help to underscore some important features when delivering a training intervention. There is a need to find a balance between regularity and recovery to optimise training results. If the break given between training sessions is too long gains may be harder to achieve. A recovery period is needed after exercise for muscle damage repair and the metabolizing of waste; it is likely there are analogous processes related to brain plasticity. The need for overloading the system, exceeding the normal demands, may have relevance for cognitive training. The principle of progression can be related to the concept of schema formation and development and a resultant need to increase the intrinsic load of a task. Balance is less relevant in this instance as we are targeting a specific problem area as opposed to conditioning the whole system, but it may be important to train the target function with multiple tasks as well as training related and supporting functions, this further ties into the principle of variety. Finally, Paas & Gog, (2009) emphasise on sustainability being a solution to the problem of reversibility. They suggest that the way to protect against the loss of gains made when training has stopped is to ensure the enhanced function is integrated into everyday behaviour. Within physical exercise "maintenance programs" or "reduced programs" are used to maintain gains, however, in this instance the goal is to strengthen a weakened system and as such it is hoped that once strengthened this system can be integrated into everyday functioning, though this may require a training intervention aimed at integrating newly acquired functions into existing patterns of behaviour (as a side note, it may be that the poor levels of transfer observed in the literature reflect this need to integrate newly acquired functions into existing patterns of behaviour).

Table 1 Seven principles for increasing physical fitness taken from the U.S. Army Fitness Training Handbook

Principle	Description
Progression	To improve your level of fitness you need to gradually increase both the intensity and duration.
Regularity	It is also important to maintain an exercise regimen that is consistent with exercise taking place at regular intervals.
Overloading	Exercise sessions should exceed the normal demands you place on your body.
Variety	It is important to add variety by including different activities, not only to prevent boredom also to increase motivation.
Recovery	The rest periods between training are just as important as the training itself, the optimum recovery time is between 24 and 48 hours.
Balance	It is important to exercise all areas of the body equally to achieve a balanced level of fitness.
Reversibility	Your muscles will atrophy and the cellular adaptations will reverse if you discontinue training.

Some of the intervention design principles identified in this chapter are:

- Implement intrinsic motivation
- Target multiple aspects of inhibitory control with a number of tasks
- Vary task difficulty below the trainee's maximum capacity
- Use performance tracking algorithms to assess their current capacity and adjust task-difficulty appropriately
- Task difficulty should be increased by increasing intrinsic load
- Ensure that the targeted skills comprise the core mechanics of the game

7 Equipment, programming, and algorithms

In the preceding chapters I presented: (i) a context for a cognitive training intervention, (ii) a rationale for the remediation of inhibitory gaze control deficits, (iii) a review of the deficits observed, (vi) an overview of the various systems involved, and (v) a review of design principles by which to develop the training intervention. In the succeeding chapters I present: (i) how the intervention was programmed, (ii) the specifics of the tasks used, (iii) how it was pilot tested, and (vi) the design and methods subsequently refined and the delivery in the main proof-of-concept study.

The development of the assessment tasks and the training intervention game was a three-stage iterative process. The initial phase involved developing the assessment tasks. The early assessment tasks were rudimentary implementations of classic inhibitory control tasks and a number of original specifically designed tasks. Development of the assessment tasks involved designing and programming the tasks, but also developing procedures to ensure good data quality and instruction to participants. The assessment tasks were pilot tested and refined a number of times with a number of non-ADHD populations. Following this phase, training games designed to improve performance on the assessment tasks were developed to proof-of-concept sage. Finally, this proof-of-concept training intervention, together with the assessment tasks and procedures, was evaluated and refined in collaboration with volunteers from an ADHD population.

Below I outline the equipment used, the program logic and algorithms, and eye-tracking procedures.

7.1 Equipment

For the development and testing of the intervention a single CPU was used. Attached to the CPU were the eye-tracker and two monitor screens. The first screen was the stimulus screen to display the tasks to participants and the second screen was for use by the experimenter as a control screen to initiate and monitor the tasks. The control screen contained (i) a mimic window that allowed the experimenter to see where the participants was looking on the stimulus screen and thus to observe if the participant was performing the task correctly, and (ii) a camera window that allowed the experimenter to monitor the quality of the image recording. An alternative set-up would be a dual-PC set-up in which each monitor is attached to its own CPU, thus providing more processing power. However given the additional technical challenges this would entail, the impracticality of shifting this setup to collect data in schools or other locations outside of the lab, and given that the single-PC setup appeared to have sufficient capacity to meet the demands placed on it, a single PC set-up was kept.

The eye-tracking assessment tasks and the training intervention game were programmed in Matlab (Matlab, 2012). Within the Matlab environment Cogent (Cogent, 2000) was used to aid the display of stimuli and the Cambridge Research Systems toolbox (Cambridge Research Systems, 2012) was used to control the operation of the eye-tracker.

The high speed Cambridge Systems Eye-tracker was used to gather the eye gaze data. Listed below in Table 2 are the technical specifications for the CRS eye-tracker. This eye-tracker uses a chin rest and a forehead band to stabilise the head. The tracker has an adjustable table used in conjunction with an adjustable chair (with booster seat if needed). The CRS high-speed eye-tracker has a sampling frequency of 250Hz, meaning an image of the eye is taken every 4 milliseconds. The recorded image is then processed within the eye-tracker interface box and sent onto the CPU via a firewire connection. The high speed recording and processing allow for perceptible real time gaze contingent programming, that is, tasks can be programmed that allow for real-time gaze contingent stimuli presentations. The most limiting temporal factor is the monitor refresh rate which is 16.7ms.

The CRS eye-tracker projects two infrared lights at the cornea of the eye and picks up their reflections, "first purkinje images", with an infrared sensitive video camera. These reflections, together with the outline of the pupil are identified by the CRS software, VideoEyeTrace, and recorded as an ellipse with crosshairs (Cambridge Research Systems). By taking into account the relative positions of the purkinje reflections relative to the pupil position, the software calculates head movement and eye-rotation, and hence gaze direction. The eye-tracking software calculates this automatically online and outputs a location along with a time stamp every 4 ms to

Matlab. The calculations for determining the direction of gaze are tuned to each particular participant for each particular session by calibrating them at the start of each session.

Table 2. Eye-tracker specifications

Sampling frequency:	250Hz
Resolution:	0.05°
Accuracy:	0.125° - 0.25°
Horizontal range:	±40°
Vertical range:	±20°
Allowable head movement:	±10mm

The CRS high-speed eye-tracker used is a monocular tracker, that is, it collects gaze data from a single eye. It is possible to decide which eye to collect data from. When using a monocular eye-tracker there are two possibilities: using the same eye for all subjects, or using the dominant eye for each subject. The advantage of using the same eye for all subjects is that the data will be more consistent across subjects. This is because of the distortion associated with extreme left or right gaze locations. This will be less of an issue when the experiment only involves central gaze locations. The advantage of using the dominant eye is that the data will be less noisy. The non-dominant eye can tend to make 'glissades', small eye movements to align itself with the dominant eye at the end of a saccade. These will not be present to the same extent in the dominant eye. A simple method to determine the participant’s dominant eye is to place a small hole in a piece of card and ask the participants to hold the card to their eye and read a piece of text through this hole. The participants will hold the hole in the card up to their dominant eye. The majority of people are right eye-dominant. For the pilot studies reported here I collected data from the right eye in all cases; however, in the main proof-of-concept study with

ADHD participants I shifted to recording the dominant eye around the midpoint of data collection. Participants reported greater fidelity between their experience of where they were looking and gaze contingent game action when data was gathered from the dominant eye.

7.1.1 Limitation of the eye-tracker

A major limitation when eye-tracking is that the full circle of the pupil and the Purkinje images (eye reflections) must be clearly visible within the video image at all times. Loss of data is inevitable, but measures can be taken to reduce this. Critical to the development of the eye-tracking tasks is appreciating the constraints of the equipment and factoring this into the task programming and collection procedures. Both the participant and the eye-tracking equipment need to be managed to optimise the chances of obtaining good quality data.

Image loss of the pupil or Purkinje images can occur for a number of reasons. The eyelids or eyelashes can obscure the image; particularly problematic if the participant has long eyelashes or wears mascara, if the eye lid is drooping because the participant is sleepy, or if the pupil is much dilated. To reduce data loss participants were asked not to wear mascara. Care was taken to ensure that the participant's pupil was located in the centre of the video screen before starting the calibration process. Participants were encouraged to ensure they were well rested before turning up for data collection. Pupil dilation was reduced by having the room well illuminated and by not having the background images on the monitor screen too dark (note however that too much room illumination can interfere with the Purkinje reflections). The centre of the monitor screen was raised up slightly relative to eye-level which can help to prevent the eyelid clipping the top-most part of the pupil. This does introduce some bias into the data as the automatic calculations used to determine the direction of gaze require that the eye be in line with the centre of the monitor screen (dependent on the spatial accuracy requirements this may be an acceptable trade-off). In this instance this was considered a reasonable trade-off. The image is of course lost when a participant blinks but the eye-tracker can typically relocate the pupil very quickly. The wearing of glasses or contact lenses was not a problem. I ensured that participants were wearing their glasses or lenses in order that they could see the screen clearly when gathering data. Occasionally light reflections on the surface of glasses were problematic. In such cases changing the orientation or location of the eye-tracker with respect to the light source remedied the problem. Participants will have a natural tendency to move their head in addition to their eyes when making a saccade. While the chin rest reduces this tendency, it can prove to be problematic with children below the ages of 7. Participants were reminded not to move their head when making a saccade. I avoided having stimuli at the extreme bottom corners of the screen. If the eye-tracker was having trouble picking up the pupil or was taking excessively long to do so after a blink, then the focus and aperture of the camera were altered via the rings above the camera. Slightly reducing the aperture of the camera (which should by default be fully opened) was found to be particularly useful, and while the image of the eye observable on the control monitor often appeared less clear when the size of the aperture was reduced, the performance of the software identifying the pupil was often improved.

Another approach for improving the quality of the data collected is to use gaze contingent eye-tracking paradigms. One of the benefits of gaze contingent tasks is that both the experimenter and the participant will be made aware of poor image quality and data loss. For example, in the current training and assessment program is an algorithm that requires that a clear image of the participant's pupil and Purkinje Images be present before the start of each trial. The program algorithm will wait until the pupil can be identified, and will also wait until both the X and Y coordinates are less than 3 cm form the centre of the screen, before starting a trial. While the pupil image and Purkinje Image can be lost once the trial is initiated, this algorithm helps to identify a problem within a single trial. It also serves to remind participants to keep their eye opened sufficiently wide. The alternative is for the task to passively continue to present stimuli regardless of whether a clear image of the eye has been identified.

When it comes to processing and interpreting the data collected it is important to consider the loss of data that has occurred. The loss of data may contain a direction bias common for all participants, particular to one participant, one session, or one block. A directional bias in the loss of data is typically seen for saccade to targets on the bottom of the screen. This is due to the fact that downward saccades tend to result in the lowering of the eye-lid which can obscure the pupil. This can impact on the calculation of the RTs. If after making a saccade the pupil is lost and then relocated a moment later this can produce an apparently longer RT than the actual RT (dependent on the method used to identify saccades). Additionally, if a participant has shifted their head slightly left or right with respect to their initial set up position a horizontal bias can be introduced as their pupil can move out of the image if they make a sideward saccade in the same direction as the head shifts.

A large amount of data loss can distort the results in a number of ways. In a stop signal task the loss of the pupil during a saccade to a target on a stop trial can result in the appearance of a successful inhibition of a saccade. Conversely, the eye-tracker can fail to identify a saccade and the participants will receive immediate negative feedback despite having made a saccade. Equipment failure such as this can bias task strategies. Participants can become frustrated if gaze continent tasks are not working well due to the loss of data. In such cases the distortion of their performance resulting from frustration will be an idiosyncratic distortion that does not reflect their ability to perform the task or learn, but which reflects dispositional factors related to frustration and equipment limitation. It can also lead participants to engage in behaviour that they feel may aid the eye-tracker, such as forcefully widening their eye, which can also distort data. Poor data generally leads to ambiguity as to whether a successful or failed trial was due to the participant's on task behaviour or directly or indirectly due to the eye-tracker losing the pupil. Some individuals will be more prone to provide poor quality data than others independent of their ability to complete the experimental task or follow instructions. It is important that these issues are minimised and considered by maximising the quality of the data collected, factoring these issues into the programming of the tasks, and being aware of the potential for bias during data processing and analysis.

The eye-tracker has limitations with regards to gaze location accuracy. Slight shifts in head position can lead to inaccurate calculation of the eye-gaze direction. Attempting to have a high spatial accuracy threshold increases the need to conduct frequent recalibration procedures. For this project it was felt that a high accuracy threshold would be particularly problematic for an ADHD population, therefore our tasks set a low accuracy threshold. This is not seen as a limiting factor in the task design as the focus of the intervention necessitates precise temporal accuracy and only a degree of spatial accuracy. Having a reduced spatial accuracy threshold avoided problems such as the need for frequent recalibration and also most likely avoided participant frustration.

7.2 Programming tasks

7.2.1 Saccade Identification

The main data output supplied by the eye-tracker is a set of X and Y coordinates. A new coordinate is produced every 4ms. There is additionally an automatic calculation that computes whether the participant is fixating or not for a given coordinate (1 = they are fixating and 2 = they are not). Time stamps are also produced for each of these points. Given the X and Y coordinates it is possible to determine the distance between the location of gaze and any given point on the screen using Pythagoras's Theorem. In a right angled triangle the square of the hypotenuse is equal to the sum of the squares of the other two sides, see figure 5 below). Given the X coordinate (the adjacent) and the Y coordinate (the opposite), the distance between point A and point B (the hypotenuse) can be determined, the square root of $X^2 + Y^2$ = the hypotenuse. Building on this, we can specify in a task script that if the distance between point A and point B is greater than a certain value, or is less than a certain value, a particular command should be executed. For example, to ensure that participants are fixating at the centre of the screen before each trial we can use this algorithm to determine a participant's gaze location with respect to the centre of the screen. We can stipulate that if the gaze shifts away from the centre of the screen by more than a specified value within a given period then the trial will not start but instead the previous set of commands will be repeated. This algorithm will continually repeat until the participant holds his or her gaze stable at the centre of the screen.

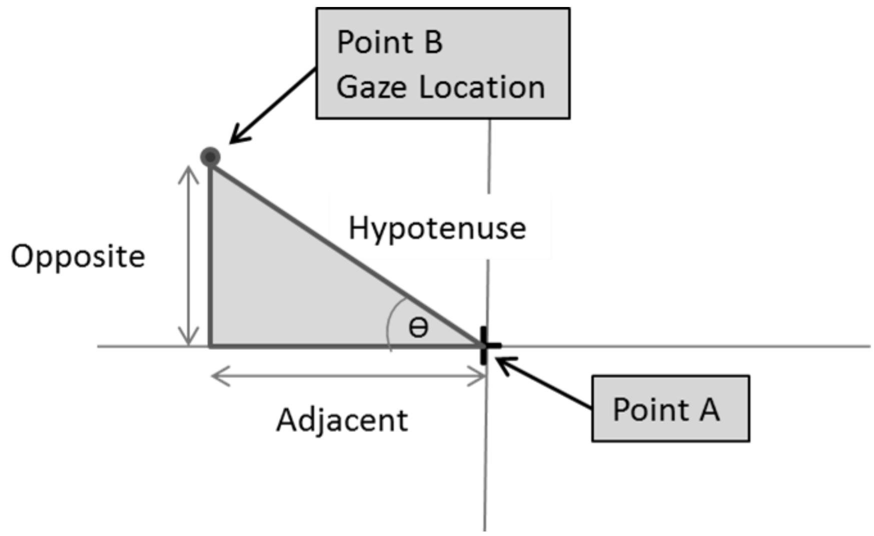


Figure 5. Method used for calculated gaze direction

7.2.1.1 Regions of interest and velocity based methods

Two broad sets of saccade detection algorithms were developed for the tasks used. The first is a region of interest algorithm. Regions of interest were defined based on distance from the centre and angle. While a participant is completing a task during any period of interest within a trial the eye-tracker outputs their current gaze location and whether they are fixating or not. Based on this it is possible to determine either the distance of their gaze from a point of interest or whether their position is within a predefined distance from a given point (e.g. in figure 6 greater than C but less that C + B) and within a given degree of visual angle (e.g. in figure 10 angle a). By defining regions of interest and the periods of time within which these regions are of interest saccadic movements were inferred. For example, participants must first fixate at the central fixation cross for a set period at the beginning of a trial. The trial is classified as a failed trial if there is any movement greater than approximately 1 degree away from the fixation cross before a defined period. Following this a target, or distractor or both will appear. If the direction of gaze is then directed at a region of interest within a defined period a saccade is inferred. This method was used mainly for real-time gaze contingent programs.

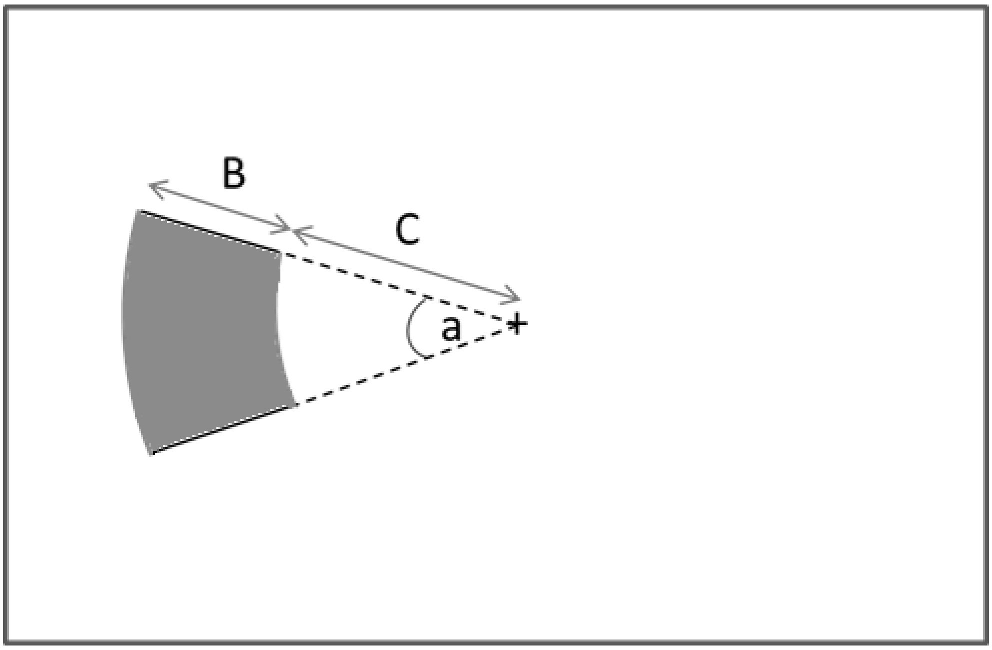


Figure 6. Illustration of the method used to calculate if the direction of gaze falls within the region of interest.

The second method used to identify saccades is based on the velocity of eye movements, that is, changes in distance over time. These calculations were typically conducted off-line. When processing the data off-line a number of technical issues were identified when importing the raw data. Loading the saved Matlab files back into Matlab created errors in some cases such that for some trials for some participants a portion of the X-Y gaze position row vector was shifted to a new row. This rendered the data impossible to work with. The solution developed was to import the raw data file into excel, save it as a worksheet, and then import it into Matlab. The cause of this problem has not been identified but may relate to the length of the X-Y array. Upon loading the data into Matlab a further problem was identified. In some instances segments of data were inappropriately ordered. The solution was to reorder data based on the time stamp variable.

Once the data is correctly loaded and ordered the periods of interest are defined. Stimulus onsets time markers saved while the task is being completed are used for this purpose. The periods of interest typically segment the data into (1) the period before the arrival of the target (pre-jump period), (2) the period in which a saccade should be made to the target, the target interval, and (3) the period after the target interval, post-target period. The pre-jump period is first analysed to identify if the trial contained a premature saccade or if the participants have failed to hold fixation at the central fixation cross before the target arrived. If neither of these is true the target interval is analysed to identify if a saccade was made during this period and the start and end point of this saccade. If no saccade is identified in either the pre-jump period or target period, the post target period was then analysed to determine if a late saccade was made, and if so to where.

Saccades are identified by firstly calculating "Distances", all distances between adjacent gaze coordinates. This is calculated as the square root of the difference between all adjacent X locations squared plus the difference between all the adjacent Y locations squared, equation 1 below is the Matlab code used.

Equation 1

```
Lengths= sqrt((X(2:end)-X(1:end-1)).^2+(Y(2:end)-Y(1:end-1)).^2)
```

This gives N-1 number of "Distance" points. These distances constitute the distance of movement in eye gaze over 4 millisecond periods. A sliding window of size 7 was then run the length of the "Distances" variable. Within each window the average is calculated and subtracted from the adjacent window to give smoothed velocity between points (see equation 2). The degree of smoothing is determined by the size of the shifting window. The greater its size the more noise it removes but the less sensitive it becomes to changes.

Equation 2

```
For bb=WindowSize+1:length(Lengths)-WindowSize-1

Eye_velocity(1,bb)=mean(Lengths(bb:bb+WindowSize-1))-mean(Lengths(bb WindowSize:bb-1));

End
```

The script then checks for changes in velocity (acceleration and deceleration) in order to identify the point of saccade onset and offset. A peak detection algorithm, for which a threshold value is set (typically set between 0.5 and 0.7), is then run on the list of velocities to determine the location of velocities greater than the threshold value. This helps to identify the onset of the saccade which is the period just before the point of highest peak velocity. We can similarly determine the point of saccade offset as the period just after the lowest peak velocity (a velocity reduction). This can be seen in figure 7 which shows a plot of generated velocities. It can be seen that there is a spike increase and immediate decrease between samples 70 to 80. Given a number (N) of X and Y coordinate that were collected for an unbroken period of time, the number of coordinate points will equal the period of time in millisecond divided by 4 (given that the sampling rate of the eye-tracker is 250Hz). Therefore, if the peak is identified as occurring 50 sample points the appearance of the stimulus the peak of the saccade is 200 ms after the target appearance (50 sample points by 4 ms per sample point). In addition, by examining the post-saccade location it can then determine whether the saccade was made to the target location, distracter location, or some other location.

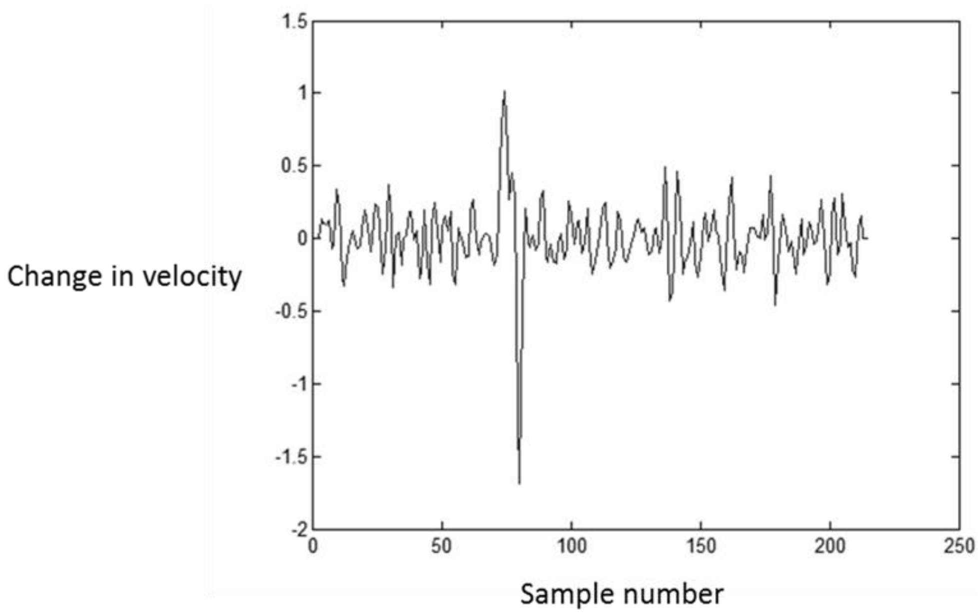


Figure 7. Smoothed increases and decreases in saccade velocity across samples.

Early on in task development post-test identification of saccades based on a velocity based method was conducted in a semi-automated manner. This ensured the accuracy of the method and helped to establish the identification parameters. Subsequently, data was processed with the use of a fully automated saccade identification algorithm. A visual inspection of data plots for a subset of trials was conducted to validate the method used.

7.2.1.2 Dealing with missing data

Due to the nature of eye-tracking technology missing data is an issue. There are a number of reasons why one will have missing data. In the majority of cases the problem arises due to the fact that the pupil or Purkinje Images are not clearly visible within the video image. If there is a period of missing data around the period at which a saccade is initiated the trial must be eliminated as there is no way to determine an accurate reaction time or location landing point. It is important to then calculate the proportion of correct response trials and proportion of incorrect trials as opposed to the absolute number of trials. Such data loss will occur with current eye-tracking technology and the best solution is to collect many trials and to ensure that steps are taken to maximise the quality of the data collected.

7.2.2 Programming logic and algorithms

Both the training and assessment gaze contingent eye-tracking programs followed a general structure. See appendix 3 for sample scripts. When developing an assessment task a single script was created that contains all the required lines of codes, that is, a single script that was self-contained. These scripts do not draw on any additional function, apart from the toolbox functions of Cogent, CRS, and Matlab.

The essential elements of the assessment task scripts are as follows;

I. The script begins with housekeeping commands, these load various files, set up variables, and set parameters.
II. The required images and sounds are loaded or generated.
III. The script then enters a loop that will repeat for a specified number of cycles, with each loop constituting a trial.
IV. Within each loop a central fixation cross / dot is presented. The script will halt here until the direction of gaze is fixating on this point for an unbroken specified duration.

V. Once this stipulation is satisfied the central gaze point continues to be displayed for a further period of approximately 1 second. This is to ensure that the participant has time to settle his or her gaze before the next trial begins. At the end of this period a time stamp is generated to record the start of the period of interest for later processing.

VI. Then the task specific commands are executed, that is, the task specific stimuli are presented at the specified times. Gaze locations and stimulus time stamps are recorded, and the processing of eye-tracking data specific to that task is executed.

VII. Towards the end of this loop participant feedback may be given, and the data for that trial are saved.

VIII. When the program has finished the specified number of trials loop iterations it continues onto the housekeeping at the end of the script that closes various operations and ends the program.

Unlike the assessment tasks the training program structure utilised multiple scripts written as Matlab functions. It follows the same overall structure as the assessment tasks but the operations are distributed across multiple functions. These functions can be broken down into four types with each performing a different type of function.

I. Firstly, the master function that performs all the initial housekeeping, sets the task order, loads the parameters that determine the difficulty of the task, and initiates the loading of all other function.

II. Secondly, the import function that loads all the images and sounds that are used in the tasks.

III. Thirdly, the task function, these make up the majority of the functions utilised. They determine the order and timing of onscreen stimuli for a single trial including within trial data processing and on screen feedback.

IV. And lastly the results screen function that processes the data collected and displays the end of block performance summary screen.

7.2.3 Eye-tracking procedure

The eye-tracking procedures and set-up was the same for the pilot studies and both the assessment and training tasks of the proof-of-concept study. The screen was a distance of 620mm from the participant, with dimensions 380mm by 300mm. For data collected in the University of Nottingham IMH lab the room had no natural light or window. Illumination was from florescent bulbs and was consistent for participants in all session. The Summer Scientist Week and School data (see sections 8.2.1 and 8.2.3 for details) were not collected in the IMH lab. Efforts were made to reduce the amount of natural light entering the room in an effort to have consistent lighting conditions for all participants.

All superfluous objects visible around the eye-tracker that may be a source of distraction or noise were minimised. This included experimenter generated noises such as ruffling through sheets or moving about in the chair.

Once seated participants were given a moment to get familiar with sitting in the eye-tracker chin rest position before aligning the camera with their eye. It was made clear to participants that they should be in a comfortable position/posture. People will often sit quite erect to begin but after a period will slouch. Before calibration began participants were made aware of this tendency to slouch and encouraged to adopt a natural posture which they could maintain throughout the session. If I noticed that the participants had changed their position (slouching or shifted right or left) once the experiment started I considered recalibrating based on the quality of the data.

First the height of the table, chair, and chin rest was adjusted. Some of the child participants also needed a booster seat. Participants looked at the direct centre of the monitor. Having decided whether the left or right eye data would be collected the camera was moved left or right to correctly align their eye on the horizontal axis, ensuring their pupil was in the direct centre of the camera window. There are two adjustable rings at the top of the camera. The aperture ring (alters the exposure, the amount of light entering the camera) is opened fully as a default, however based on the quality of the data gathered it is closed slightly for some participants. This was found to greatly improve the quality of the recording for some participants. The second ring is used to focus the camera. The camera is focused on the pupil, not the eye lashes.

Sitting in the eye-tracker can be tiring on the neck muscles; participants were given short breaks between blocks and longer breaks between tasks. The tasks were programmed to ensure all participants had to wait a minimum amount of time between blocks and tasks. During breaks they were free to sit back from the equipment but this was not encouraged between blocks. The advice is to recalibrate after a participant sits out of the equipment. I however did not find that this made a difference in instances where they sat back and their eye assumed the same position in the camera screen.

Participants, especially children, will often move their head in addition to moving their eyes when making saccades. This is extremely problematic for the quality of the data if the movements are large. Participants were reminded not to move their head and told that this was more important than making fast saccades. I found this to be an insoluble problem for children aged 7 and younger.

Calibration

Before an eye-tracking experiment can be run participants must be calibrated on the equipment. This is an automatic procedure run by VideoEyeTrace that will adjust the eye-tracker parameters to the specific subject. It requires the subject to fixate on a point that is being moved to a number of locations on the screen. Calibration takes approximately 20-50 seconds. Firstly the experimenter adjusts the table height, chair, chin rest, and the camera and ensures the participant is sitting comfortable, and that there is a clear image of the eye in the camera window. The camera is focused and the camera aperture is opened fully. 16 small circles are presented in a random order. The computer calculates the difference between where the participant is looking (the circle locations) and where the system would have predicted the participants to be looking based on the Purkinje Image. A summary graph showing difference between these two is displayed at the end of calibration procedure to assess the quality of the calibration (larger differences tend to indicate problems with the procedure). Based on the calibration data the eye-tracker extracts a number of parameters that subsequently aid the calculation of eye gaze direction while the eye-tracking tasks are being completed. These calculations are automatically performed by the equipment software.

8 Pilot studies

In Chapter 5 (What to train) and Chapter 6 (How to train) I addressed two main questions in broad theoretical terms - what should we train, and how should we train it? The details of what and how the cognitive functions are trained in the main proof-of-concept study were informed by a number of pilot studies. The main proof-of-concept training game is composed of assessment tasks and training tasks. The assessment tasks were developed and pilot-tested on a non-ADHD sample; based on the results the tasks and testing procedures were refined, and further pilot testing conducted. Refined versions of the stop-signal, anti-saccade, and timing tasks described below were subsequently used as assessment tasks in the proof-of-concept study. The tasks progressively integrated increasingly complex features, more precision, and a number of original tasks were added. Building on the pilot studies additional assessment tasks and the training intervention were developed for the proof-of-concept study.

Conducting the pilot studies helped to refine the implementation and to gamify the tasks; validate the theoretical underpinnings of the tasks; and establishes convergent validity for the tasks. During the pilot studies different storylines, game features, and game mechanics were employed. Participatory design components were included to allow participant feedback to shape task development. The development of the tasks involved programming, but it also involved developing procedures for conducting the intervention (e.g. for maximising the quality of the eye-tracking data; monitoring performance to identify if the participant needed a break) and giving instructions to participants (e.g. encouraging them to reflect on their performance and why they think they performed poorly or well).

The goal of the pilot studies was

- To refine the assessment tasks and to inform the development of the training intervention. I detail here the most relevant insights and changes made.
- To identify parameters to track and assess task performance.
- To validate the Competitive Integration Model (Godijn and Theeuwes, 2002).
- To establish convergent validity for the assessment tasks used.

This process involved

- Identifying task parameters that could be modified to vary the difficulty with respect to the construct of interest
- Developing a reward/penalty structure that mapped onto the construct of interest to incentivise improvement
- The production of summary feedback on performance
- Embedding the task into an aesthetically pleasing game environment; this involved the development of graphics, modes of graphic presentation, and the creation of game sounds
- The creation of a coherent back story that integrated the tasks with the overall game objectives
- Modifying the structure of the task blocks to emulate the structure of computer games
- The development of a "levelling up" structure to the blocks to signal increasing difficulty as a result of improved performance
- Develop and embed short movie sequences to explain tasks

The groups used for the pilot studies were –

Early pilot studies

- A typically developing adult population, N = 9, mean age = 26.7, *SD* =3.5, range = 22 – 32
- A second typically developing adult population, N = 28, mean age =21.2 years, ages 18 to 32

Later pilot studies

- 'Summer Scientist Week' children in 2012 N = 55, ages 7 to 12
- 'Summer Scientist Week' children in 2013, N = 74, ages 7 to 12
- Data collected from schools: children from year 5 and 6 children, N = 66, aged 10 and 11

All five pilot studies were within-subject designs. In all cases participant data was gathered in a single testing session. In all instances ocular motor data was collected with the CRS high speed eye-tracker. All the pilot studies were approved by the University of Nottingham medical school ethics committee, except for the school data collected with year 5 and year 6 children for whom we received ethics approval from the Derby NHS ethics committee. Post-testing data processing was conducted in Matlab and statistical analysis was conducted with SPSS 16 and 17.

8.1 Early pilot studies

These studies were useful for gaining a familiarity with the eye-tracking equipment and to develop tracking algorithms and procedures for post hoc data processing. The importance of, and challenges association with, obtaining good quality eye-tracking data became apparent. Matlab skills were acquired when programming the tasks and processing the data. Importantly, these studies were used to validate the Competitive Integration Model of saccade generation. The results reported are for the Sudden Onset Distractor task. This task is a reproduction of a task used by Godijn & Theeuwes (2002) and provides support for the Competitive Integration Model. To analyse the data we developed semi-automated saccade identification algorithms. This work supported the development of subsequent gaze contingent task programming.

Procedures

Upon arrival all participants were presented with an information sheet, this was discussed and they were given the opportunity to ask questions. After consent forms were completed demographic and the psychometric data was gathered. Participants were given the CAARS-Self-Report: Short Version (CAARS-S:S)(Conner et al. 1998) to complete. Then, once calibrated on the eye-tracker, participants completed the eye-tracker task.

8.1.1.1 Sudden Onset Distractor Task

Participants completed 128 trials divided into 4 blocks of 32 trials with a compulsory 20 second break between blocks. Each trial started with a central fixation point (blue circle 0.4^{o} in diameter) and six equidistant red circles (1.3^{o} in diameter) positioned around this central fixation point in an imaginary circle of radius 9.6^{o}; this was presented on a black background. The red circles were positioned at clock position 1, 3, 5, 7, 9 and 11. Prior to commencing the task participants were told that one of the red circles would turn grey (the target) and that they should make a saccade to this target when this occurred. One red circle at a clock position of either 1, 5, 7 or 11 turned grey after 600ms.

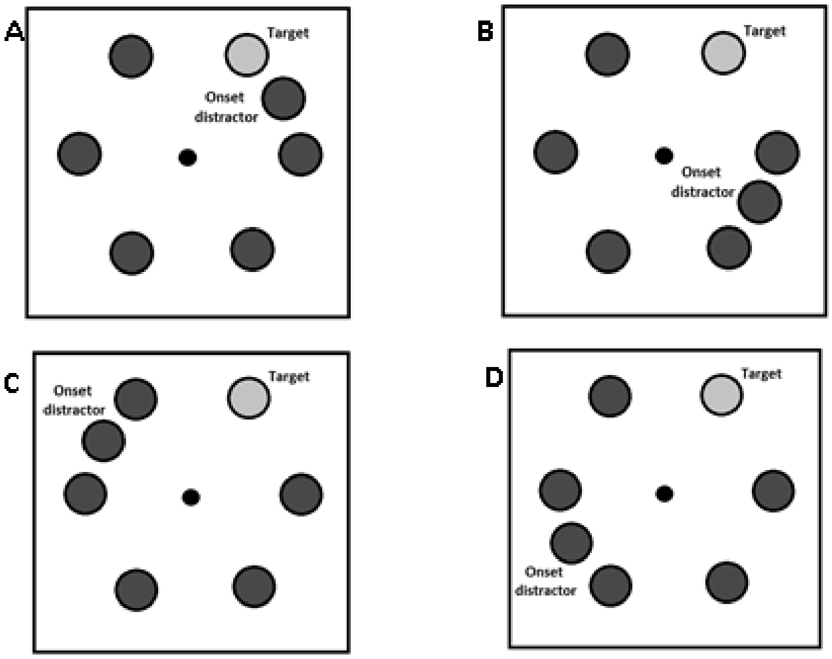


Figure 8 Example stimuli used in the sudden onset distractor task for trials in which a distractor was present. A: A near distractor with a narrow (30^{o}) angular separation between the target and onset distractor. B & C: A Medium distractor with a medium (90^{o}) angular separation between the target and onset distractor. D: A far distractor with a wide (150^{o}) angular separation between the target and onset distractor.

Participants were also warned of the possible appearance of an additional red circle (a distractor) and were instructed to ignore this when it occurred. These additional red distractors appeared on 50% of the trials at the same time as the grey target circle. The occurrence of a distractor was randomised. The distractor appeared at a clock position of either 2, 4, 8 or 10. On distractor trials the angular separation between the target and onset distractor was either a narrow (30^{o}, 16 possible near distractors), a medium (90^{o}, 32 possible medium distractor), or a wide angular separation (150^{o}, 16 possible far distractor) (see figure 8 for example trial stimuli). After 1200ms all objects were removed from the screen and the blue central fixation point reappeared signalling a new trial. See figure 9 for an example of the stimulus sequence.

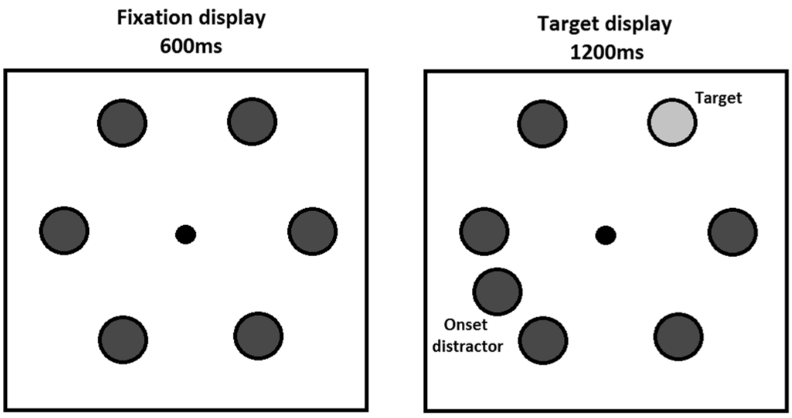


Figure 9 An example of the trial stimulus sequence used in the sudden onset distractor task. (Source: Adapted from Godijn and Theeuwes, 2002)

In brief, the Competitive Integration Model posits the existence of a retinotopic saccade map upon which endogenous (internally) and exogenous (external) activation is integrated (Godijn and Theeuwes, 2002). A saccade target location is represented by the mean vector of activity on the saccade map. A lateral interaction structure is present, whereby activation at a particular location on the saccade map spreads to neighbouring locations and inhibits distant locations. Two nearby locations will produce combinatory activations and two distant location activations are mutually inhibitory. Top-down inhibitory mechanisms can act directly on exogenous activation to reduce activation and thus ensure a saccade is not made to this location. Such location specific inhibition can pre-empt the arrival of a distractor and can cause a sub-baseline level of activation at this location. A saccade is triggered when activation at a particular location reaches a set threshold. Our experience and expectations lead to both the activation and inhibition of regions of the saccade generation map (Godijn and Theeuwes, 2002). See chapter 4 for a more detailed description. Based on the Competitive Integration Model for the Sudden Onset Distractor task we would expect longer RTs on far distractor trials due to mutually inhibitory effects and we would expect faster RT's for near distractors due to combinatory activation of the saccade map.

8.1.2 Adult population 1

This was a very early pilot study with a small sample of 9 participants (all female, mean age = 26.7, *SD* =3.5, range = 22 – 32). A typically developing adult population was recruited with posters erected within the University of Nottingham campus. We offered participants £10 in compensation for taking part.

For the purposed of analysis participant scores were grouped based on their CAARS scores with a cut-off score of 50. The high group (N = 4) had an average CAARS score of 57.8 (SD = 5.5), and the low group (N = 5) had a mean of 45.3 (SD = 4.6). A repeated measure ANOVA examined the trial type: capture trials (participants looked at the distractor), no distractor, short, medium, and long distractors, with an ADHD score between subject factor. An effect for trials type was observed, $F(4, 40) = 5.2$, $p = .02$. There was also an interaction for trial type x ADHD score, $F(4, 40) = 2.7$, $p = .043$. Post hoc analysis revealed that the high (M =291, SD =53) and low (M =390, SD =138) ADHD symptom groups differed significantly only on their RTs for trials with near (short distance) distractors, $t(12) = 1.95$, $p = .001$. A comparison of the number of capture errors was not found to be significant.

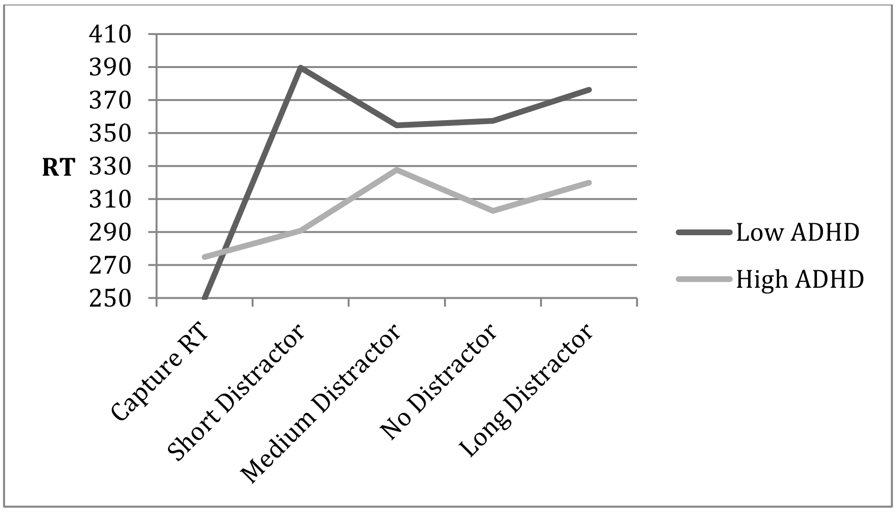


Figure 10 Reaction times (RT) for a high and low ADHD rates typically developing adult population for capture, short, medium, no distractor, and long duration trials.

An ADHD high-low interaction by trial effect is driven by the relatively fast short-duration for the high ADHD symptom group and relatively slow short duration for the low ADHD group. In contrast to the faster RT's seen in the high ADHD group the inhibitory control literature reports longer RT's for the ADHD population. However, it should be noted that this is a typically developing population rated on an ADHD scale. As such, the effect should not be over interpreted, but may reflect a bias towards a fast and less cautious response pattern in the high ADHD group, and a slower caution response pattern in the low ADHD group who draw more heavily on inhibitory control.

8.1.3 Adult population 2

A third year medical student as part of her placement was supervised in the gathering of data examining saccade behaviour associated with subclinical ADHD scores in a typically developing adult population. Participants were recruited with posters erected within the University of Nottingham campus; N = 28, aged 18 to 32 with a mean age =21.2 years.

As hypothesised, there was a main effect between the different distractor types on the saccade latency. This was significant $F(3, 81) = 10.133$, $p < 0.01$ after Greenhouse-Geisser correction for violation of sphericity. The saccade latencies are shortest for near distractors, whilst saccade latencies are longest when there is a far distractor. Saccade latencies for trials with no distractor or a medium distractor present are between the latencies for near and far distractor types.

We used a polynomial contrast to test for a linear relationship between the distractor conditions when the distractor type was entered in the order of near, medium, no distractor, and far distractor last. This input order is based on the predictions of Godijn & Theeuwes (2002) that the effect of a near distractor would result in the shortest saccade latencies, while the effect of a far distractor would result in the longest saccade latencies, with medium and no distractors being intermediate between the near and far distractors. This analysis showed a significant linear contrast $F(1, 27) = 18.930$, $p < 0.01$, see figure 11. A significant linear effect was also obtained when the input order of the medium and no distractor conditions was reversed, $F(1, 27) = 13.43$, $p = 0.001$. In neither case was the quadratic term significant ($F < 1$ in both cases). This result again supports the Competitive Integration Model.

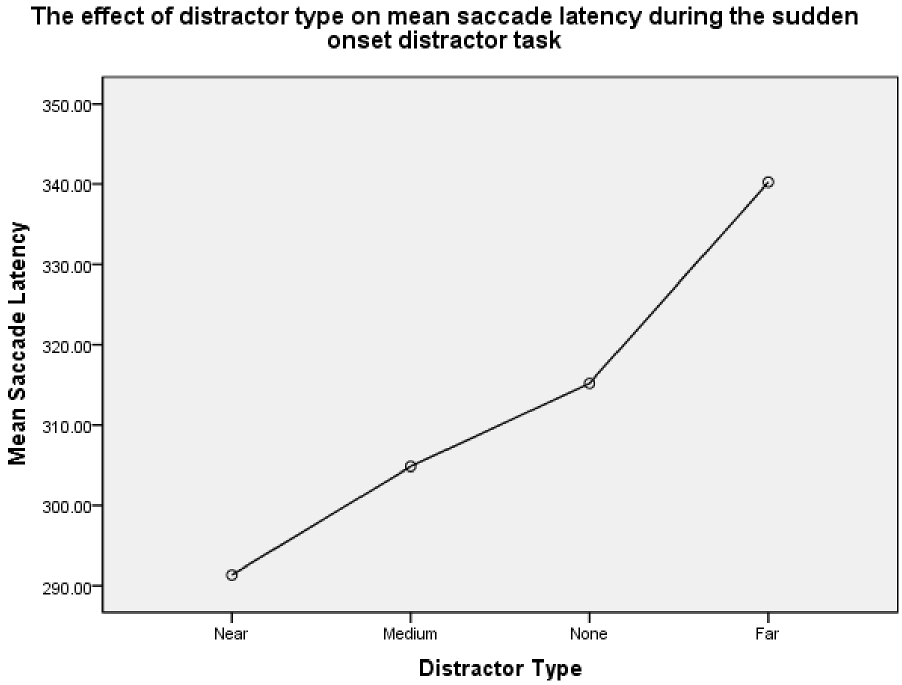


Figure 11. The effect of distractor type on the mean saccade latency during the sudden onset distractor task. The graph shows a significant linear contrast $F(1, 27) = 18.930$, $p < 0.01$.

Pairwise comparisons between the distractor type and saccade latency shows the mean difference is significant between far distractors when compared to a near ($p = 0.02$), medium ($p < 0.01$) or no distractor ($p = 0.03$), after a Sidak adjustment for multiple comparisons. When, as before, the conditions were entered in the order near, medium, no distractor, and far distractor last, polynomial contrasts indicated a significant linear relationship between the ADHD score and the effect of the distractor type on saccade latency, $F(1, 25) = 4.255$, $p < 0.05$. Examination of the parameter values indicated that the regression coefficient for ADHD score as a predictor of latency was more negative for the near distractor condition than for the other conditions. See figure 12 below.

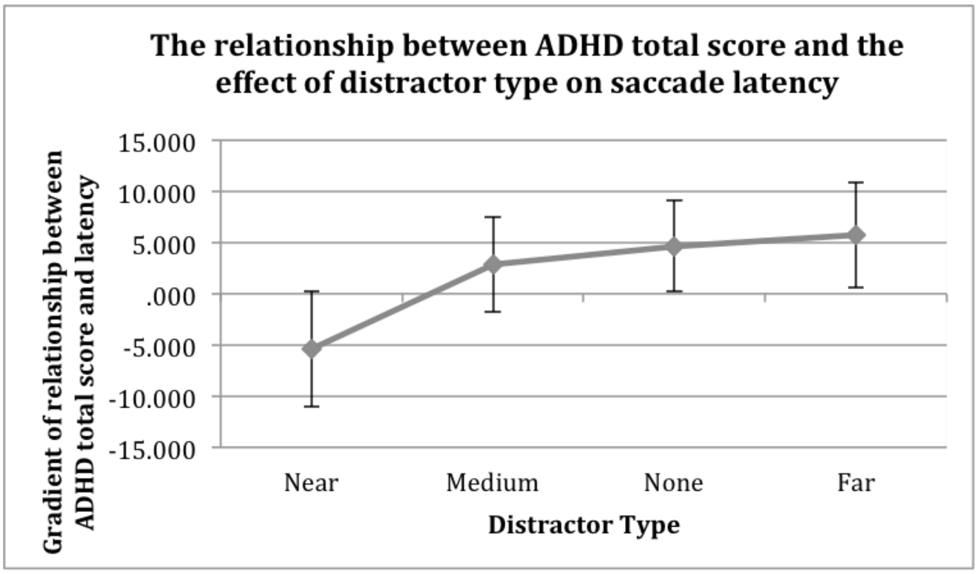


Figure 12. The relationship between ADHD score and the effect of distractor type on saccade latency. Y axis is the gradient of relationship between ADHD total score and latency. Error bars represent standard errors.

When the near distractor condition was omitted from the analysis, ADHD score did not significantly interact with the other distractor conditions, $F(2,54) = 1.432$, $p = 0.248$, indicating that ADHD score did not significantly affect the latency differences between medium, far, or no distractor conditions. As with the adult population 1, a high ADHD score is associated with a faster RT for near distractors. Again, this is not an ADHD sample but this effect may suggest that having traits similar to ADHD may impact on the inhibitory control system or behaviour strategies when completing inhibitory control tasks. Both data sets are broadly in line with the Competitive Integration model. Finding support for this model provides some validation for the eye-tracking and collection methods used and provides a degree of validity to the use of the competitive integration model to guide the development of the training intervention.

8.2 Later Pilot Studies

Gathering data with the 'summer scientist week' (see section 8.2.1 for a description) children and with local schools allowed me to develop and test a number of scripts, identify errors, refine the tasks, determine best practice when gathering data from children, and provides a normative data set for future studies with ADHD children. The children also provided useful feedback and insight on the tasks.

A superhero theme was used in these tasks. The participants were told that they were a superhero with laser vision. In the various tasks they had to use their laser vision to defeat the villain. The laser vision game theme was chosen because it has a close correspondence to the gaze control task objectives of the tasks.

To develop these assessment tasks I first developed a number of tasks that assessed inhibitory control and related functions. The starting templates for the game tasks were classic inhibitory control tasks. After an examination of the inhibitory control literature the stop signal and anti-saccade tasks were chosen. As I had identified timing as a critical aspect of inhibitory control I developed a task that required the production of timed saccades. I was also interested in more naturalistic gaze movements and therefore gathered ocular-motor reading data.

Gathering data from both the summer scientist week and schools required that the eye-tracker, computer, and monitors were transported to the allocated spaces provided. The tasks used for the summer scientist week were the Stop-Signal Task, The Anti-saccade Task, and Timing Task. For the schools data collection I additionally collected reading data. The tasks described below were subsequently used as the assessment tasks in the proof-of-concept study - the stop-signal, the anti-saccade, and timing tasks.

8.2.1.1 Stop Signal Task

The stop-signal task used is an implementation of the classic stop-signal task. This task is an ocular-motor version of the stop-signal task, sometimes referred to as the countermanding task. Individuals with ADHD have been shown to have altered performance on the stop signal task (Hanisch et al. 2006; Armstrong and Munoz, 2003). This task measures participants’ ability to inhibit the execution of a programmed saccade movement.

This version of the task has four blocks, the first is a pro-saccade block and the subsequent three are stop-signal blocks. The prosaccade block is comprised solely of 34 go trials. Participants are told to catch all the targets as quickly as possible.

Double the median reaction time for the first block is used as the response window for the remaining blocks. The remaining three blocks (blocks 2 to 4) are comprised of 40 trials with a ratio of 2:1 'go' to 'stop' trials. Between each block a minimum break of 20 seconds was given.

Participants were told that they had to “use their laser vision to stop an evil villain”, and that they should “zap him as soon as he appears on screen” by looking at him. They were additionally told that the villain had a hostage and that they must not “shoot” the hostage. They were told that the appearance of a large block box on screen indicated that it was not safe to shoot and that they must stay looking at the cross at the centre of the screen.

In this task a fixation cross is at the centre of the screen for a random period of between 510 and 1020 milliseconds (that is between 30 and 60 screen refreshes). If the participant's gaze moves during this period the message "wait" appears on the screen for 1360 milliseconds. The target image then appears randomly off to the right or left at an angle of 5 degrees. Participants must make a saccade to this location within the response window time limit. However, if it is a 'stop' trial the outline of a large black box appears after the stop signal delay (SSD) period. This indicates that the participant should not look at the target image, but must instead maintain their gaze position at the central fixation cross. For 'go' trials a participant will either make the saccade to the target in time (Hit) or fail to make it to the target in time (Miss). For 'stop' trials they will either successfully maintain fixation at the central fixation cross (Successful Inhibit) or fail to (Failed Inhibit). See figure 13 for a summary of the task sequence and stimuli used). After every trial immediate feedback is given informing participants whether they missed or hit the target on 'go' trials, or failed to inhibit or successfully inhibited a gaze shift on 'stop' trials. The visual feedback of “hit, +1”, “miss, -1”, “oops, -2”, or “well done, +2” are each accompanied by a distinct auditory sound. A summary of the participants overall score is given at the end of each block.

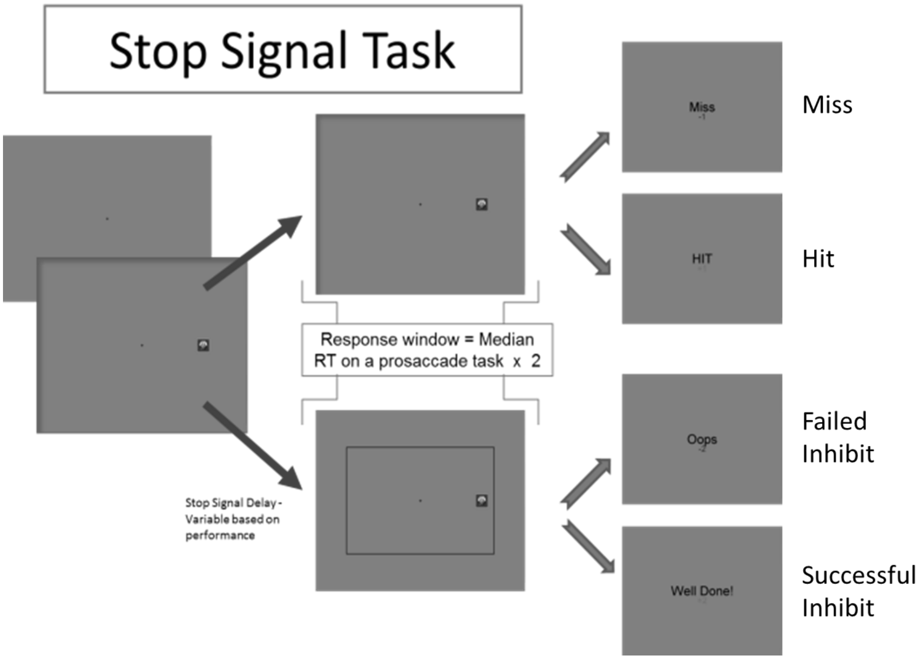


Figure 13. The temporal sequence of screens for the stop-signal task and the stimuli used.

The SSD tracked performance during the stop-signal task. The duration of the SSD is determined by a tracking algorithm. It is initially set to 51ms (3 screen flips) and increases (task becomes more difficult) or decreases by 17ms (one screen refresh) based on 'stop' trial performance. If the participant successfully inhibits a saccade to the target it increases, and if he or she incorrectly made a saccade it decreases. When a sufficient number of trials with a tracking algorithm are completed the SSD duration should begin to stabilise. Once it has stabilised it is possible to infer how long it takes the participant to cancel the planned go response, this is referred to as the stop-signal reaction time (SSRT) (Logan, Schachar, and Tannock, 1997). However, due to time constraints when collecting data an insufficient amount of trials were delivered with a stable SSD, therefore the mean inhibitory rate, that is, the proportion of successful inhibits given the number of trials in total, was used as a measure of performance.

8.2.1.2 Anti-saccade Task

The anti-saccade task is an ocular-motor inhibitory control task. It requires that a response is directed in the opposite direction to a peripheral target. This entails the suppression of a response to the target and voluntary control (endogenous/internally generated) over saccadic movement to make a saccade in the opposite direction.

Participants are told that the evil villain has managed to poison them and that their laser vision is out of control. They are told that in this task there will only be innocent targets and that they must avoid shooting the innocent targets by looking in the box in the opposite direction to the targets as quickly as they can.

The programmed anti-saccade task is comprised of 80 trials. For the inter-trial period of 170ms a circle appeared in the centre of the screen and remained there until the participant fixates on the centre of the circle. The start screen has a fixation cross at the centre and two empty boxes at five degrees to the left and right. If participants move their gaze from the centre of the screen before the appearance of the target the message "wait" appears on the screen, then the next trial begins. On each trial after a random period of between 680 and 1360 milliseconds (40 to 80 screen frames) a target appears randomly in the left or right box. A response window time limit of 1360 (80 frames) is used. If no response is recorded within this response window, "no response" appears on screen. In instances where the target appears and they look at the target, its colour inverts, the text "wrong direction" appears and a negative buzzer noise sounds. If they successfully look at the box in the opposite direction to the target a successful ding noise sounds along with the words "well done". The feedback appears on screen for 700ms (see figure 14). The main outcome measures used to assess performance are the mean reaction time and the proportion of correct responses.

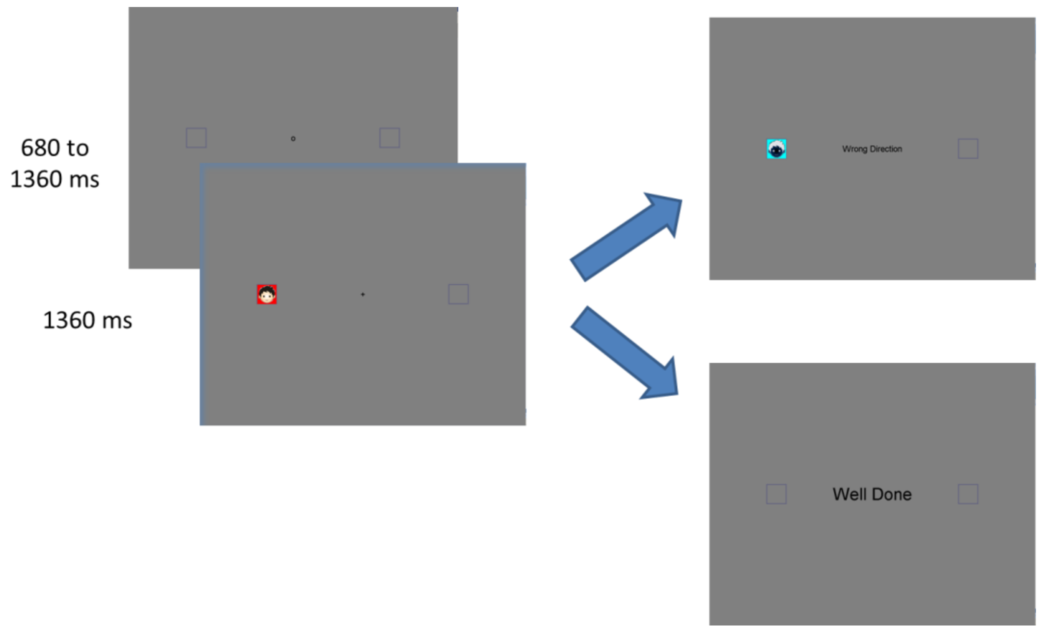


Figure 14. The temporal sequence of stimuli in the anti-saccade task.

8.2.1.3 Timing Task

The Timing Task is a timed saccade generation task. It is an original task developed specifically to test the temporal accuracy of participants' saccade productions across three different durations. Previous work has demonstrated that ADHD participants tend to make early responds in similar tasks.

Participants are told that they must defeat the evil villain in his robotic suit and to do this they need to time their laser zaps to the left and right. The target reliably alternates his appearance to the left and right, and an arrow in the centre of the screen at the start of a trial indicating the side of the screen on which he will appear reinforces this. After the arrow a fixation cross and simultaneous "bing" noise inform participants that the interval during which they should wait before looking to where the target will appear has begun. This interval must be learned across trials by noting the duration between the fixation cross and noise and the appearance of the villain. The target villain will appear for the last 80ms of the interval duration. This brief appearance is designed to guide the timing of saccades on subsequent trials, but is too short for participants to simply make a prosaccade based on its appearance. Participants are told that they must "zap" him just as he arrives or get there slightly before him.

Feedback is given after each trial informing the participant whether their saccade was early, late, or on time, and a score indicates the level of difficulty they had managed to achieve. The level of difficulty is a tracking algorithm that determines the temporal accuracy needed to be "on time". Changes to the temporal accuracy demand window always alter the forward boundary of the interval. A late response has no effect on the accuracy demand window. An early response decreases the temporal accuracy demand and an on time response increase temporal accuracy demand. Long runs of either on time or early responses change the accuracy demand window by 20% (6 of the last 6 trials), short runs by 10% (5 of the last 6 trials) and singe trials by 17ms (4 of the last 6 trials). Structuring the tracking algorithm in this way allows for large changes in the task demands when the difficulty of the task is very high or very low, thus increasing the speed at which the algorithm can find the limits of the participant's ability, while also allowing for minor changes when the task difficulty is near the limits of the participant's ability.

The task is comprised of three blocks, each with 40 trials. The duration period participants must learn in block one is always 1377ms (medium duration) of which the last 527ms forms the initial temporal accuracy demand window. At the start of block two participants are told that the evil villain has turned on his hyper-drive and will be much faster in this block. In block two the interval is 1003ms long (short duration) of which the last 493ms forms the initial temporal accuracy demand window. At the start of block three participants are told that the evil villain is getting tired and that he will be much slower to arrive. In block three the interval is 2125ms (long duration) of which the last 765ms forms the initial temporal accuracy demand window (see figure 15). The performance measure extracted for each block separately was the root mean square error of the final temporal accuracy demand window, that is the temporal accuracy needed to be "on time".

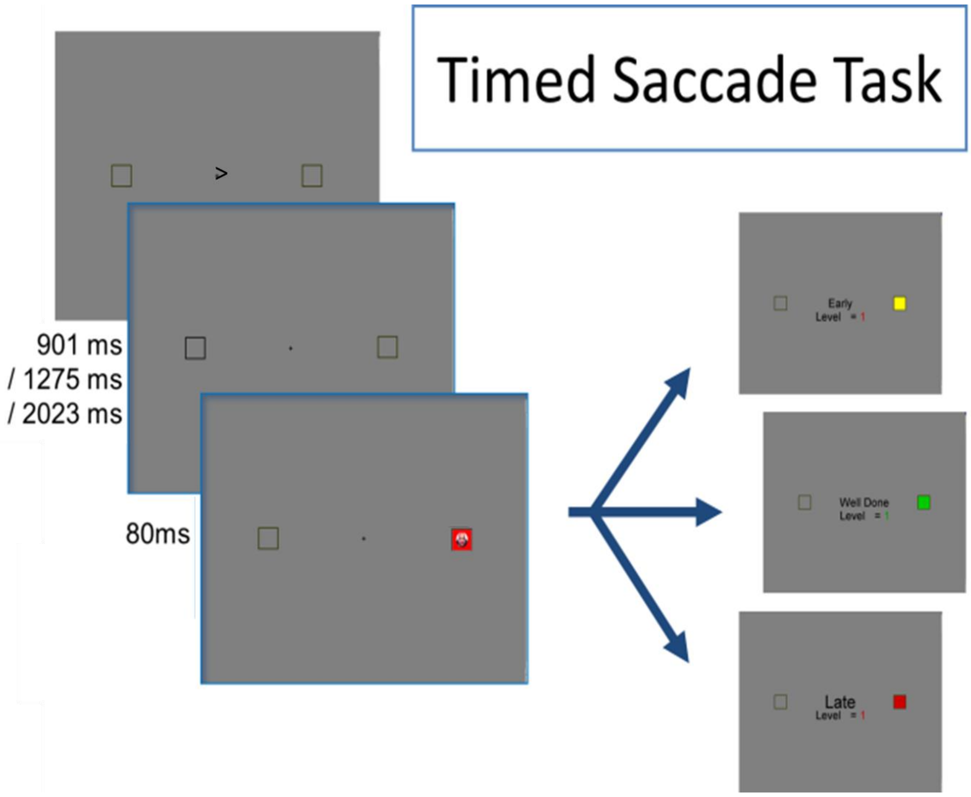
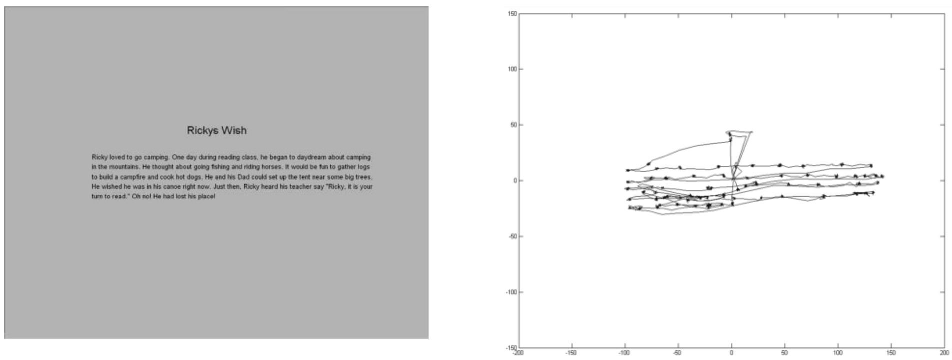


Figure 15. The temporal order of stimuli presentations in the Timed Saccade Task

8.2.1.4 Reading Sample task

The Reading Sample task was composed of text with a level of difficulty appropriate for fifth and sixth year school students (aged 10 and 11 years). Four screens of text were used. The instructions that appear on screen are read out to the participants, "read the text that appears on screen, but not out loud". Participants inform the experimenter when they have finished reading the current screen; this was also monitored by the experimenter in the mimic screen on the researcher's control screen. After each screen of text the participant was asked a question about the content of the text to ensure that they had read the text. Then the next screen of text appeared. Figure 16 provides a plot of the data gather with the eye-tracker alongside the text a participant read to generate this data.



A B

Figure 16. A. An example of the reading text given to participants. B. An example of the saccade pattern of a participant while reading the text.

8.2.1 Summer Scientist Week 2012

Data was collected at the Summer Scientist Week (SSW) in 2012 and 2013. SSW is an event organised and hosted by the University of Nottingham. Parents and their children aged between 5 and 14 are invited to a day of activities and to learn about and participate in psychological research. The data obtained is of a particular type given that the children who take part have turned up for a day of fun and games. The children are presented with a large amount of stimulations and have expectations of fun activities. In a minority of instances children withdraw their participation, typically because they would prefer to engage in the other activities available on the day. A time limit of 20 minutes with each child is imposed on the researchers. Children are approached in the communal games area by the researchers, asked if they would like to participant in their game, and then taken to a shared relatively quiet research area. Background standardised psychometric data is available on all participants.

For SSW 2012 an N = 55 was recruited, aged 7 to 12. The parents of the children completed the Strengths and Weaknesses of ADHD-Symptoms and Normal-Behaviours (SWAN) Rating Scale (Swanson, 2005). This is a standardised ADHD rating scale. It provides an ADHD inattentive score, an ADHD hyperactive score, and a combined ADHD score. A number of technical problems with the newly developed tasks have been encountered and problems resulted also from shifting the equipment from the lab to the SSW location. This resulted in data loss and poor quality data in some cases. I present here data for the stop-signal task.

A partial correlation controlling for age revealed a significant effect for the percentage of hits for 'go' trials and ADHD combined total, $r = 0.297$, $p = 0.032$, and ADHD Inattentive total, $r = 0.293$, $p = 0.032$. A partial correlation controlling for age revealed a borderline significant effect for the percentage of hits for 'no-go' trials (i.e. successfully inhibiting) and ADHD Inattentive total, $r = -0.264$, $p = 0.056$.

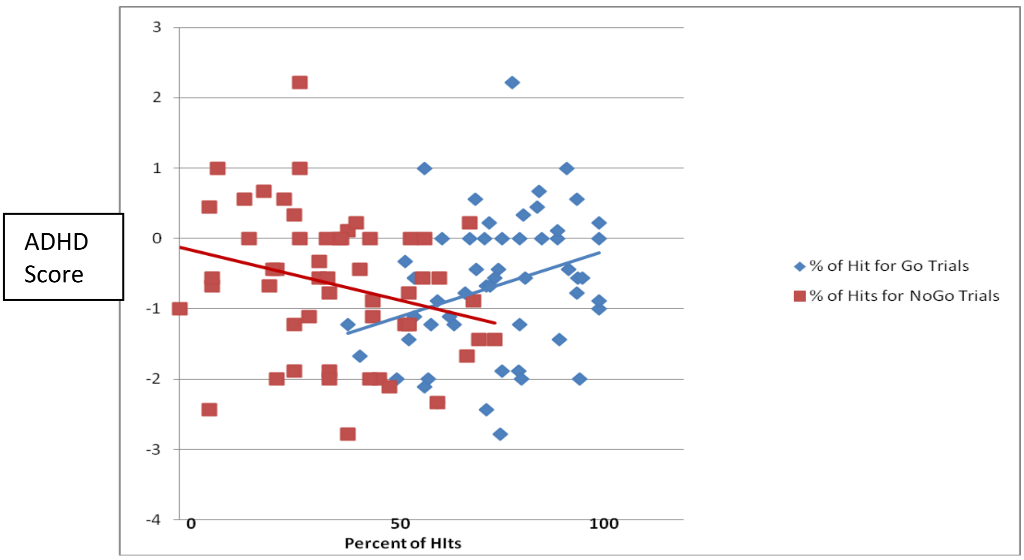


Figure 17. On the x-axis is the percentage of hits for 'go' trials (blue) and successful inhibits (red); on the y-axis is the ADHD Inattentive score.

These results suggest that if one scores higher on the ADHD scale one is likely to inhibit less responses on 'stop' trials and have a higher amount of hits on 'go' trials.

If one scores lower on the ADHD scale one is likely to inhibit more responses on 'stop' trials but has a reduced amount of hits on 'go' trials. This may indicate a trade-off between success on 'go' trials and on 'stop' trials, and indicates that those scoring higher on the ADHD scale are biased towards 'go' trials at the expense of successfully inhibiting on 'stop' trials. This strategy would optimise performance if there is poorly developed inhibitory control, or conversely, a tendency to not to inhibit could lead to the underdevelopment of inhibitory control.

8.2.2 Summer Scientist Week 2013

For the second SSW in 2013 I recruited 74 children, aged 7 to 12. The same tasks were used but due to improved equipment, programming and procedures the quality of the data was of considerable higher quality. Fully automated saccade extraction programs were developed to process the data. On a subset of participants a semi-automated extraction program was used to validate the automated program. Given the age range of the participants the focus of the analysis was the impact of age on the development of the cognitive function of interest. This subsequently informed the development of the training intervention used in the proof-of-concept study as regards the question of what functions and age range should the intervention target.

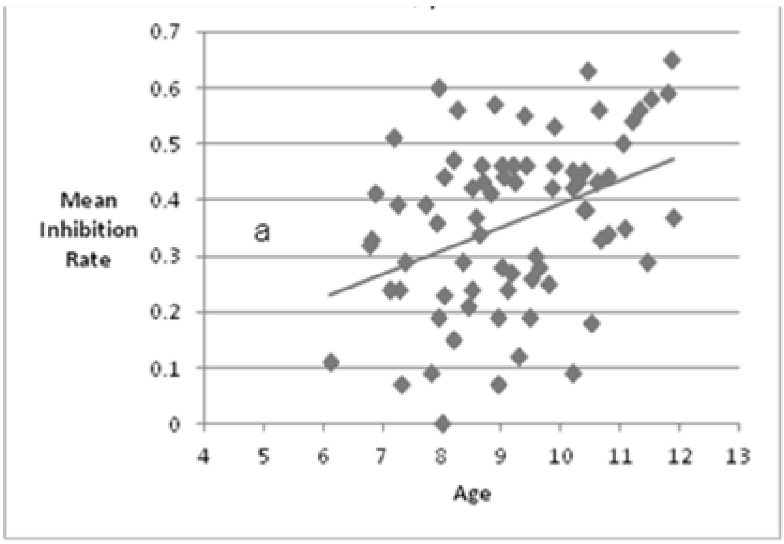


Figure 18. A scatter plot for anti-saccade task showing mean inhibition rate by age

For the anti-saccade task a bivariate correlation was observed for age and the mean inhibition rate, $r = 0.39$, $p = 0.01$. As can be seen in figure 18 the older the child the higher the mean inhibition rate, indicating a better inhibitory gaze control performance.

For the timed saccade task the temporal accuracy of saccades for each of the trial durations was calculated as the root mean squared temporal error variance. A correlation between age and temporal accuracy for the short and long duration intervals was observed: short interval (901ms) $r = -0.377$, $p = 0.011$, medium interval (1275ms) $r = -0.205$, $p = 0.176$, and long interval (2023ms) $r = -0.340$, $p = 0.022$. The older the child the more accurate is their saccade timing. A reduction in the variance of the root mean squared error variance indicated increased consistency in interval production: for short durations (901ms) $r = -0.360$, $p = 0.015$, medium durations (1275ms) r = -0.367, $p = 0.013$, and long durations (2023ms) $r = -0.420$, $p = 0.004$ (See figure 19).

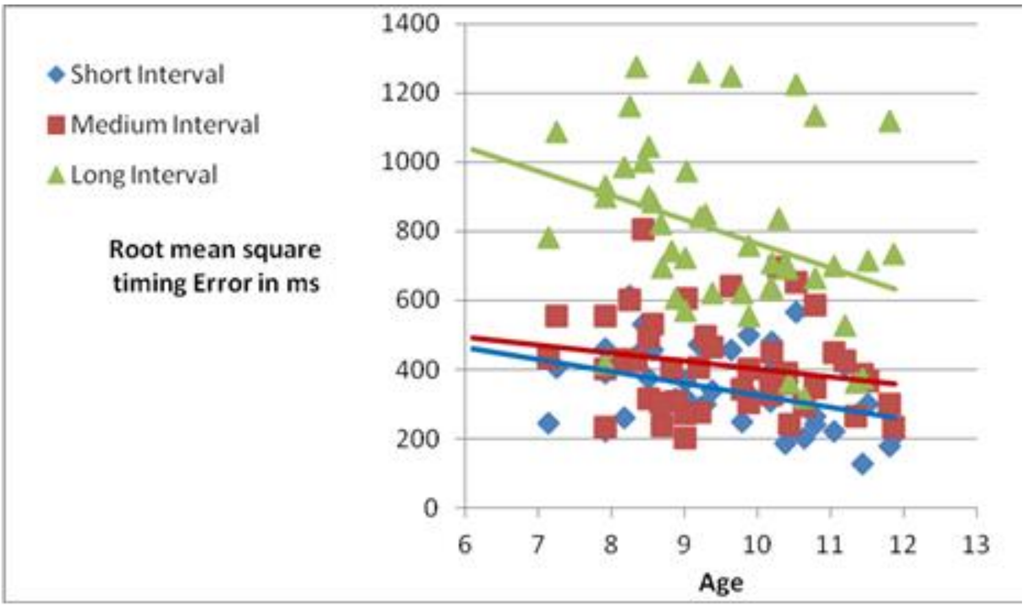


Figure 19. A scatter plot of the Timed Saccade task for the temporal accuracy of saccade on Short (blue), Medium (red), and Long (green) trials by age.

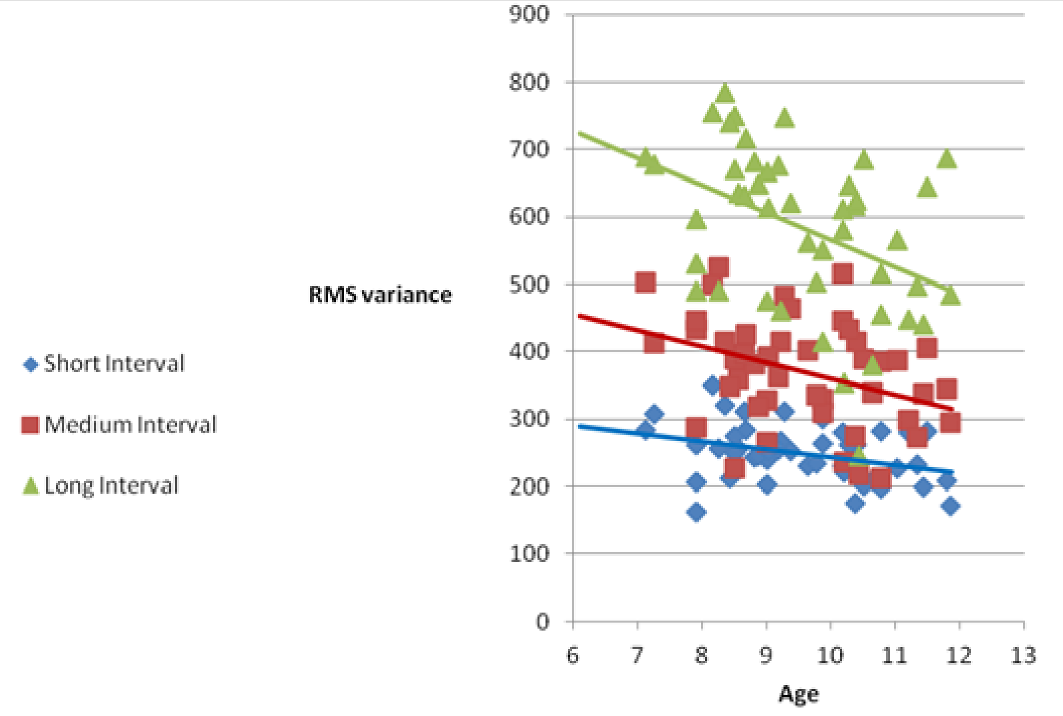


Figure 20. A reduction in root mean squared error variance with age.

The findings suggest that as children age they improve in the timing of their planned saccade for short (901 ms), medium (1275 ms), and long durations (2023 ms). They improve in both their temporal accuracy and reduce the variability of their timed saccades.

Using the procedure described by Meng, Rosenthal, & Rubin (1992) the correlated coefficients were compared for the long and short durations to give a Steiger's Z = 0.429 (short duration, r = - 0.360, long duration r = -0.420, short-long correlation r =0 .372, $t(71)$ = .51, p = 0.305). While age may appear to have a greater effect on longer versus shorter durations given the steeper line slope for longer durations a comparison of these slopes did not produce an significant result.

8.2.3 School data

Building on the SSW data arrangements were made to enter two local Nottingham schools, each for a week, to gather data from year 5 and year 6 children (N = 66, aged 10 and 11). The tasks used were again the modified versions of classic inhibitory control tasks (stop-signal task and the anti-saccade task) and the timed saccade task. Additionally a more ecologically valid measure, a reading sample, was employed. This homogeneous age sample is intended to serve as a normative data set to which children with ADHD can be compared in future RCT studies. It additionally served to examine the relationship between task performances on the various tasks to provide construct validity, i.e., does the successful completion of the various tasks draw upon a similar range of abilities - inhibitory control and functions peripheral to inhibitory control? Additionally I sought to test for a correlation between inhibitory control tasks and reading parameters extracted.

Research ethics were obtained and arrangements made to enter each of the two schools with the eye-tracking equipment for a week. When the schools were first contacted I was encouraged by the schools to use opt-out consent. It was suggested that I would be unlikely to collect a reasonably sized sample with opt-in ethics. In line with the ethics granted by NHS Derby the parents of the children were informed that the research was being conducted in their child's school and that they should contact the school if they or their child did not wish to participate.

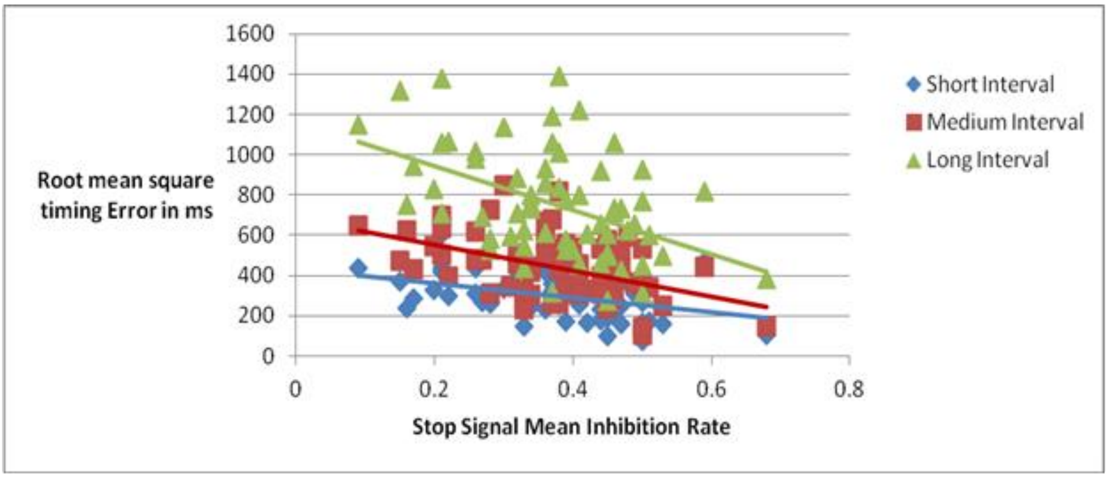


Figure 21. The correlation between stop-signal mean inhibition rate and percent of correct anti-saccade trials.

The data gathered was processed with the fully automated saccade identification algorithms programmed and developed in Matlab. The results were put into SPSS for analysis. Strong correlations were seen between a numbers of task measures.

As expected there was a strong correlation between the inhibitory control tasks used, i.e., the stop-signal task and the anti-saccade task. There was a correlation between the percent of correct anti-saccade trials and the stop-signal mean inhibition rate, $r = -.491$, $p = .001$. This relationship is displayed in figure 21 below. This correlation shows that the higher the proportion of successful 'stops' the lower the number of errors on the anti-saccade task.

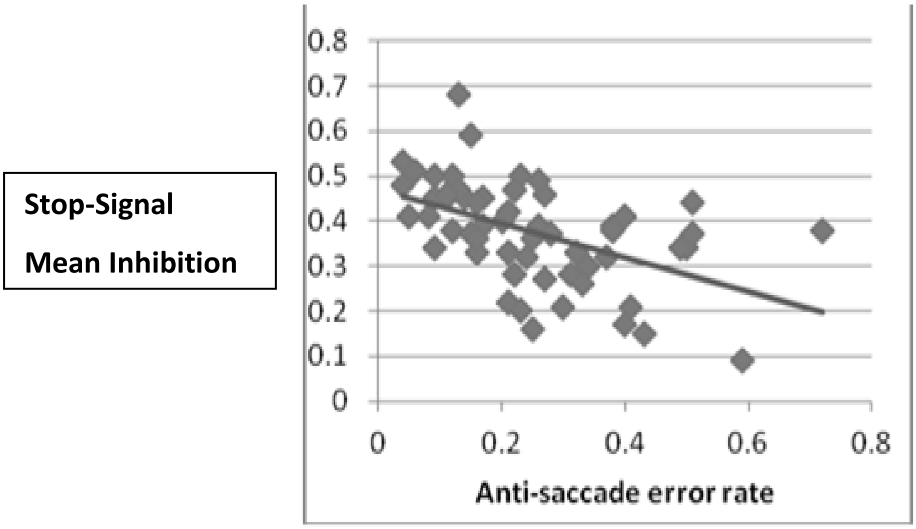


Figure 22. A scatter plot with trend lines for correlations between the mean inhibition rate on the stop-signal task and the root mean square temporal error for short, medium, and long timed saccade durations.

When examining the relationship between the stop-signal task and the timed saccade task, the mean inhibition rate for the stop-signal task correlated with the root mean temporal error square of the short (901ms, $r = -0.362$, $p = .003$), medium (1275ms, $r = -0.451$, $p < 0.001$), and long (2023ms, $r = -0.429$, $p < .001$) timed saccade estimations (see figure 22). Better temporal accuracy is associated with successfully inhibiting in 'stop' trials. This is consistent with the theory that the ability to optimise the timing of responses contributes to success on the Stop-Signal task (Liddle et al, 2009). and that the same mechanism may underlie Stop-Signal Task and Timing impairments in ADHD.

The error rate for the anti-saccade task correlated with root mean temporal error square of the short (901ms, $r = -0.333$, $p = 0.011$), medium (1275ms, $r = -0.419$, $p < 0.001$), and long (2023ms, $r = -0.442$, $p < 0.001$) timed saccade durations (see figure 27). Increased temporal accuracy is associated with a reduction in the number of anti-saccade errors.

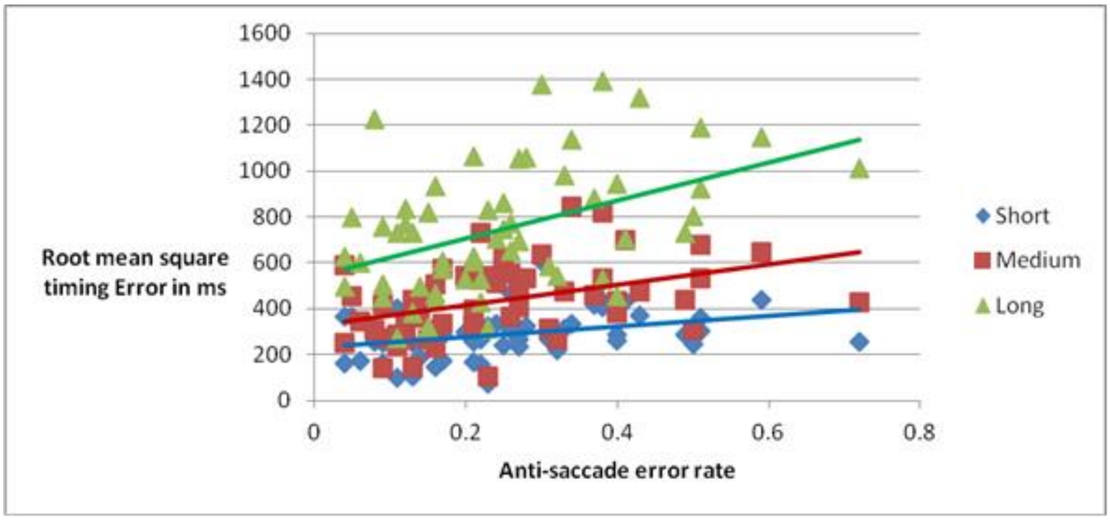


Figure 22. A scatter plot with trend lines for correlations between the error rate for the anti-saccade task and the short, medium, and long timed saccade durations.

A number of different parameters extracted for the stop-signal, anti-saccade, and timing tasks were found to be correlated. Table 3 shows the correlation for the predicted stop-signal values, the mean reaction time for correct anti-saccades and the predicted accuracy for the short, medium and long timed saccade durations.

Table 3 Correlations between the timing task root mean squared error, the proportion of anti-saccade errors, and stop-signal task mean inhibition rate.

	Anti-Saccade	Timing Task Short	Timing Task Medium	Timing Task Long
Stop Signal Mean Inhibition Rate	R = -0.336 p = 0.011	R = -0.257 p = 0.040	R = -0.319 p = 0.010	R = -0.314 p = 0.011
Anti-Saccade Error		R = 0.323 p = 0.014	R = 0.260 p = 0.051	R = 0.273 p = 0.040

The number of right and left saccades was extracted for each participant and used as a measure of gaze control during reading. To establish an estimate of the number of saccades needed to read the text while controlling for catch-up saccade after regressions/ backward saccades have been made to revisit a location, the leftward saccades (too small to be return sweeps) were subtracted from rightward saccades. This calculation was made as it was felt that regressions may be partly related to comprehension as opposed to gaze control. The resultant metric was found to correlate with the Stop-Signal mean inhibition rate for all four reading blocks.

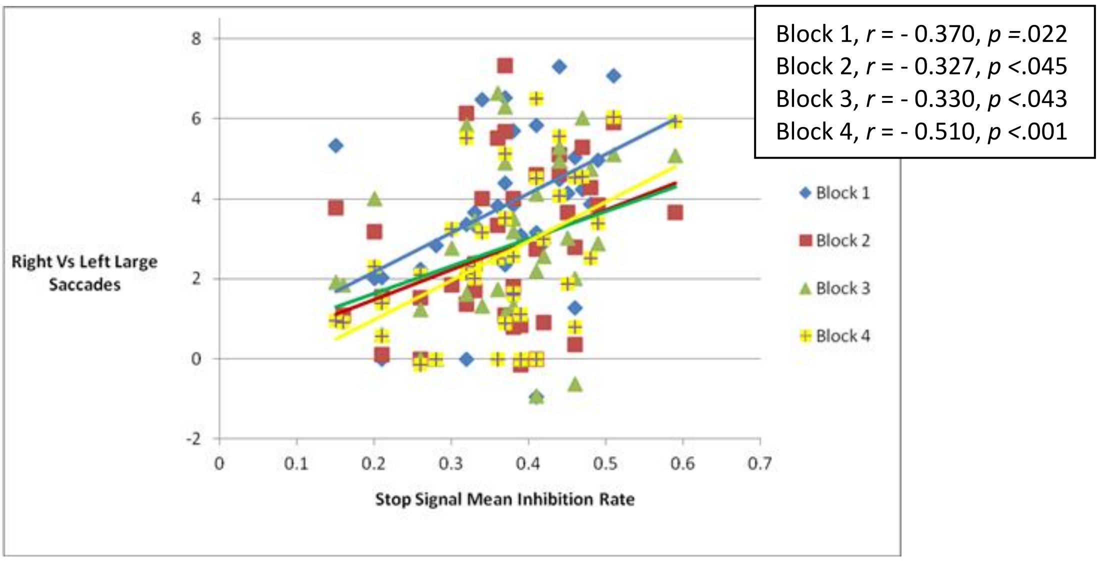


Figure23. Bivariate correlation between Stop-Signal mean inhibition rate and the right left subtraction of large saccades

In figure 23 the y-axis is a metric indicating the number of rightward saccades controlling for the number of leftward saccades. A lower number indicates fewer rightward saccades. Less rightward saccades were found to be correlated with a worse stop signal mean inhibition rate. This relationship was found across all blocks. One interpretation of this data is that the children who make more rightward saccades are exhibiting better control over their gaze while reading and that this is associated with better inhibitory control as illustrated by a better inhibitory control performance. However, contra to this interpretation Rayner (1998) reports that dyslexic and beginning readers exhibit shorter saccades than skilled readers, as do less skilled readers (Ashby, Rayner, & Clifton, 2005).

8.3 Summary of results

The pilot studies yielded important findings for task development for the proof-of-concept study. The findings of the early pilot study work with typically developing adult populations suggested that individuals with high scores on ADHD rating scales tended to respond faster, potentially utilising less inhibitory control. A similar finding was observed for the 2012 SSW sample. On the stop-signal task a higher ADHD inattentive score was associated with more hits on 'go' trials but less successful inhibits on 'no go' trials.

For SSW 2013 data an examination of the development of children’s inhibitory control skills allowed us to identify the most appropriate age group at which to direct the training. This consideration took into account the child’s developmental stage with respect to the cognitive functions of interest and also their ability to use the equipment/provide good quality data. The biggest hurdle to gather useful data is the inability of smaller children to (i) sit still and not to shift about and (ii) not to move their head while making saccades. If it is decided that the intervention should be delivered during developmental critical periods these results would suggest that children have established inhibitory control skills by the age of 10 / 11.

The school data provides a normative sample for further RCT’s with ADHD children aged 10 and 11 years. Analysis of the school data revealed strong correlations between performances on the various tasks providing some convergent validity that the tasks are drawing upon similar abilities.

The pilot studies were instrumental in the development of the game. The children’s feedback helped to refine the mechanics of the game and the procedures of its delivery. The pilot studies afforded an opportunity to identify and resolve technical issues related to ensuring the quality of the data gathered.

8.4 Task refinement

A single task, such as the stop-signal task, can be modified and gamified in multiple ways. Different methods for defining parameters can be deployed, different graphics and sounds can be used, and different storylines or instruction can be given. In addition there are many subtleties in the programming of a task that will affect the experience of the task and therefore the behaviour encouraged in participants, for example, spatial accuracy parameters, or how peripheral game stimuli impact on the salience of the target stimulus. For the development of the proof-of-concept training intervention 9 different tasks were developed. In addition, a framework to link the tasks together, a training schedule, procedures to provide feedback to participants, and procedures to ensure the quality of the eye-tracking data collected were developed. Given that there are numerous elements to be altered in the development process many of the decisions made are based upon the experimenter's best judgement. Such decisions were based on integrating the feedback elicited during the pilot studies, the pilot performance results, participant's behavioural observations, and the quality of the data recorded with the eye-tracker. Discussed below are some of the many changes implemented across the pilot studies that aided the development of the training intervention.

The equipment did fail on a number of occasions in the early pilot testing. The eye-tracker tended to overheat. One potential solution considered was to use a dual CPU setup. However given the likely technical difficulties and the increased transportation difficulties such a setup would entail, this solution was not chosen. Improving the RAM and storage of the computer resolved the overheating and equipment failure issues.

A number of changes were made to the data collection procedure to maximise the quality of the eye-tracking data gathered. Many of the lessons learned are summarised in section 8.1.1 "Limitations of the eye-tracker". For example, participants tend to sit up-right when they first sit into the eye-tracker but subsequently slouch. The following procedure was found to be of particular use when using the eye-tracker with children: Initially some time was taken to adjust the chair and eye-tracker height. Letting the children then watch a short video (e.g. 30 seconds) with their chin on the chin-rest allows them time to find their natural relaxed position. At the end of the video minor readjustments were made to the equipment to account for the more natural slumping position the participant will typically adopt. Only after these adjustments have been made the calibration process is conducted.

An important change made to the set-up of the eye-tracker resulted from the decision to collect data from the participants' dominant eye (note the system used in monocular tracker). In the early pilot studies the data was always collected from the left eye. There are advantages to both these approaches but on the whole gathering from the dominant eye increased the fidelity of the tracker and thus made the gaze contingent programs more responsive.

The testing of children under the age of 7 was found to be problematic. These children had a tendency to shift their head in conjunction with their saccade movements. Drawing their attention to this had little impact on reducing this movement and as a result led to an excessive amount of data loss (note this may not be an issue with other eye-tracking technologies not using a chin rest). Older participants were told "sometimes the eye-tracker may not work; sometimes this is because you have moved your head a little bit," which resolved the issue.

Across successive iterations of the tasks the verbal and onscreen instructions given to participants were improved. These were refined in conjunction with the back story given to participants to set the context for the task being completed. Having the children explain and describe the task in their own words after they had completed the task was found to be a useful method for refining the instructions given to future participants. In the proof-of-concept study short video demonstrations of how the tasks worked were given and were followed by simplified scaffolded versions of the tasks.

In the development process with successive iterations the tasks progressively integrated more sophisticated algorithms. For example, later versions of the tasks had greater correspondence between the programmed time of a stimulus presentation and the actual time a stimulus appeared on screen. The greater precision was achieved by having the time periods specified in the script correspond to the refresh rate of the monitor. That is, participant's RT should be calculated based on the time at which a stimulus actually appears on the monitor. If the task program states that the target stimuli should appear on the monitor 30 ms after time point x, and if the monitor refresh rate is 17ms, then there is uncertainty as to when the stimulus will appear. If the monitor is presenting a new image every 17 ms we first need to know the state of the monitor at time point x. The solution is to lock script command executions to the monitor refresh rate, that is, to when the monitor will present the new stimulus. We can state in the script that time point x is the time when a new monitor image has appeared. At this time point zero milliseconds of the 17 ms has elapsed. We can then be exact in the duration of stimulus presentations by specifying stimulus presentations based on temporal chucks of 17ms. We can therefore present images for 17 ms, 34 ms, 51 ms, 68 ms etc.

Early scripts provided no feedback or merely simple correct/incorrect feedback. The feedback participants received about their performance increased in complexity providing information on the reaction time, the task difficulty, or comparing their performance to that of the previous block. The proof-of-concept training tasks also presented an end of block summary results screen with a graphical presentation of the trainee's performance.

The pilot studies were used to guide decisions on the lengths of training and assessment sessions, and how long to make the blocks that comprise a training session. It was found that fatigue was common for sessions above 50 minutes and for blocks longer than 5/6 minutes. In the proof-of-concept study the length of the blocks was approximately 4 minutes and the length of a training session was 45 minutes to an hour with many small breaks throughout.

A number of programming errors were identified. For example, a problem with the identification of a proportion of downward saccades was detected. In the anti-saccade task downward saccade to the left of the centre line were not picked up but saccades to the right were. In a number of cases the programming errors were noticed by identifying consistencies across participants' comments, e.g. "I'm pretty poor at the downward saccades", "I'm often to slow for the bottom targets" etc. and by observing eye-gaze behaviour on the monitoring screen.

Efforts were made to increase the efficiency of the programming, e.g. by pre allocating space to variables created. This increased the efficiency of the program operations, ensured that Matlab functions could be executed quickly and reduced the chances of software crashes. This also had the effect of speeding up the transition time between programs. Other programming improvements eliminated the need to make manually changes between tasks to adjust task difficulty to performance.

A high contrast between the presented background and foreground stimuli appeared to place a strain on the eyes for a subset of participants and to make them sleepy when performing tasks. This seemed to be particularly true when black backgrounds were used. Having extreme contrasts and black backgrounds were therefore avoided in the proof-of-concept training and assessment tasks.

Valuable feedback from children on how engaging they found the tasks was gained both from the school data and the SSW data. The motivation of children in school is expected to be quite high owing to the fact that participation meant having a break from their typical classes. For the SSW data the children participating had a selection of games to choose from as motivation since the context of Summer Scientist Week delivered expectations that the game that they were taking part in would be fun and interesting. After the child had participated they were asked what their favourite and least favourite tasks were and why. Through this process children identified the stop-signal task as being "sneaky" or "unfair" "because sometimes it doesn't tell you not to go until it's too late". Based on this feedback the instructions given to participants emphasised that for the stop-signal task the villain in the game would try and trick them in this way on some trials. A large proportion of participants identified the anti-saccade task as being the task they liked the least. The reasons identified were that it was seen as repetitive and for some very difficult. Based on this feedback the proof-of-concept training game version of this task was much shorter than the pilot test version (120 versus 45 trials) to reduce boredom. Also the proof-of-concept assessment version of the task was reduced (120 versus 80 trials). The response window was identified as the main parameter that determined the difficulty of the task; this window was therefore increased to an appropriate level. In addition, the inter trials interval (ITI) was identified as being too short. A short ITI does not allow the participants sufficient time to recover between trials and leads to a higher cognitive load and poorer results, however poorer results in this instance do not necessarily reflect poor inhibitory control. Thus, the duration of the ITI was increased.

Improvements were made to the algorithms used, e.g.

- Improvements were made to the performance tracking algorithm implemented in early versions of the timing task; early on changes in the size of the target duration increased or decreased by a single screen refresh rate (17ms) contingent on performance on the previous trial. In order to increase the speed at which the tracking algorithm zones in on the limit of the participant's ability, and based on the logic that a run of successful trials indicated a degree of proficiency for a given duration, the size by which the target duration increases or decreases was greater (two refresh rates) if the participant had a run of successes or failures. The improved tracking algorithm generated more data of interest and was more effective at maintaining the participants' interest as a result of optimising the challenge of the task with respect to their ability.

- For the stop-signal task a response window (the period of time within which a response must be made) was initially determined by examining the RT derived from a prosaccade task. Participants' response window was the 90th percentile of the prosaccade reaction time plus four times their interquartile range. However, this was found to create excessively short response windows in a number of instances. The problem identified was that for some participants a high number of trials with poor data quality resulted in a distorted response window size when the above response window calculation method was used. The response window subsequently used in the proof-of-concept study was 2 and half times the median RT.

Examining typically developing children and adults in the pilot studies provided useful performance targets for the training intervention. Indeed the school sample collected was intended as a normative sample for a child ADHD clinical sample for use in future studies in a clinical child ADHD sample.

Improvements were made to the saccade identification algorithms and real time saccade identification algorithms were developed. In the early programs feedback was not given. This often led to confusion in participants as to whether they had performed the task correctly or not. In later versions of the tasks real-time saccade identification algorithms were deployed and participants were given immediate feedback. For some tasks this feedback included information such as their reaction time and an indication of the task difficulty. Some of this information was subsequently simplified or removed as it proved to be a distraction form the most important information. For the proof-of-concept study end of block "high score" announcements, for blocks where a participant had achieved a personal best, were introduced as well as graphical representations of performances across the blocks.

The task stimulus feedback participants received improved and attempted to encourage specific behaviour. For example, in the forward timing task participants were given both auditory and visual feedback that reflected the temporal accuracy of their saccade. Initially in the forward saccade task the points participants received were always positive and increased linearly until a cut-off point. Saccades made after this cut-off point were punished with a negative score. Due to this point structure a proportion of participants preferred to secure points by making early saccades and avoid the risk of losing points with a late saccade. As a result they settled for a degree of temporal accuracy below their potential ability. However, the aim of the intervention is to encourage participants to challenge themselves to be more accurate. The solution was to remove the negative scores for late responses (participants now scored zero for late responses as opposed to negative scores) and the linearly increasing point structure was changed to a quadratic curve (see figure 24) so that very early responses received negative points and responses close to the cut-off point were more highly incentivised dependent on their proximity to the target interval.

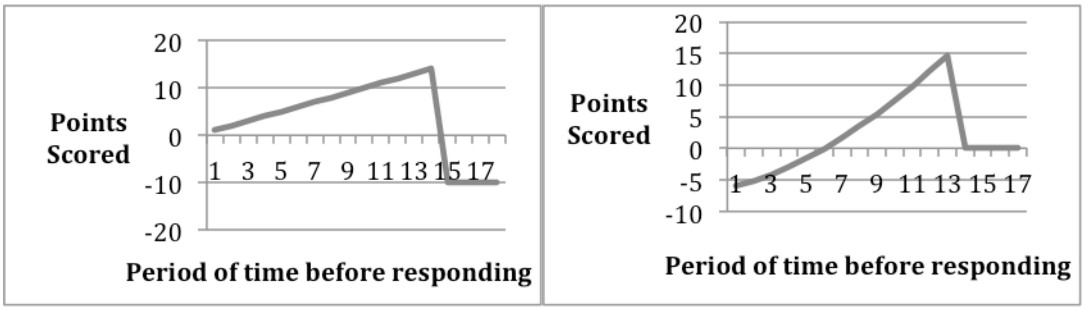


Figure 24. Illustration of alterations made to the point reward structure for temporal accuracy.

General improvements were made to the mechanics of the game: The final game tasks combined task instruction videos, scaffolded task practice versions, tracking versions to identify the optimal level of difficulty, and a set level structure with a staircase of increased difficulty across and within blocks.

9 A Proof-of-concept study

I hypothesise that reinforcement deficits in the ADHD population give rise to the underdevelopment of a number of cognitive abilities generally developed in the course of typical development, particularly inhibitory control skills. Impaired inhibitory control does not necessarily mean a lack of capacity to develop inhibitory control skills. Motivational incentives have been shown to normalise behavioural performance and neural activity in the ADHD population, suggesting a capacity for inhibitory control. Inhibitory control is a skill that is acquired over the course of typical development, but further, both individuals with Tourette Syndrome and bilinguals demonstrated enhanced inhibitory control, suggesting it may be explicitly trainable. With sufficient motivational incentive it may be possible to scaffold the development of inhibitory gaze control in an ADHD population. Remediating inhibitory control deficits may additionally improve attention and reduce hyperactivity. The training intervention attempts to provide participants with an opportunity to engage with a motivating game that isolates abilities that have been underdeveloped, allowing trainees an opportunity to engage in deliberate practice. We know the brain is plastic, sustainable gains may be possible with sufficient practice.

To summarise the rationale behind the training protocol: Training inhibitory gaze control was identified as a potential means of training inhibitory control more generally, and the feed-forward and competitive integration models were discussed as useful frameworks for understanding the visual system. However, inhibitory control is not used in isolation during the training, therefore the intervention also targeted cognitive control more generally, including elements of attention and timing ability. There is a need to ensure the training intervention is directed at the functions of interest; the tasks used should have an intrinsic load with respect to the functions of interest while minimising the extraneous load. As the training seeks to target specific underdeveloped functions it was decided that the functions of interest should be targeted with precision, that is, with simple as opposed to complex tasks. I propose that this approach will minimise the use of compensatory strategies when completing the training. Given that any task will draw on multiple functions the cognitive constructs of interest will be assessed and trained with multiple tasks, that is, I attempted to use multiple tasks that converge on inhibitory gaze control. The theory is that each task draws on a different constellation of functions, but for the successful completion of all tasks inhibitory gaze control will be an essential component.

I have suggested that impaired reinforcement is a primary reason for the failure to develop inhibitory control, it is thus critically important that the trainees are sufficiently motivated and engaged with the training. In addition, I have argued that intrinsic motivation is of particular importance when trying to strengthen a weakened system and to avoid the use of compensatory skills. Intrinsic motivation will ensure a willingness to expend cognitive capacity on developing the targeted function. If the training is sufficiently engaging the trainee will be intrinsically motivated to increase capacity and engage in deep learning, especially if the targeted function has latent capacity since this implies a favourable trade-off between gains made and energy spent. Critical to ensuring the trainee is intrinsically motivated is the need for intrinsic integration; by ensuring that the core mechanic of the game constitutes the target of the training we encourage an investment in the germane load and deep learning.

It was suggested that the trainee, particularly ADHD trainees, may need to be extrinsically encouraged to invest cognitive capacity in the training when they first begin to train. Extrinsic motivations such as game points contingent on successful performance, entertaining video footage, and a compelling background story are used in an attempt to motivate trainees to engage with the training tasks. The novelty of using eye movements to play a game may additionally be motivating to trainees. However, these factors serve only to engage the participants' interest and are unlikely to hold their attention across sessions. Central to holding their attention are interesting game mechanics.

With respect to the delivery of extrinsic rewards there is a need to carefully gauge their size. If the extrinsic rewards for success are too little we might expect participants to be insufficiently motivated to invest energy and thus fail to identify the new skill as worth investing in. If the rewards are too great they may continue to rely on compensatory abilities unwilling to produce a poor performance in the short-term. The size of the extrinsic reward should be enough to draw them in but leave enough room for intrinsic motivation to take root. In any game the point structure is critical; what the point structure rewards or punishes will determine the focus of the participant's efforts. As such, in the training game the points awarded are dependent on performance with respect to the target of the training, the core mechanics of the game. In this way trainees are focused on the core mechanics, and as the extrinsic value of the points diminishes the point system instead can serve to support the intrinsic goal of increasing competence.

The continuous feedback with respect to performance as delivered by the point structure serves to scaffold functional development. The shift to intrinsic motivation is supported by highlighting to participants that their current level of ability can be improved by providing performance summaries at the end of blocks. It should also be noted that a central function of the reinforcement system is to enhance motivation for activities that are functionally beneficial. Therefore if the training intervention is increasing the functionality of the systems involved and trainees are aware of this then they are more likely to be motivated to engage with the game.

The tasks developed have adjustable parameters that can be altered to modify the difficulty of the intrinsic load of the tasks. The tasks additionally utilise performance tracking algorithms to ensure trainees are challenged within their zone of proximal development. To ensure participants have capacity to process the germane load the task difficulty is pitched below the level of maximum capacity. In addition, the difficulty of the tasks is varied within blocks. As the block progresses the difficulty of the task increases to stress to trainees that there is a need to improve, and towards the beginning of the block the difficulty is reduced to ensure the trainee has sufficient capacity to invest in improving their level of skill (the germane load).

By creating an artificial learning environment it is possible to simplify the learning of the skill being targeted and control the amount of exposure trainees receive to the learning content, thereby circumventing potential learning and reinforcement impairments. Creating an environment in which they are motivated and have an opportunity to engage in deliberate inhibitory control practice may remediate the deficits seen. The training intervention essentially attempts to present an externalised representation of their inhibitory control system and provide trainees with an opportunity to exercise this system. The training intervention aims to lay bare the underlying function and provide a way to develop the system in a playful way. This external representation if pitched at the correct level of difficulty should aid the development of cognitive schemas (Schnotz & Bannert, 2003) and enhance the use of metacognitive strategies (Ainsworth & Loizou, 2003). The visual feedback is used as a means of detailing the current operational capacity of the underlying saccade and attentional systems.

The intervention until this point had been developed with a non-ADHD sample. However, our results suggest that subclinical ADHD symptoms are associated with altered gaze control and potentially a bias towards response strategies that deemphasise the use of inhibitory control. The aims of the proof-of-concept study were:

- To further refine the intervention with respect to an ADHD population,
- To obtain feedback and assess the feasibility of delivering the training intervention and assessments to an ADHD population
- To examine improvements in gaze control associated with the delivery of the intervention.

Building on the assessment tasks developed and refined in the pilot studies the training intervention was composed of modified versions of the Stop Signal, Anti-Saccade, and Delayed Saccade tasks to train inhibitory control. Forward and Backward Timed Saccadic production tasks were also developed. The Jumping Bomb task was developed to train multiple functions, including vigilance, maintenance of fixation in the presence of peripheral cues, and temporal discrimination. And finally, the fixation task was developed to train the maintenance of fixation in the face of distractions. These tasks are further detailed below.

9.1 Methods

9.1.1 Study design

This was a proof-of-concept pilot study. The study used was a test-retest design; it comprised a training intervention made up of 8 training sessions, and a pre and post assessment session (see figure 25).

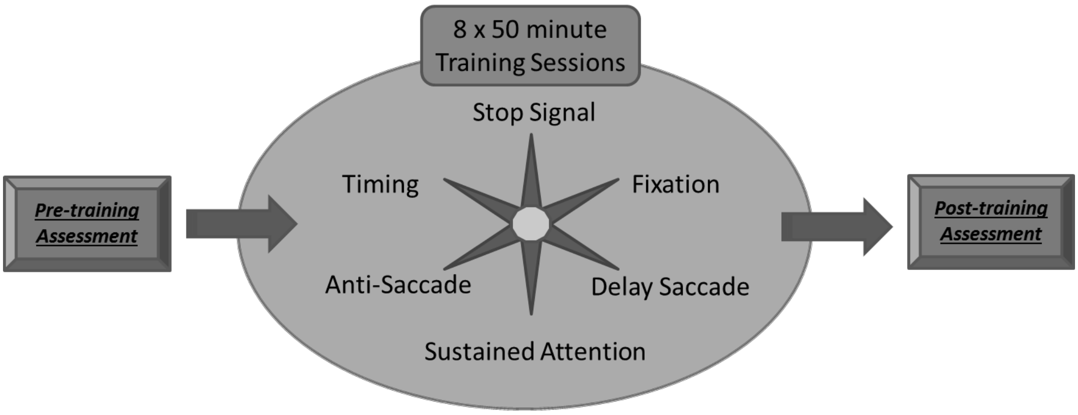


Figure 25. The structure of the study design used in the proof-of-concept study.

9.1.2 Ethics

As the study involved a clinical sample NHS ethics approval was required. This was obtained from the Derby NHS ethics committee. This process involved first obtaining the support of the research sponsor, the University of Nottingham, who first approves the NHS ethics application. The application is extremely detailed containing (i) a detailed proposal, (ii) a list of all risks and benefits, (iii) descriptions of all the tasks and assessments participants will complete and (iv) all documents used for the intervention, including information sheets, consent forms, letters to be sent and recruitment posters. This application is then sent to the NHS ethics committee. The committee arranges a panel meeting to discuss the project with the applicant in person. When approved by the committee all application documents are then submitted to the Research and Innovation department at the University for further approval. This process takes approximately 3 months. Amendments to the ethics approval granted can be applied for in the same way. A panel meeting is not required for amendments. The amendment process takes approximately 6 weeks.

9.1.3 Recruitment

Participants were recruited via posters, ADHD clinics, and ADHD support groups. The recruitment advert specified that participants should have ADHD. The age range criterion was 8 to 50 years of age, and it specified that those with comorbid Tourette Syndrome could not take part. Males and females could take part in the study. The poster informed potential participants that participation in the study involved 10 visits to the University and that participation involved a significant time commitment. The poster used contained a number of scan links that lead to a video content showing the training intervention game and a website with the study information sheet. Website addresses for this content were also on the poster. The poster also contained contact details as well as tear off contact detail tabs. The recruitment poster used in appendix 5.

The recruitment of participants was problematic for a number of reasons. The intervention requested that participants (and their parent if aged under 16 years) attend the university 10 times within the space of 3 to 4 week. This places a large demand on participants and potentially their family. Despite this I did manage to recruit 10 participants, primarily from a local ADHD support group.

After recruitment the major concern was the retention of the participants. It was emphasised to participants that participation in the study would require a sizeable commitment. Participants who showed an interest in participating but subsequently failed to follow through with appointments early on or repeatedly rescheduled appointments were not put under any obligation or pressure or pursued to continue with participation. It was felt that such participants were potentially more likely to be less intrinsically motivated to engage with the intervention and as such were less likely to engage with the intervention in the manner required for the intervention to work in the hypothesised manner. Participants were reminded about appointments via a text the evening before or on the day of testing. Participants decided the times and dates for their training and assessments. The only stipulation was that their assessments (pre and post assessments) should take place at the same time of day, and that medication if taken must be the same on both assessment days. Only one training session could be conducted per session and a training and assessment session could not be completed on the same day.

In an effort to minimise participant attrition the participants completing the intervention were facilitated in a number of ways. Participants were provided water and savoury snacks at the start of sessions and between blocks. Sweet snacks were also available to take away at the end of the session. For one participant I also provided a small meal at the start of her training session as the session took place immediately after her working day. For one participant a cup of tea at the start of each session and a cigarette break in the middle of the training session were expected and given. Taxi and bus payments were typically made the following session, alternatively immediate payment for taxis was made if preferred. Participants were allowed to choose when the sessions took place, in some instances this resulted in sessions being grouped together or being very spread out on some occasions.

9.1.4 Participants

10 participants were recruited in total, 2 dropped out before completing all training sessions. The first participant was extremely eager to continue with participation but was not able to do so due to poor health. The second participant similarly expressed an eagerness to complete the training but felt that he could not follow through due to other time commitments. Given the number of visits required I was pleased with a retention rate of 80%.

Eight participants (4 male; age = 25.6, *SD* = 8.4) completed the eight training sessions and two assessment sessions. Five out of eight participants had a diagnosis of ADHD, two awaited a diagnosis, and one suffered from attention problems not due to ADHD. Four of the participants were on medication throughout the training and assessments. Participants were paid £40 for their participation or £5 per session for those who did not complete all sessions. The costs for lunch on the assessment days were covered. Participants' transportation costs were reimbursed.

9.2 Procedure

9.2.1 Assessment procedure

Upon showing interest in participating in the study prospective participants were given information sheets in person, via post, or via email at least a week prior to the first assessment session. On the initial assessment day all participants were presented with an information sheet and given the opportunity to ask any question pertaining to the study. Time was given before the assessment to allow the participant to adjust to their surroundings. An effort was made to ensure participants felt comfortable and relaxed. Water and savoury snacks (e.g. peanuts and crisps) were on offer before and during the assessment should the participants wanted a short break. A half hour/hour break and money to buy lunch were provided in the middle of the assessment procedure. After consent forms were completed demographic and psychometric data was gathered. This data was only gathered in assessment one. In addition to the demographic data listing in participants completed the CAARS-Self-Report: Short Version (CAARS-S:S) (Conners, Erhardt, and Sparrow, 1999) and Autism Spectrum Quotient-10 (AQ-10) (Woodbury et al., 2005) questionnaires. The questions were read to the participants by the experimenter to ensure that reading ability was not a confound. Separate to the assessment tasks and training tasks participants also completed the WASI metric and verbal reasoning tests to obtain an IQ estimate. This data was gathered after a training session of the participants' choosing.

Each participant’s pre and post training assessments took place at the same time of day. Participants first completed the Qb Test (a continuous performance task with infrared motion tracking), followed by the WRAT test (reading and arithmetic), Stroop task, cancellations task, and TOWRE test (word and non-word list reading). They were then given a half hour to an hour break to get some food and rest. They were asked not to consume caffeine or refined sugar during this period. After the break they completed the eye-tacking assessment tasks in the following order: (1) the reading sample, (2) spot the difference task, (3) fixation task, (4) stop-signal task, (5) anti-saccade task, (6) timing task, and (7) the delayed saccade task. Without using the eye-tracker they then completed the Cantab tasks: (1) Manual

Stop-Signal task, (2) Intra-Extra Dimensional Set Shifting task and (3) Information Sampling task (Neuropsychological Cognitive Testing, 2015).

9.3 Assessment tasks

The assessment battery lasted approximately 2 and a half hours. A range of tasks was used to examine performance on a subset of trained tasks, on more ecologically valid gaze tasks, and more standard cognitive assessment tasks. The assessment tasks used were a mix of tasks developed specifically for this purpose and established psychometric tasks. The benefit of developing tasks in-house is that they can target the function of interest in a specific way. The benefit of using established tasks is that there is literature to draw upon as regards reliability estimates and, in some cases, normative data for comparison purposes.

Table 3. Assessment tasks used for the pre and post training intervention assessment

Task Type	Task		Measures
Trained Eye-tracking tasks	Stop-signal task		Ocular inhibitory Control
	Anti-saccade task		Ocular inhibitory Control
	Timed saccade task		Timed saccade production
	Sudden onset distracter task		Ocular inhibitory Control
More ecologically valid gaze tasks	A reading sample		Ecologically valid measure of gaze control
	Spot the difference task		Ecologically valid measure of gaze control
Standard assessment tasks	Qb-test; CPT with infrared motion tracking		Hyperactivity and attention
	CANTAB	Set shifting	Rule acquisition and reversal
		Manual Stop Signal	Manual inhibitory control
		Information sampling	Impulsivity and decision making
	WRAT4	Arithmetic	Written maths problems
		Untimed reading	Simple word reading
	Digit span	Forward	attention and short-term memory
		Backward	Attention, short-term memory, and working memory
	TOWRE word reading	Words	Gaze control reading down vertical lines and reading

Non-word	Gaze control reading down vertical lines and phonological decoding
Stroop	Attention and executive function
Cancellation task	Visual scanning

To develop these assessment tasks I first developed a number of tasks that assessed inhibitory control and related functions. The starting templates for the game tasks were classic inhibitory control tasks. After an examination of the inhibitory control literature the stop signal and anti-saccade tasks were chosen. Given that no task is function specific/process pure the delayed saccade task was developed to allow inhibitory control to be targeted in an alternative manner. Drawing on the Competitive Integration Model of saccade generation the delayed saccade task requires more delicate regulation of endogenous and exogenous retinoscopic saccade map activation. As I had identified timing as a critical aspect of inhibitory control I developed a task that required the production of timed saccades. Gaze stabilisation was an obvious target; therefore tasks tapping the maintenance of fixation were also developed. I was also interested in more naturalistic gaze movements; hence data for a reading sample and a spot the difference task were developed. In addition a number of standardised assessment tests were used. The assessment tasks are listed in Table 4.

9.3.1 Assessment of trained tasks

The stop-signal, anti-saccade, and timing tasks used in the pilot studies (as described in chapter 8) were adapted for the proof-of-concept study. These tasks are classified as assessment tasks for the trained tasks because the functions they assess are explicitly trained in the training intervention, though they take a slightly altered form in their training game version (described below in section 9.4.2 Training Game Tasks). In addition to these three tasks the delayed saccade task and fixation task were both trained and assessed. These tasks are described below.

9.3.1.1 Stop Signal Task

Participants must make a saccade to this location within the response window time limit. However, if it is a 'stop' trial the outline of a large black box appears after the stop signal delay (SSD) period. This indicates that the participant should not look at the target image, but must instead maintain their gaze position at the central fixation cross. This is the same task as described in section 8.2.1.1 except that the response window used in the training assessment (double the median reaction time for the first block) is also used as the response window in the post training assessment. Using the same response window in the pre and post-training assessments is to ensure performances are more readily comparable across assessments.

9.3.1.2 Anti-saccade Task

This task is as described in section 8.2.1.2. The anti-saccade task is an ocular-motor inhibitory control task. It requires that a response is directed in the opposite direction to a peripheral target.

9.3.1.3 Timing Task

This task is as described in section 8.2.1.3. The Timing Task is a timed saccade generation task that examines the temporal accuracy of participants' saccade productions across three different durations.

9.3.1.4 The fixation task

This task has three parts. The first part has an image of a character with a blue dot superimposed. The participant is told that to defeat this enemy character they must maintain focus on the blue dot. Over the course of 18 seconds the image of the character decreased in size appearing to be pushed into the distance until it was smaller than the blue dot. The location and size of the blue dot remains stable throughout. Between the first and second, and second and third parts of the task the enemy character appears on screen laughing and the text on screen reads that he is coming back again. In the second part only the blue dot is presented on screen. Participant is told that the enemy character is hiding behind the blue dot and that they should maintain focus on the blue dot to defeat him. The dot appears for 18 seconds. In the third part participants are told that the enemy character is going to try to distract them away from the blue dot but that they should only look at the blue dot. The blue dot then appears at the centre of the screen for 18 seconds.

Every second a single new black circle appears on the screen for either a second or a hundred milliseconds; this was determined randomly.

9.3.1.5 Delayed saccade Task

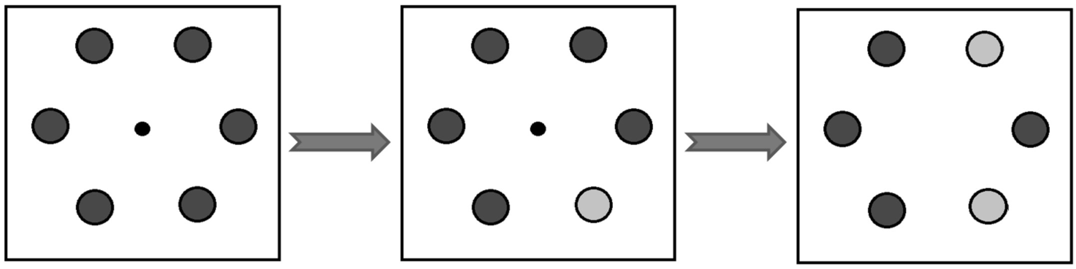


Figure 26. The temporal sequence of stimuli in the Delayed Saccade Task.

This task was developed after considering the saccade generation system as described by Godijn & Theeuwes (Competitive Integration Model, 2002). The successful completion of a trial utilises inhibitory control and careful regulation of endogenous and exogenous excitation of the saccade generation map. The participant must fixate on the central fixation dot for the trial to begin. The trial begins when six red circles at one, three, five, seven, nine, and eleven o'clock appear around the fixation dot at 7 degrees from the centre. The participant must fixate at the central dot for a randomly determined period of between 1000 to 2000 ms, then one of the six red circles randomly selected turns grey. After a further random period of between 1000 and 4000 ms a second red circle turns grey and simultaneously the central fixation dot disappeared. This screen appears for 1000ms and is the response window within which the participants must look at the first grey circle. The participant instructions are that they should look at the first grey circle when the second grey circle appears (see figure 26). No feedback is given to participants in this task. However, participants' gaze movements are monitored by the experimenter in the mimic screen. If participants appear to execute the task incorrectly they are reminded of the instructions.

The performance measures used to evaluate performance in the delay saccade task are the mean RT and the proportion of correct response. A successful performance with a fast RT in the delayed saccade task requires that participants exercise inhibitory control to withhold a saccade until the first grey dot that appears. During this random interval of between 1000 – 4000 ms they must not overly suppress activation in response to this exogenous stimulation in order to be prepared to make a saccade to this location and must remain vigilant for the arrival of the second grey dot. The disappearance of the central fixation dot combined with the appearance of the second grey dot results in the natural tendency to look at the second grey dot, a tendency increased by the fact that the appearance of the second grey dot is a relevant temporal marker. The arrival of the second grey dot produces exogenous activation, necessitates a large amount of suppression and the simultaneous endogenous activation of the first grey dot location. This task requires the participants to delicately manipulate activation and inhibition over the saccade generation map.

9.3.2 Assessment of untrained tasks

These assessment tasks were not trained explicitly with the training intervention. They were assessed as they each utilise the ocular-motor system and have more obvious relevance for daily functioning than the other assessment tasks. The tasks used to assess untrained ocular-motor function were a reading task and a spot the difference task.

9.3.2.1 Spot the different task

This task entailed the presentation of seven screens. On each screen a pair of images was presented with a single difference distinguishing them. The participant was told to state the difference when they saw it. If a minute elapsed without the participant identifying the difference a prompt was given, such as "the difference is contained in the lower half of the image", and after a further minute the location of the difference was given. Different images were given in the pre and post-assessments. These images were not counter balanced across assessment.

9.3.2.2 Reading Sample task

Different text was used for the pre and post-assessments. The text was not counter balanced across assessments (see appendix 4 for a sample of the text used). The letter spacing of the on-screen text was not standardised or controlled for.

Four screens of text were used in both assessments. The text used was graded for fifth year students. The instructions that appeared on screen were read out to the participants, "read the text that appears on screen, but not out loud". Participants informed the experimenter when they had finished reading the current screen. Their gaze movements were also monitored by the experimenter on the control screen to ensure they were reading the text. After each screen of text the participants were asked a question about the content of the text to ensure that they had read the text. Then the next screen of text appeared.

9.3.3 Standard Assessment Tests

All of the assessment measures listed in this section have normative samples and the results are age corrected. Using standardised assessment tests allow us to assess a broad range of function and rule out major cognitive deficits in other domains. These tests also provided a means of comparing our population to the general population. This can thus indicate whether performance scores that were low at the initial assessment had been normalised at the post training assessment (as a result of the intervention), and if so to what degree.

9.3.3.1 QbTest

The Qb-test has been developed by QbTect Ltd to assist clinicians with the assessment of ADHD symptoms. The test entails completing a continuous performance task while movements are recorded. It is a reliable and validated measure of hyperactivity, impulsivity and attention. Using the Qb test provides a reliable test retest measure and also provides a normative ADHD sample to compare to our sample. The QbTest produces a number of outcome measures related to the amount of movement, reaction times, and the omission and commission errors made.

The Qb test combines a computer-administered continuous performance test (a 'go'/ 'no go' vigilance response task; CPT-type) with high resolution motion tracking. The tracking system uses an infrared camera to follow a reflective marker attached to a headband worn by the participant. The position of the marker is sampled 50 times per second, and the spatial resolution is 1/27 mm per camera unit. The continuous performance task lasts approximately 20 minutes. Participants view one stimuli at a time as they appear on the screen. The stimuli are a red circle, red square, blue circle, and blue square. The participants should click a response button they hold in their hand when the stimulus presented is the same as the proceeding stimulus (for more information visit - http://www.qbtech.se/products/qbanalysis).

A study by Sharma and Singh (2009) examining the clinical validity of the QbTest reported an 81% specificity and a 96% sensitivity of the QbTest to differentiate individuals with ADHD from individuals with disconfirmed ADHD. In a study evaluating the stability of the test performance 40 typically developing adults with a mean age of 25 were tested twice with a gap of between 1 to 22 days (mean = 5, *SD* =4.6). Pearson correlations used to examine the test retest revealed adequate to high test retest correlations for primary output measures (amount of movement, reaction times, and the omission and commission errors made) (Ulberstad, 2012).

9.3.3.2 Cantab

The Cambridge Neuropsychological Test Automated Battery (Neuropsychological Cognitive Testing, 2015, Robbins, 1994) is a cognitive assessment hardware and software package produced by Cambridge Cognition. It comprises a touch screen tablet and an additional response pad. It has a range of cognitive assessments. Three assessments were selected for our pre- and post-assessment.

9.3.3.2.1 Manual Stop Signal

Manual Stop Signal is a measure of response inhibition. Participants must respond to centrally located arrows pointing to the left and right by pressing the respective buttons on a response pad. However, if they hear a beep they must withhold their response. The output for the analysis of the Stop Signal task is the SSRT for the last half of the test. For the Information Sampling task the parameter extracted for analysis are the discrimination error and the box opening latency.

9.3.3.2.2 Information Sampling Task

Information Sampling Task (IST) is a test of impulsivity and decision making. The participants see an array of 5 x 5 grey boxes and two coloured boxes below. When they touch a grey box it reveals one of the two colours underneath. The participant must open a number of boxes before deciding if the 5 x 5 array contains more of one colour or the other. There are two phases of this test. In one phase the opening of a grey box reduces the amount of points that can be earned for a correct response, and in the other phase the same amount of points can be earned regardless of the number of boxes opened. Three performance parameters were extracted for this task:

1.) The Discrimination error is the number of trials in which the participants chose a colour that was not in the majority of cases at the point they made their decision, even if the colour chosen was revealed to be correct (lower is considered better).

2.) The IST total correct is the total number of trials for which the participant correctly chose the colour in the majority of cases (higher is considered better).

3.) The open box latency is the time elapsed between the participant opening a box and then opening a subsequent box, or the time between the start of a trial and the opening of the first box (lower is considered better).

9.3.3.2.3 Intra-Extra Dimensional Set Shift

The Intra-Extra Dimensional Set Shift (IED) tests rule acquisition and reversal. This test is an analogue of the Wisconsin Card Sorting test. Two images appear on screen composed of colour filled shapes overlaid by white lines. The participants must learn which of the image features is correct through trial and error. This feature will change after a period and they must then identify the new correct feature. The performance parameter extracted for the IED task was total errors adjusted. This is a measure of the participant's efficiency in attempting the test. It is the sum of the number of errors made; lower is considered better.

9.3.3.3 Wide Ranging Achievement Test

The Wide Ranging Achievement Test (WRAT4) is a measure of basic (untimed) reading and arithmetic skills. In the reading test word recognition is assessed. Participants must read the words on a card at their own pace. The words become progressively more difficult. In the math test they have 14 minutes to answer as many of the question presented as possible. Their ability to solve increasingly difficult written math problems is assessed. For both tests there are two versions (Tan and Blue versions), this allows for test retest with new stimuli. For both tests the output is simply the number they get correct. This is then age normed to produce a standardised score.

9.3.3.4 Forward and backward digit span

The forward digit span test primarily taps short-term auditory memory and attention, while the backward digit span additionally measures their ability to manipulate verbal information in temporary storage, that is, information in working memory. These tests are part of the Wechsler Adult Intelligence Scale (WAIS) battery (Wechsler, 1997). The participants listen to the experimenter calling out a sequence of numbers which they must repeat back. In the forward test they repeat them back in the same order and in the backward test in reverse order. If the participant gets the sequence correct the length of the sequence gets progressively longer.

9.3.3.5 TOWRE timed single word reading test

TOWRE timed single word reading test is a timed reading test (Wagner, Torgesen, and Rashotte, 2011). The participant is given first a card with columns of words to read. The words become increasingly difficult. They are given 45 seconds to read as many of the words as possible. Then they are presented with a similar card containing non-words and again are given 45 seconds to read as many as possible. The participants were recorded and the number of words corrected was counted. The performance output is the number of words that a participant reads within the 45 second period. Thus, the number is the norm corrected based on the age of the participant. However, the normative scores do not take into account that in some instances participants finishing reading the list of words with time to spare. For this reason the normative scores were not used. Instead, as the relevant measure was within-subject change, the raw score was used, and for those participants who had time remaining an estimate of the number of words the participant could have read in the total time period was used.

9.3.3.6 Stroop Test

The Stroop Test involves reading a list of colour words each printed in an incongruent colour ink, e.g. the word "blue" is written in red ink. Participants have 60 seconds to go through the list as quickly as possible naming the colour of the ink (Stroop, 1935). Responses are recorded and the number of correct responses counted. This test was not norm corrected.

9.3.3.7 Cancelation task

For the Cancelation task a visual array of letters is presented on a sheet of paper. Participants must search the array and mark as many "A"'s and "E"'s as possible within 60 seconds (Diller et al., 1974).

9.4 The Training Game

The current version of the game is the result of many modifications. However, additional refinement will be made to subsequent iteration of the game to improve it further. It has been observed that some training interventions available appear not to refine their intervention once a significant effect has been observed and the intervention is brought to market soon after. It is hoped that such a model will be avoided in this case and that should an effect be identified in the planned RCT's, further refinement of the intervention seeking to maximise the effect will continue to be made.

In the story of the game the player is a superhero with laser vision. This theme was chosen because it has a close correspondence to the task objectives. Evil villains are flying around in planes dropping different types of bombs. The player is flying after the villains attempting to zap the bombs they drop with his or her laser vision while avoiding zapping hazardous distractor bombs. The superhero is positioned on the left of the screen and the enemy plane or helicopter is positioned in the top right corner. A variety of backgrounds are used, and a sense of motion is conveyed through the use of the right to left movement of the foreground and clouds. Both the foreground and clouds have two layers that move at a different rate to one another. There is a fixation cross located in the centre of the screen, surrounded by 12 boxes that indicate the locations of potential targets and distractors; 6 boxes at 5 degrees form the centre of the screen at 2, 4, 6, 8, 10 and 12o'clock, and 6 boxes at 10 degrees from the centre at 1, 3, 5, 7, 9, and 11 o'clock (see figure 27). As short video sample of the game can be seen here:

https://youtu.be/5t1JjXs77LM

Figure 27. The start screen for each of the tasks with boxes indicating the potential locations of targets.

The training intervention comprised 8 training sessions completed over a 3 to 4 week period. Within a training session participants typically completed 8 to 11 training blocks or game levels. Each training session lasted 45 minutes to an hour. Each of the blocks was made up of three sub-blocks of 20, 20, and 15 trials respectively. Automated auditory and visual feedback was given after every trial. The 55 trials (20 + 20 + 15) lasted approximately 4 minutes.

The purpose of having many short blocks is to increase the intensity of the training and avoid exercising the participant until exhaustion. Short duration and high intensity blocks are felt to be a potential fruitful approach for increasing the capacity of the systems being utilised. Shorter blocks also allow for more frequent opportunities to evaluate performance, and further help to avoid some of the movement problems that can emerge from prolonged periods of sitting with the head in the chin-rest of the eye-tracker.

Each block of 55 trials was typically composed of a single task type. There was seven main task types: (i) stop-signal task, (ii) anti-saccade task, (iii) forward timing task, (iv) backward timing task, (v) jumping bomb task, (vi) sudden distracter task and (vii) fixation task. Different colour bombs were used for each task type. Participants were not exposed to all seven task types from the first training session. Instead they completed only three task types on day one and over the subsequent session the other tasks are introduced.

In addition to blocks being composed of different task types there were also two types of blocks - a tracking block and a levelling block. The tracking block structure was used to determine the participant's level of ability with respect to the task type selected. The difficulty parameter unique to that task type was automatically increased or decreased through the use of tracking algorithms across the block based on performance. The levelling block used a set difficulty parameter as determined by the tracking block. Based on this difficulty parameter the difficulty of the sub-blocks within the levelling block was defined. In the first sub-block (first 20 trials) the difficulty of the task was set to 75% of difficulty achieved in the tracking block, in the second sub-block the difficulty was set to 85%, and in the final sub-block (15 trials) the difficulty was set to 105%. The intention was to have the first 20 trials at a manageable level of difficult (75%) that familiarised the participants with the task, gave them confidence in their ability to success in the task, gave them a performance target in which they could achieve 100% correct responses, to consolidate existing ability, and allow them an opportunity to potentially try different strategies when completing the task at that manageable level of difficulty. The second 20 trials were set at a manageable but challenging level of difficulty (85%). A good performance could be achievable but required sustained effort. The final 15 trials were set above the level of ability of the participants (105%). It demanded a short intense exertion of effort to do well and highlighted to participants that there was a need to improve task competency. Participants were informed that the difficulty of the task increases across the "waves" (sub-block). At the start of each sub-block "Wave 1", "Wave 2", or "Wave 3" appeared on screen. One of the advantages of using a game style training intervention is that the participants are familiar and comfortable with concepts such as "levelling up".

Upon first seeing each of the training tasks an introductory video showed participants how that particular task worked. They were then given simplified practice version of the task to scaffold performance. The training lasted between 20 to 30 trials for each task type. Immediately after the practice they completed an easy version of the task with a levelling structure. At the end of the block a summary results screen was displayed and a graph of results was explained to trainees. Then a tracking version of the task was completed. The result of the tracking version provided the starting difficulty for subsequent levelling versions of the task. For the levelling version of the task when participants began to achieve a 70% success rate the difficult parameters were increased. Each task type had a particular difficulty parameter.

In any game the point structure is critical; what the point structure rewards or punishes will determine the focus of the participant's efforts. As such, in the training game the points were dependent on performance with respect to the target of the training, the core mechanics of the game. This entailed the real time processing of data to identify saccades and supply feedback about performance. Success or failure feedback in all tasks was provided to the participants immediately after each trial in the form of visual stimuli, that is, the explosive destruction of the bomb if they were successful or the release of a gas cloud if they were unsuccessful, paired with auditory sounds. Additionally, participants received immediate onscreen points (positive, negative, or zero) contingent on performance. In some instances the points received reflect reaction times or temporal accuracy. A proposed consequence of an altered dopamine reinforcement system in ADHD (as posited by the Dynamic Developmental Delay Model) is an altered reinforcement gradient. As such, there is an increased need for temporal proximity between behaviours and their consequences in order to facilitate the establishment of associations, and thus facilitate learning. Providing immediate feedback is seen as critical to participants' learning and the success of the intervention.

At the end of each block participants received a summary of their score, a breakdown of their score with the number of hits, missed, failed inhibitions etc., and they additionally received a graphical representation of their performance across trials (see figure 28). The highest score for each task type was also displayed between blocks. In addition, performance targets were set, and reviewed when achieved. Performance targets were decided upon in collaboration with the participants. The aim was to have participants continually work within their zone of proximal development.

I wanted the intervention to be a convincing game to encourage intrinsic motivation and a receptive state. Playing a game is a reward in itself, this has implications for the degree of engagement and encourages a creative mind set towards achieving objectives. Games are an on-going process, failure is more acceptable and feedback becomes a tool to refine skills and strategies as opposed to being simply an evaluation of performance. Identifying a task as a game draws on pre-existing connotations of games being fun, but also on knowledge of game structures to aid communication of the structure of the training intervention.

Figure 28. This is an example of the performance summary provided at the end of a block.

As stated previously, making the training intervention feel like an engaging game will result from having interesting game mechanics that support the player in utilising a function or set of functions. However, games must also draw the interest of the player. There is a certain level of aesthetic and entertainment value needed to grab the player's attention. To achieve this the intervention uses a combination of premade graphic spites, generated images, audio clips, and generated sounds as the game stimuli stimulus. A variety of foreground and background landscapes were created. The foreground and cloudscape have multiple layers that move across the screen at varying rates to simulate parallax effects of depth and motion. A number of the objects on screen, such as the superhero character and the enemy planes are programmed to move in subtle hovering patterns separate to the background images. This motion gives the stimuli depth and draws them forward from the background images. The variety of background and foreground images adds interest. Short video sequences are used to introduce a task type and the start of a sub-block. This gives participants a short break, allows them to chart their progress, and provides an indication of what to expect. For example, when the video sequence of a helicopter flying onto the screen is shown the participant knows to prepare for the timing task, and when "Wave 3" appears on the screen they know that they are about to begin the final sub-block and that the task will increase in difficulty. Simultaneous audio and visual feedback is delivered to participants. For example, auditory and visual explosions are simultaneously triggered when participants look at a target bomb. In the fixation task the pitch of a generated noise changes contingent on the duration of the fixation already achieved, and simultaneously the size of the diamond positioned in the centre of the screen vibrates and increases in size. Together these stimuli give the impression of building tension and energy and give the participants information on how much longer they need to maintain fixation. In this way a believable game world is created.

9.4.1 The role of the experimenter

Having the right procedures in place to guide the delivery of the intervention effectively is as important as having the training game programmed well. Good procedures will remove obstacles to engagement, encourage a committed motivated attitude towards the training, and ensure the difficulty is pitched optimally to encourage cognitive functions development. It is worth noting that many of the intervention delivery procedures could be automated to some degree with more sophisticated programming. The need for some procedures reflects the limitations of the technology or are in place to support the researcher's evaluation of the intervention, and as such do not pertain to the intervention directly. It is anticipated that the full automatisation of the training procedures would be possible in subsequent iteration of the game and with the use of more advanced eye-tracking technologies.

Many variables determine each participant's engagement with the training and assessment tasks on a given day. Given that individuals with ADHD tend be more disorganised, often have poor sleeping patterns, and tend to have more problems in their work or academic activities etc. we might predict that they will tend to be more variable in their disposition across training sessions. Another important determinant of performance is the dynamic of the experimenter-participant relationship. When the intervention is delivered by the experimenter this relationship is difficult to control for or measure. Given this, in subsequent RCT it may be desirable to fully automated training procedures.

On the first day of training the purpose of the training intervention was discussed with participants. While they had been provided with an information sheet to provide an overview of the intervention, on the first day of training the importance of their need to engage with the training and a need for them to challenge themselves to continually improve on the tasks was emphasised. Attention, timing ability, and inhibitory control were described as "brain muscles" that could be trained and strengthened. The training game was described as an external representation of their internal functional ability and that they should think of improved performance as reflecting the strengthening of internal neural systems.

In developing the intervention I attempted to limit the use of externalised motivation. While I did pay participants for their time this was a low amount, £40 for completing the 10 sessions. This amounts to approximately £3 per hour (£40/13.5 hours of participation). When initially planning to deliver the intervention to children with ADHD, the idea of giving the children an activity folder with stickers and games, with additional sheets to add across sessions was entertained. The intention was to motivate children to maintain their interest in the training sessions. However, it was felt that the game component of the intervention should in itself be sufficiently motivating if the training was to work. The introduction of an external motivator may have acted to weaken the intrinsic motivation in the game, that is, the reasons for the child's engagement with the game would be pulled in an more extrinsic direction by the off task rewards. While this did not prove relevant to the delivery of the intervention to the mainly adult population used in the proof-of-concept study this has relevance to future delivery of the intervention.

During training sessions participants had access to water and savoury snacks were provided (crisps and nuts). They were encouraged to use the toilet at the start of the session and they were allowed to take breaks at any stage during the session. While the participant was engaged in a task peripheral noise was eliminated. The participants were discouraged from conversing with the experimenter while completing a task except conversing about an issue immediately pertinent to the task.

Each training session for each participant had been planned before they arrived with regard to the choice of tasks to be completed, the difficulty of the tasks, and the order of the tasks. The performance of the participant on the previous training session was reviewed and assessed, and decisions made about whether the difficulty parameters should be increased (or occasionally decreased). While parameter changes can be made within a training session this was generally avoided as reprogramming takes time away from the training and hurried changes can lead to programming errors.

Participants did not have exposure to the entire set of training tasks from the first session. Dependent on the training session new tasks are introduced. On the first session participants completed the stop-signal task, the anti-saccade task, and the forward timing task. In session two the fixation task was introduced, in session three the jumping bomb task, in session five the backward timing task, and in session six the delayed saccade task. This was done to ensure participants were not overwhelmed with learning a large amount of tasks during the early session, and to maintain a degree of novelty across the training sessions. When any task was first encountered participants first complete a task learning block which is a simplified or scaffolded version of the task, for example, for the anti-saccade task directional cues are provided, for the timing task visual cues are provided to support the learning of the target temporal interval, and for the stop-signal task multiple salient stop-signal cues are provided in conjunction with a short stop-signal delay. Over the course of the training block these features are eliminated. At the end of the block a results screen summarising the task difficulty, points and reaction time data is explained to participants. This explanation is reiterated on the subsequent block and participants are encouraged to interpret and explain this data to the experimenter.

For the first two training sessions extra time was taken to ensure that the participant was seated properly and comfortably at the eye-tracking equipment. While this may seem trivial it can have a large impact on the quality of the data collected (as has been discussed in chapter 7). Time was taken to show the participants how they could vary the chair high, the tilt of the seat, the tilt of the back of the seat, and the height of the eye-tracker and table. In addition, at the start of each session the participant was given the opportunity to take some time to relax and talk with the experimenter. It was felt that this was particularly important for some participants as they tended to arrive at the session in a hurried state.

Each participant's task preferences were noted. A negative attitude towards a disliked task tended to became more positive as their performance improved on that task. Participants' preferences with regard to trial order were taken into account if they had any; giving them their favourite task as the first task in a session was found to be good for getting them focused and settled. This task was often the forward timing task, a very good task for settling participants as it requires them to wait and be patient while also being focused. How the tasks are organised reflected participants' preferences to some degree. Some of the participants liked variety and wanted the tasks to change on each block; others liked to have the same task twice for self-competition to see if they could beat their score just achieved. Where possible I switched between a task that required fast responses such as the anti-saccade task and tasks that had a waiting component such as the timing task. Participants were monitored for boredom and fatigue. Longer inter-block breaks were given if needed. If fatigue appeared to be an issue the session was typically reduced in size (e.g. reduced from 50 minute to 40 minutes).

After the task learning block a performance tracking version of the task was completed to determine the optimal difficulty setting for subsequent levelling blocks. For subsequent trials participants completed the task with a predetermined level of difficulty. The experimenter altered the level of difficulty (typically upping the difficulty) across sessions based on task performance in the previous training session. Different task performance indicators are described above in section 9.4.2 Training Game Tasks, see table 5 for a summary. In the anti-saccade task, jumping bomb task, and delay saccade task the response window was reduced; in the stop-signal task the SSD was increased; and in the timing task the accuracy dependent performance feedback was altered. A number of other task changes were made across sessions independently of these task difficulty parameters. These changes were based on the number of the training session as opposed to the participant's performance. For example after two training sessions the inter-trial period was changed from a set value (500ms) to a random period (e.g. 300 to 1300ms). In the stop-signal task and the jumping bomb task additional visual cures that scaffolded performance were removed. For the delayed saccade task the random period range between the appearance of the target cue and distracter-go cue was increased.

Table 4. A summary of the difficulty parameter changed for each of the tasks across training sessions.

Task	Main Difficulty Parameter	Additional Parameters
Stop-Signal Task	Stop-Signal Delay	Response Window
		Salience and modality of stop signal
Anti-Saccade Task	Response Window	
Timing Task	Temporal accuracy needed to receive positive feedback	The target interval changes between training session
Jumping Bomb	Response Window	Duration of the penultimate Bomb
		Salience of Distractor Bombs
Delayed Saccade Task	Response Window	Random period between visual distractor/temporal cue bomb and target bomb
Fixation	Number of Distractors	Period of central fixation leading to trials success
		Period of non- central fixation leading to trial failure

A degree of subjective interpretation was involved when varying the task difficulty parameters. Participants performing at around 70% success rate in a task were considered ready for a more difficult level. If they performed consistently at 50% decreasing the difficulty in the next session was considered unless there was a reason for the poor performance, e.g. suffering from a cold, being very tired etc. If a good performance was seen only near the start of the session but then a drop in performance for that same task was seen later in the session then I tended not increase the difficulty. The success rate criterion of 70% is only a rough approximation. The difficulty was kept slightly easier early on to build participants' familiarity and confidence, and then progressively the achievable success rate was decreased. These decisions were made at the experimenter's discretion. It is possible to automate this procedure to some degree but it would be difficult to take account of all the motivational and frustration issues etc. that were taken into consideration.

If delivering an automated version of the training intervention (where the experimenter is not present in the training environment) it would still be possible to have the experimenter make covert manual alterations to the task difficulty settings between training sessions. In setting task difficulty is should be noted that early on there will be easier gains but that diminishing returns in improved absolute performance scores are expected across sessions.

A possible solution might be to allow the participant to set the difficulty level themselves within certain parameters. For this setup it would also be possible to provide information on their improvement rate when the task is set to various levels of difficulty. This might afford a mechanism by which they can learn about their own learning process. However, such additions may also destroy the flow of the game and can detract from the intentioned focus.

Independent of the between session changes to difficulty parameters, the task difficulty within a single block/level automatically increased across the three sub-blocks or "waves". The first wave had a difficult of 75% of their maximum ability (20 trials), the second wave was set at 85% (20 trials), and the final wave was set at 105% (with the exception of the anti-saccade task set to 100%).

The period between blocks, approximately 2 minutes, provides participants with a short break. This break allows participants a short moment to recover and reflect on their performance. An effort was made to dissuade participants from rushing between tasks. Between blocks the role of the experimenter was to encourage participants to (i) verbalise their strategy for the task completed; (ii) be explicit about what they are doing when they complete the task; and (iii) reflect on their performance asking themselves why they performed well or poorly. The difficulty of the task was also discussed with participants and they were asked how difficult they found various parameter settings. A brief review of the performance in the session was discussed at the end of a session. Participants were congratulated after good performances and encouraged to set performance targets for subsequent blocks. Setting targets was found to be extremely motivating for some participants. For such participants having the same task type with the same difficulty settings back-to-back was a useful form of motivation. Participants who did not wish to discuss the tasks or their performance were not pursued.

A critical function of the experimenter was to monitor the quality of the eye-tracking image. A good image is essential to ensure the gaze-contingent algorithms are executed correctly. A poor quality image can be the result of a participant's shift in position, a poorly focused image or occasionally simply due to equipment failure. It is the role of the experimenter to maximise the quality of the eye-tracking data and to ensure that failed or successful trials reflect the participant's performance. Incorrect automated feedback has the potential to undermine the whole training intervention. It can lead to frustration in participants and lead to the development of strategies focused on circumventing the limitations of the equipment as opposed to improving the target of the training intervention. If it is obvious that automated incorrect feedback has been given to the participants it is important that the experimenter highlights this immediately. Participants need to have confidence in the feedback they receive in order that it can guide their learning. If they begin to question the feedback the efficiency with which the training program can focus their learning on the critical features of their performance is undermined. In order to maintain their trust in the automated feedback they receive they should be reassured upon equipment failure that this is an exception. It helps to explain to the participant why the equipment failed (if the reason is known).

9.4.2 Training Game Tasks

9.4.2.1 Stop Signal Task

The stop-signal task is the paradigmatic inhibitory control task. It provides information on how quickly an individual can inhibit or cancel a planned action. The action, in this case a saccade, is considered "planned" because the majority of trials are 'go' trials and because there is insufficient time to plan a saccade after the stop signal has arrived. As such, the stop-saccade task involved cancelling a pre-potent response.

This Stop Signal task was delivered to participants from the start of their training and was typically completed at least once per training session. It is based on the traditionally stop-signal task. The participants must make a saccade to a target location within a set time window unless a stop-signal is presented.

The method used evaluating performance on the stop-signal task is to have a tracking algorithm that alters the delay between when the cue to go is given and when the cue to stop is subsequently given. This delay is referred to as the stop-signal delay (SSD). If the SSD is shorter it is easier to cancel the planned action. If the SSD is longer it is harder to cancel the planned action. To evaluate an individual's performance on the stop-signal task a tracking algorithm that varies the length of the SSD based on performance is typically implemented. If the participant correctly inhibits their response when the stop signal appears the SSD is increased, and vice versa. When a sufficient number of trials with a tracking algorithm are completed the SSD duration should begin to stabilise. Once it has stabilised it is possible to infer how long it takes the participant to cancel the planned 'go' response, this is referred to as the stop-signal reaction time (SSRT) (Logan, Schachar, and Tannock, 1997)

For the intervention the saccade target can appear at any of the 12 locations. The target is always a black bomb. For 'go' trials the target appears and the participant has a finite period, the response window, in which to respond by making a saccade to the target location. In 'no go' trials the target bomb appears, then, after the SSD period has elapsed, the stop signal appears indicating that on this trial they should not make a saccade to the target location, but instead maintain fixation at the central fixation point. The ratio of 'go' to 'stop' trials was 2:1. The stop signal was the outline of a red circle with a circumference at 7 degrees around the centre of the screen, a radioactive sign on the former target bomb, and an auditory tone. A circle around the central fixation point was used to ensure the appearance of the visual stop signal did not pull the gaze in a specific direction.

The primary parameter changed to increase and decrease the difficulty is the SSD. However, the response window was sometimes very gradually reduced across trials, but increased again if participants began to fail a large proportion of 'go' trials.

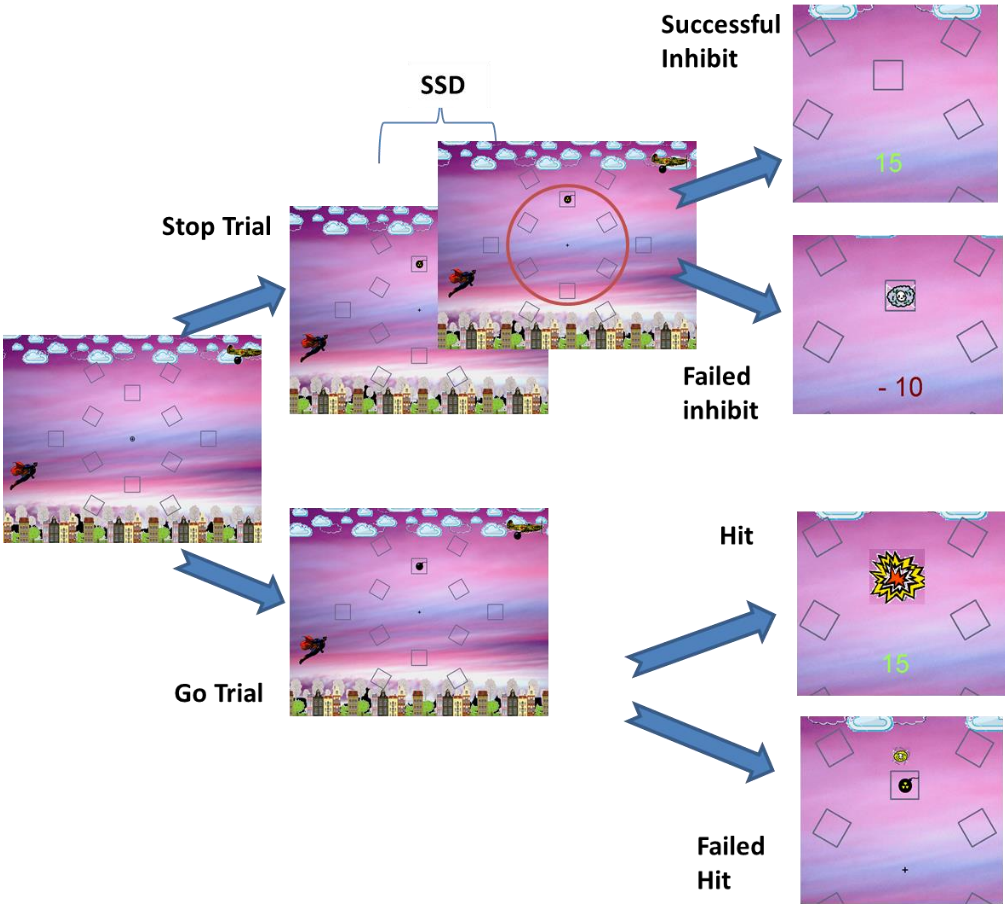


Figure 29. The trial sequence for the stop-signal task. The trial can be either a 'stop' trial in which a participants will either be successfully inhibit or fail to inhibit a saccade, or a 'go' trial in which they either successfully make a saccade to the target (Hit) or fail to make the saccade to the target (Failed hit).

A number of variations of the stop-signal task were used during training.

- During the first two training sessions, after the SSD, the stop-signal presented was the outline of a red circle, a radioactive sign on the former saccade target, and an auditory tone. In session 3 to 8 the radioactive sign was no longer used (there was also the capacity to increase the stop-signal salience if participants are having difficulty but this was not needed). Additionally, when it appeared that the easy performance gains had been made (improvements began to reduce in size) modified versions of the task that only had an auditory or visual stop signal were introduced. It was hoped that training both visual and auditory stop trials separately may aid transfer by not being modality specific (though an alternatively interpretation is that this may simply train up the two modalities separately).

- If participants appeared to be struggling with the stop-signal task the SSD could be reduced to zero or negative numbers. This technically is not a stop-signal task as the saccade is not planned, it is something similar to a 'go'/'no go' task. However, a negative SSD was typically not needed, and if used it was only early on in the training to allow the participant to increase their competency. All participants shifted to positive SSD’s within the first few training sessions.
- A modified version of the stop-signal task with an extremely long response window (3500ms) and extremely long SSD (1500ms) was also given on one or two occasions in the first or second training sessions. The aim of this version of the task was to demonstrate to participants that the stop-signal task has a time estimation component and that the establishment and fidelity with self-imposed deadlines can improve performance. In this version of the task accurately postponing responses maximises the chances of inhibiting responses should a stop signal be presented while ensuring an in-time response for 'go' trials. Previous work has suggested that strategic slowing may be an important aspect of inhibitory control function (Band, Ridderinkhof & van der Molen., 2003)
- A modified version of the stop-signal task that alters the ratio of 'go' and 'stop' trials was also developed. The aim of having a reversal in the trial type ratio, with would mean the 'stop' trials are twice as likely as 'go' trials, was intended to be used in instances in which participants displayed a strongly biased strategy in favour of 'go' trials. However, this response bias was not observed in this sample and this modified version of the task was not deployed.

9.4.2.2 The anti-saccade task

The anti-saccade task relies heavily on inhibitory control. The participants must first maintain fixation. Upon the appearance of the stimulus cue they must inhibit saccades to the cued location, yet use the cue location information to calculate the mirrored location and then execute a saccade to this location. Unlike the stop signal task the anti-saccade task does not involve the inhibition of a planned action. Instead it involves inhibiting a saccade to an exogenously salient stimulus, but also using the stimulus arrival as a temporal cue to make a saccade and additionally generate this saccade to the calculated mirrored location.

The anti-saccade task was delivered to participants from the start of their training and was typically completed at least once per training session. It is based on the traditionally anti-saccade tasks. The objective is to look in the mirrored opposite location to stimuli that appears on screen as fast as possible.

An anti-saccade block begins with a short video sequence showing the arrival of a large bomber craft that flew from the left of the screen to the top right corner, the text "Anti-Bombs" appears in the middle of the screen. The anti-saccade bombs are always coloured purple. Each trial begins with the ITI, then the participants must fixate at the central fixation point until the cue appears, at which stage the participant must produce a saccade to the target location as fast as possible. The saccade cues and the saccade target locations for this task are always within the inner ring of locations, that is, at 5 degrees from the centre at 12, 2, 4, 6, 8, or 10 o'clock. The participant must look to the mirrored location of the cue, e.g. if the cue appeared at 2 o'clock they had to make a saccade to 8 o'clock.

The difficulty parameter that track performance in the tracking version and that is altered in the levelling version of the task is the response window, that is, the amount of time the participants have to make a saccade to the mirror location of the cue. This task becomes much more difficult when the time window is reduced. Immediate RT contingent points are awarded. Over the course of training a modification was made to this task. The last wave of the anti-saccade task difficulty was modified to make it less severe. This was because participants were consistently failing the majority of these trials in the final sub-block (last 15 trials). The difficulty was reduced from 105% to 100%. In addition, an error with the downward saccades was corrected. The error resulted in a failure of the algorithm to identify a proportion of downward saccades. This error would have resulted in a failure to pick up less than 8.3% of successful saccades for this task.

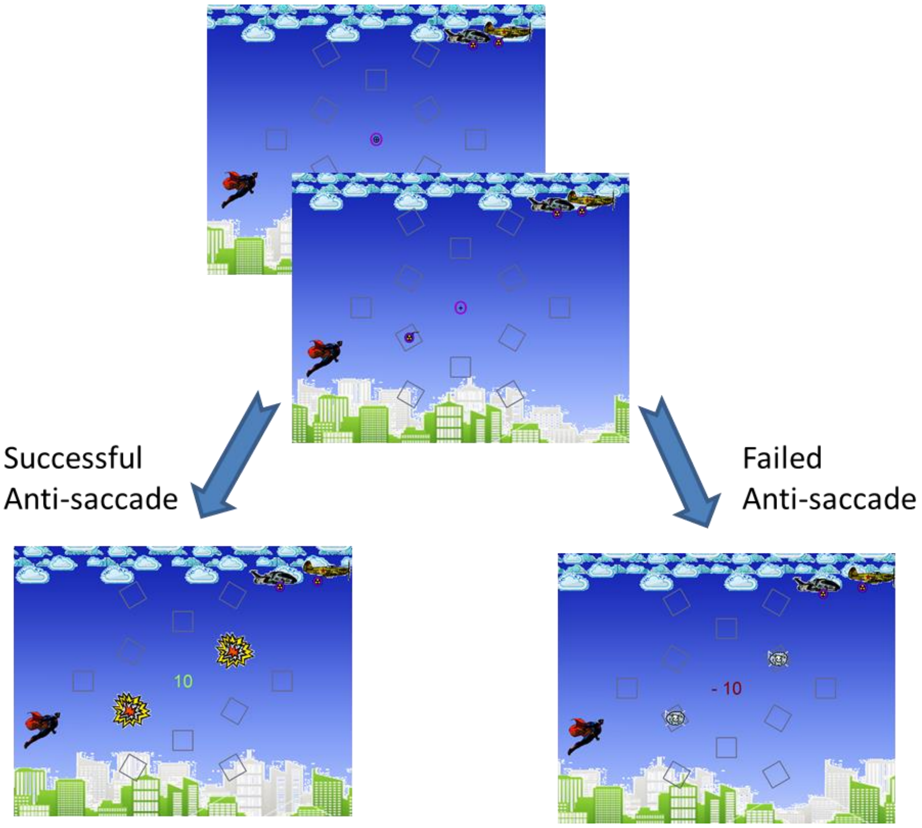


Figure 30. The sequence of game screens for the anti-saccade task. In the first screen the participant is fixating at the centre of the screen. In the next a bomb appears at the 8'o clock position. For the successful anti-saccade screen the direction of gaze is shifted to the 2 o'clock position. In the failed anti-saccade screen the gaze is shifted to the bomb location at the 8'o clock position**.**

9.4.2.3 Timing Task

There are two versions of the training timing task, the forward and backward timing tasks. These are original tasks based on time interval production. In both versions the block begins with a helicopter flying onto the screen and coming to rest in the top right corner of the screen. For each trial the participants must maintain fixation on the central fixation cross for a period 500ms a target bomb then appears randomly at any of the 12 locations. Then the participant must continue to fixate on the central fixation cross until a learnt duration has elapsed, at which point the participants should make a saccade to the target location.

In forward timing version the target bomb always appears green (see figure 31). The participant fails the trial if they make the saccade after the target duration has elapsed. Dependent on how early they are they hear single or multiple laser zap noise. If they time their saccade close to the target duration they hear a single zap and receive a higher score. The greater the difference in duration between their early saccade and the target duration the more zaps they hear and the lower the score they receive. The difficulty parameter is the temporal accuracy requirement to achieve a single laser zap. As they improve the temporal accuracy required to achieve a single zap is increased. The difficulty is typically set so that a single zap can be achieved on 40% – 50% of trials. This allows participants to always strive for single zaps without becoming complacent.

In the backward version of the timing task the target bomb is coloured turquoise. In this task early saccades result in a trial failure, that is, if a saccade has been made before the target duration has elapsed. Instead the aim is to timing your saccade to land as soon as possible after the target duration. After the target duration has elapsed a fast buzzing noise is heard until participants make a saccade to the target location. Participants were told to consistently minimise the period of time for which this buzzing noise can be heard. This requires predicting when the noise will begin as opposed to responding to it once it has begun. This task has no difficulty parameter that can be manipulated.

The forward timing task was given from training session 1 and throughout. The backward timing task was introduced in session 5. This task was more prone to suffer from the loss of the participant's pupil and was therefore less used. The target duration was different for each training session but consistent within a session. It varied between 1000ms and 1800ms. The changing of the duration was not contingent on performance. If both timing tasks were given in the same session the target duration was consistent between the tasks.

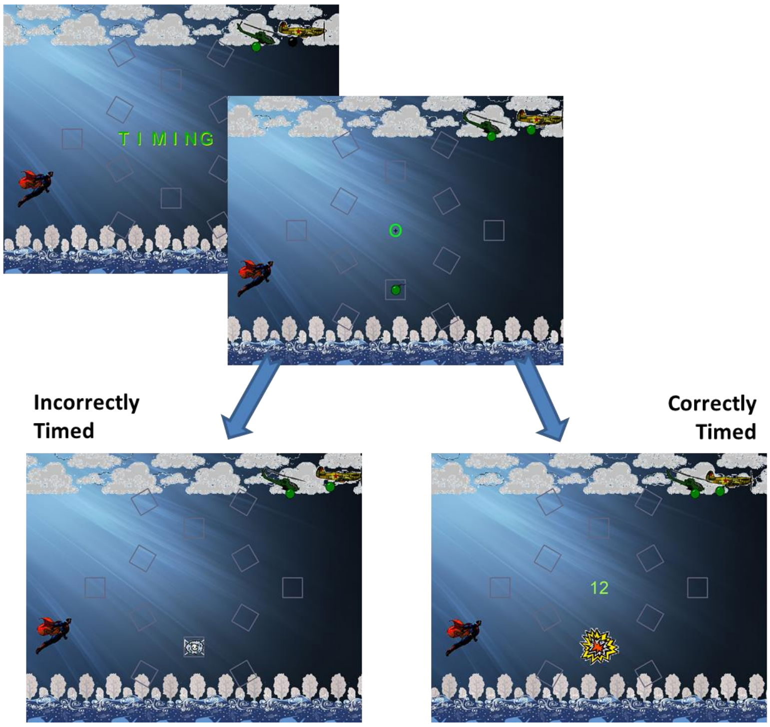


Figure 31. The sequence of the forward timing task.

Modifying the ITI for this task significantly increases its difficulty. Consistent ITI's allow the participant to develop a rhythm to their responses across trials, they can time their responses based on this rhythm across trials in addition to the within trial temporal cues. Introducing more ITI variance required that they rely less on the inter-trial rhythm and time their response solely on the within the trial temporal cues.

Modifications made to the timing tasks in the course of trialling the training intervention included reducing the points awarded for early responses and reducing the point penalty for late responses in the forward timing version of the task. This was to encourage participants to be more ambitious in delaying the timing of their saccades. It was additionally found that the ITI modification parameters were incorrectly positioned within the script. As a result the earlier training sessions conducted had a consistent as opposed to randomly determined ITI, thus reducing the difficulty of the task.

9.4.2.4 Delayed Saccade Task

This was an original task developed to train participants' ability to withhold saccades to a known target location, and to use a spatially distracting but temporally useful cue to program a saccade. It was felt that this task was more complicated in the number of functions its successful completion relied on. For this reason this task was not introduced until the fourth/fifth training session.

After the ITI and the fixation period a target bomb appears at any of the 12 target locations. However the participants should not look at this first bomb. After a random period of between 1000 and 4000ms a second bomb appears at a different location. The second bomb is larger than the first bomb. This second bomb is both a cue and a distracter. Simultaneously with the appearance of the second bomb the fixation cross at the centre of the screen disappears. Participants must look at the first bomb when the second bomb appears.

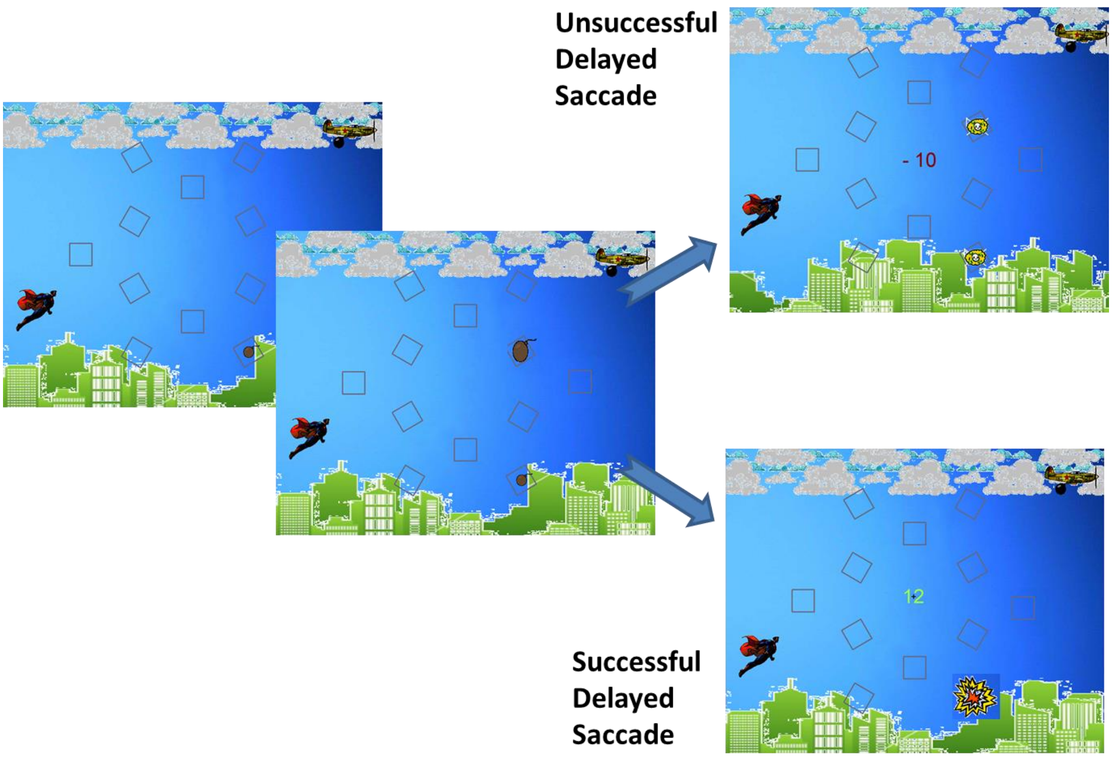


Figure 32. The sequence of the Delayed Saccade Task screens. In this example a single small bomb appears in the bottom right box, then after a period a larger bomb appears in a top right box. The participants will either successfully make a saccade to the first bomb within the response window or fail to do this.

The first difficulty parameter for this task is the response window within which participants must make a gaze shift to the first bomb location once the second bomb arrived. The second difficult parameter is the variability and range of the variability of the time period between the two bombs. In the early trials this was set to randomly selection from between 1000ms to 2000ms, and one or two sessions later the range was increased to 1000 to 4000ms. This random period is reduced if the participants performed poorly at this setting. The difficulty of this task can also be further varied by altering the first versus the second bomb salience. In addition, the task can be made easier by not having the fixation cross disappear upon the arrival of the second bomb.

9.4.2.5 Jumping bomb task

This is an original task designed to train sustained attention, the maintenance of fixation, peripheral vigilance/monitoring of cues without inducing a gaze shift, and the time discrimination. This task draws on a number of functions not engaged by the other tasks. It was introduced in the second training session onwards.

After the ITI and fixation period a bomb appears at one of the randomly selected outer target locations, that is 10 degrees off centre at 1, 3, 5, 7, 9, or 11 o'clock. It will then jump in either a clockwise or anticlockwise direction to an adjacent location a minimum of 1 and a maximum of 4 times (the number of jumps is randomly selected). After 1 to 4 jumps in either a clockwise or anticlockwise direction the direction of movement will reverse. The participant's objective is to look at the central fixation location until the bomb jumps in the reverse direction.

There are three intervals of importance in this task:

1.) The duration of time that the distractor bombs appear for. For the full duration of training this was set to 500ms, however it can be altered. Reducing this duration will place increased processing demands on the system, and increasing this duration will place greater demands on sustained attention and vigilance.

2.) The duration for which a penultimate distractor bomb appears. It always appeared for a duration longer than the other distractor bombs that proceeded it. Its role was to act as a cue for the imminent arrival of the target bomb. The salience of this cue is a function of its absolute duration and relative duration with respect to the proceeding distractor bombs. When initially presented to participants the duration of the penultimate bomb was 650ms, that is, 150ms longer than the other distractor bombs. This was reduced across trials to a minimum of 550ms, meaning participants would need to notice a disparity in temporal durations of 50ms to pre-empt the arrival of the target bomb.

3.) The response window within which participants had to respond. The target bomb, which jumped in the opposite direction to the proceeding bombs, was visible for the duration of the response window. Any movement away from the central fixation cross greater than 30mm before the target bomb's appearance resulted in a failed trial. Failure to make a saccade to the target location within the target duration period also resulted in a failed trial. The duration of the response window was the difficulty parameter used in the tracking version of the task, and was altered in the levelling version of the task as participants improved their RTs.

In addition to the response window, and the size of the temporal disparity between the distractor bombs and the penultimate bomb was altered as a difficulty parameter. A third difficult parameter that was changed after two training sessions was the removal of radioactive signs on the distractor bombs. The removal of this radioactive sign made the task more difficult as it increased the visual similarity of the distractor and target bomb.

The strength of the jumping bomb task is that lapses in attention are penalised. It requires a high level of vigilance to firstly monitor peripheral locations without initiating a saccade. Additionally, in the first instance the duration of the time window reflects participants RT in response to the reversal in bomb direction. However, by degrees participants become aware that they can improve their RT by paying close attention to the temporal duration disparity between the distractor bombs and the penultimate bomb. Upon noticing this temporal disparity they must not make a saccade until the target bomb appears to be successful in the task. When they begin to pre-empt the arrival of the target bomb, as reflected in faster RT’s, the temporal disparity between the distractors is reduced.

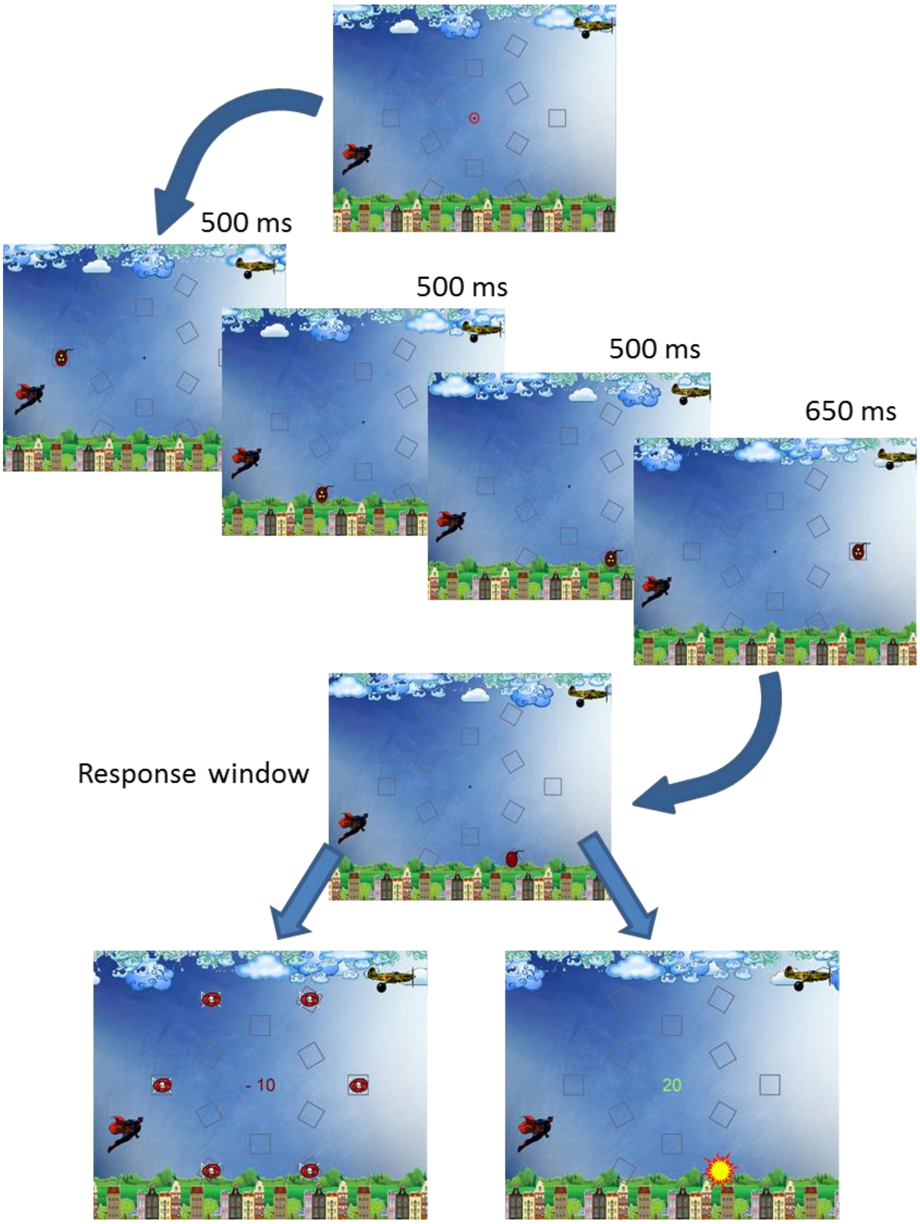


Figure 33. The Delay Saccade Task temporal sequence: all distractor bombs appear for 500 ms except the last distractor which appears for 650 ms, thus providing a cue for the imminent change in bomb movement direction, the target bomb presented for the target duration. A saccade before the target duration or failure to make a saccade to the target location during the target duration results in failure.

9.4.2.6 Fixation task

Unlike the other tasks this was a single trial task, that is, it was not delivered in a block of 45 trials. Instead it was placed at the end of a block containing a different trial type. In this way it served as an "end of level boss", a common concept in computer games. The length of a trial for the fixation task was also considerably longer than the length of other trial types.

A fixation trial began with a short video sequence in which a larger bomb falls to the centre of the screen and breaks into six bomb segments. These six segments move in spate direction to the edge of the screen. At the centre of the screen a diamond appears. Participants must maintain their focus at the diamond at the centre of the screen. The diamond disperses their laser beam to the six bomb segments to destroy them all simultaneously after a period (see figure 34).

Participants must fixate at the centre of the screen for 30 seconds in total to succeed. While participants maintain a central focus distractors appear across the screen attempting to draw their focus away from the centre. The distractors appear at various locations and vibrate or fly across the screen. If the participants spend 5 seconds in total fixating away from the centre of the screen they set the bomb off and fail the trial.

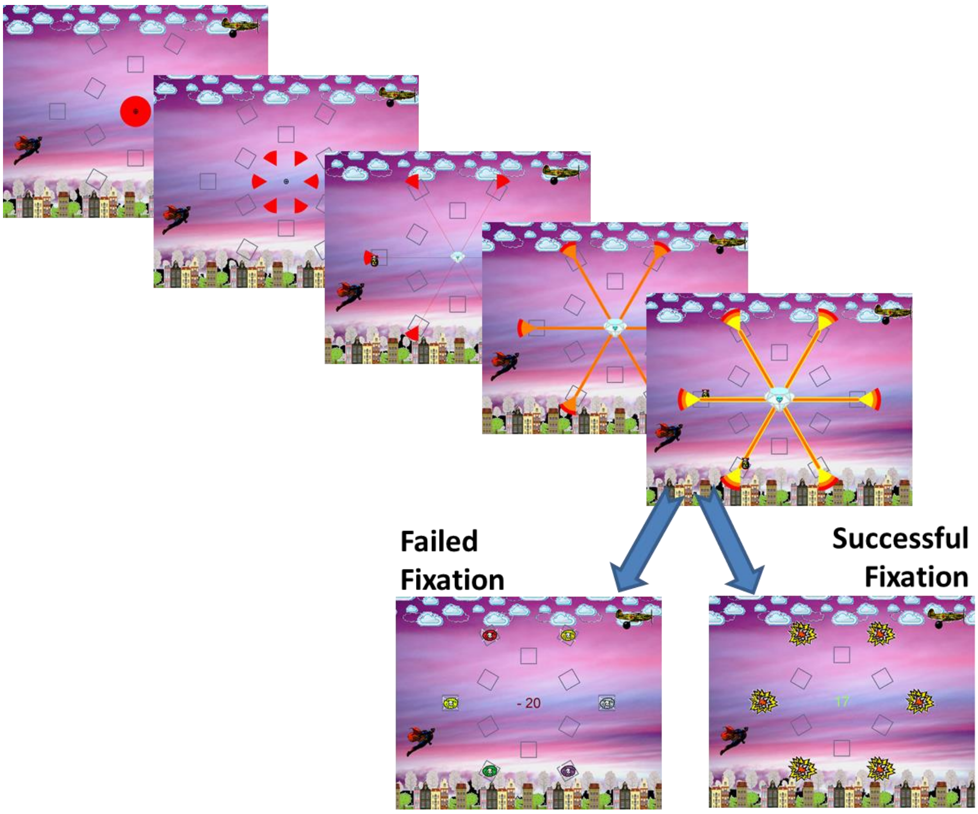


Figure 34. The sequence of screens for the Fixation Task.

The difficulty of the task is modified by altering the amount of distracters that appear. A second difficulty parameter is altering the total fixation time required to destroy the bomb, however this was not modified during the training. A potential weakness in the programming of this task is that when a participant looks at a distractor or moves in any direction away from the central fixation, all the distractors disappear; while this does serve to draw their attention immediately to their failure to maintain a central fixation, it may be of greater utility to allow them to notice this error themselves.

9.4.2.7 Additional Parameters, Tasks, and Training

In the training intervention there are a couple of parameters that can be altered across all tasks. It is possible to vary the inter trial interval (ITI) for each task separately. The ITI is the period of time between when the last trial ended and the next trial begins. The successful completion of a trial is easier when this period is of a set predictable duration. The ITI was typically set to 500ms for all task types initially, then based on the session number and the participant's performance on the individual task types, the ITI was firstly made variable (300ms to 800ms) and latter increased in the range of variability (300ms to 1000ms). Greater variability trains up sustained attention, the maintenance of a response readiness, and when the interval is particularly short a fast reaction time.

A movement allowance parameter was created that allows for the increasing and decreasing of the accuracy threshold of the eye-movements required for a response to be considered within a target range (the boundary of a region of interest). For some participants the eye-tracker can become more inaccurate across a session. Usually this is due to subtle shifts in their head position. Recalibration is not always the best option as it takes time away from the training, and additionally these subtle movements may occur more frequently towards the end of a session and would thus necessitate multiple recalibrations. At the same time the problem must be addressed. If participants are repeatedly receiving negative feedback despite the fact that they move to the correct location within the response window this will hinder their training and they additionally may become frustrated. It was felt that in such instance loosening the accuracy threshold is a solution. A movement allowance parameter was thus created to alter the saccade accuracy requirement. The movement parameter was not needed for the current proof-of-concept study.

A number of additional tasks were also created. While a single block of these tasks were given to individual participants to assess their feasibility they were not used as part of the training program. It was felt that their inclusion would constitute an excessive load in terms of the number of tasks participants would have to learn.

For this purpose the Jumping Bomb, Sudden Distractor, Fixation, Double Shot, Distractor, and Building Bomb tasks were developed. The Double Shot task, Distractor task, and Building Bomb task were dropped from the training intervention proof-of-concept study in the interest of simplicity and to reduce the cognitive load association with participants learning additional tasks. However these additional tasks may be utilised in future iterations of the game.

The Distractor task

This task is a simple prosaccade task with the addition of distractor bombs. The gaze must be shifted to the target bomb within a response window to succeed in a trial. Distractor bombs can appear before, simultaneously, or after the target bomb. The fixation point in the centre of the screen may or may not disappear. The distractor bombs may appear in a static position, may appear vibrating in a single position, or may shoot across the screen. If the participants look at a distractor bomb they fail the trial.

Building bomb task

This task is a prosaccade task but additionally requires that the gaze is maintained for a two second period before the bomb blows up. Distractor bombs also appear in an effort to draw the fixation away from the target bombs.

Double shot task

This is also a prosaccade task but the target bomb that appears must be zapped twice. The participants must first look at the bomb, then back to the centre of the screen and then back at the bomb again within a response window.

While each game task had a particular training focus the structure of the game itself also trained certain skills.

- A useful feature of using the eye-tracker is that it is possible to ensure that the participant's attention is directed back to the centre of the screen at the start of each trial, that is, the trial will not begin if they are not looking at the cross in the centre. This is a form of attention and procedural training.
- For each task there is then a period in which they should continue to fixate at the central fixation cross. Moving within this period resulted in the on-screen message "Wait", and the trial then began again. This helped to develop sustained attention and to maintain fixation, and also ensured that the participant was settled before each trial.
- For different participants the training also involves training in skills such as frustration control and resilience to negative feedback. After failing a trial or a poor block performance, participants need to continue attempting to succeed. The importance of self-regulation skills should not be underestimated in individuals with ADHD who typically have experienced a large amount of negative feedback and adverse learning experiences in the past. Where present such experiences and the development of a negative response pattern to failure, such as avoidance, can act as a barrier to learning and need to be addressed. In the course of delivering the intervention disengagement and frustration were observed in some participants in response to negative performance feedback. An advantage of having immediate trial feedback is that it provides participants with the opportunity to experience that attempting after failure can lead to improvements. Lessons such as these can be harder to identify when the task in question is large, complex, or if the feedback is not delivered for a long time. In a gaming environment the relationship between behaviour and its consequence are more readily identified and highlighted, especially when feedback is immediate and is subsequently reflected upon at the end of the block. While this was not the intentional focus of the training intervention, the participant's attitudes to negative feedback, their ability to manage frustration, and the belief that they can improve set the context within which the intervention is delivered. As such it is important, where possible, to factor in such concerns. These concerns also highlight the critical importance of pitching the difficulty of the

tasks at the right level. In cases where participants are getting frustrated there may be a need to reduce the difficulty to facilitate a higher success rate.

9.5 Data Processing

To process the data of the trained assessment eye-tracking task firstly the tasks were segmented into individual trials. Invalid trials were removed (poor data or failure to maintain fixation at the start of the trial). The first saccade in each trial was identified, the timing of the saccade and its landing point with respect to the stimuli of interest. In some instance this was calculated in real time in the task script and in others after the data was gathered. See section 7.2.1 Saccade Identification for a summary of the procedures used for saccade identification. In assessing performance in the delayed saccade task and anti-saccade task proportion of correct responses is used, but as the stop-signal task and timing task make use of tracking algorithms the tracking parameter was used.

For the timing task the size of the target window for each of the interval - short, medium, and long - was analysed. The target window is a measure of the level of difficulty achieved in this task based on consistent temporally accurate saccades to the target location. Note that the medium interval was always given first and to some degree acted as the practice block.

For the delayed saccade task the mean RT, the RT variance, the coefficient of variation, and the proportion of correct responses was extracted. The coefficient of variation affords a way to interpret the relative magnitude of the standard deviation. It is the standard deviation divided by the mean. In this way the variance measure takes into account the size of the RT. It is important that the proportion of correct response is used as opposed to the absolute number, especially when using gaze contingent tasks, as some dropped trials due to poor data is likely occur and the number of dropped trials will vary between participants.

For the anti-saccade task the mean RT, coefficient of variation and the proportion of correct responses were extracted.

As with the SSD tracked performance during the stop-signal task, this was one of the main parameters examined to evaluate performance. Two obvious pieces of summary data to examine performance, the median SSD and the SSD on the final trial are problematic. Firstly, the sensitivity of the mean or median SSD as a measure of performance are reduced by the learning/familiarisation period and the period it takes for the tracking algorithm to stabilise (that is, to find the participant's level of performance). An imperfect solution is to arbitrarily choose a number of trials to discard at the beginning of the task. Secondly, the problem with using the final SSD achieved is that a participant could have a bad run or suffer cognitive fatigue etc. towards the end of the task, thus introducing noise into this summary measure of their performance. An imperfect solution is to average an arbitrary number of trials at the end. The solution used to both of these problems was to fit an inverse curve to the SSD data. This provided an estimate of their learning rate and a smoothed estimate of their performance on the N + 1 trial. The curve is fitted with the equation $y = a + b/x$, were y is the SSD and x is the trial number. It produces a predicted value for the SSD on the 121^{st} trial, an estimate of the amount of learning, an estimate of the learning rate.

For the stop-signal task participant's inhibition rate was also extracted. This parameter is related to a longer SSD as a high inhibition rate also leads to long SSD. The difference in inhibition rate at assessment one and assessment two is an index of the point at which performance plateaued with respect to the SSD. The SSRT was calculated for the task overall but more importantly for block three. The mean number of hits minus the false alarms was extracted. This parameter was extracted based on the work of Liddle et al. (2009). Liddle et al. (2009) examined how performance improvements are achieved when a participant is more highly motivated. They examined task success rate and the RT distributions for 'go' trials and failed 'stop' trials, and how these distributions were altered contingent on positive, negative, or neural motivation condition. Their findings suggest that an improved performance as a result of greater motivation incentive to performance well on both 'go' trials and 'stop' trials is neither achieved through a shortening of the SSRT, nor through a shifting of 'go' process RT distribution (in the form of a inhibition of the 'go' process on all trials so that the ballistic point of no return is reached consistently later in each trial). Instead participants optimise their overall probability of success by increasing the consistency and temporal accuracy of their 'go' response RT's, that is, the RT distribution is distorted to be more leptokurtic.

The important point to note here is that while we may expect a faster SSRT with improved vigilance and possibly due to improved inhibitory control, the SSRT would not change as a result of alterations in line with the more leptokurtic 'go' RT distribution observed by Liddle et al. To have a measure of performance that reflected this shift in 'go' RT distribution the mean number of hits minus the false alarms was extracted.

Participant’s prosaccade RT was extracted from prosaccade section (block 1) of the stop signal task. In the case study tables presented in chapter 11 the computed response window for the stop signal task is given as a measure of prosaccade RT. In the post collection processing an inverse curve was fitted to the SSD data. This provided an estimate of their learning rate and a smoothed estimate of their performance on the N + 1 trial.

Pupillometry data was also extracted for the timing, anti-saccade, and stop-signal tasks. For each trial the minimum and/or maximum pupil dilation was extracted after filtering for low or high artifactual values. For the anti-saccade task the minimum and maximum pupil dilations for fast (RT’s above the 75 percentile) and slow (RT’s below the 25 percentile) RT trials were extracted separately for comparison. For the stop-signal task the pupil dilation at the start of the trial and 80ms into the trial were extracted.

To process the reading data, firstly the number of lines per page, number of words per line, and number of letters per word were recorded for the text. Then the number of forward and backward saccades was counted manually. From this the number of forward, backward, and forward saccades controlling for backward saccades was calculated per letter, word, and screen. For reading data the most appropriate metric is letters as opposed to visual angle as the distances traversed are determined by the number of letters, not the visual angle (Morrison & Rayner, 1981). The average dwell time (fixation period) was also calculated as the total amount of time divided by the number of saccades.

To process the data gathered for the spot the difference task the number of saccades of various sizes were calculated per second, and the number and length of fixations was calculated. Automated saccade identification methods, discussed in

7.2.1 Saccade Identification, were used to identify the number of saccades made during completion of a single trial and then averaged across trials. They are based on fick positions, that is, eye-rotations in fick coordinates (longitude and latitude). Here we are looking at values checking the distances moved over a 4ms interval.

The standard assessment tests used provided data already processed or requiring a minimal amount of processing. The QbTest produces a number of outcome measure automatically age normed related to the amount of movement, reaction times, and omissions and commissions made. The values given are Q scores, QbTest's age normed standardised scores similar to z-scores.

The Cantab test automatically produced a host of summary parameters for each task. The data of specific interests for this project were selected (i) for the manual stop-signal task the SSRT for the last half of the test, (ii) for the intra-extra dimensional set shift the total errors adjusted, and (iii) for the information sampling task the discrimination error, the IST total, and the open box latency.

For the WRAT4 reading and arithmetic an age normed standardised score was used. For the forward and backward digit span the raw score was used. As the TOWRE normative scores do not take into account the time participants have remaining if they read the whole list of words the normative scores were not used. Instead the raw score was used, and for those participants who had time remaining an estimate of the number of words the participant could read in the total time period was used (total word read correctly + time remaining x (the number of words read / time taken to read the list of words). The stoop score analysed is the number of correct responses given within the 45 second time limit. The cancellation task output is the number of correctly crossed out "A"'s and "E"'s.

9.6 Analysis

Due to the small sample size of the proof-of-concept study the effect sizes were examined. As the ingredients of a p-value are the size of the sample and the effect size, we are removing the sample size component. The difference between the pre and post assessment scores is based on Cohen's d comparison of two means.

Cohen's d is the difference in the two scores divided by the average of their standard deviations. Cohen d was computed for the mean, upper limit and lower limit.

To calculate the effect sizes within SPSS a pair sample t-test on all pre and post assessment measurement pairs was conducted to generate a table of useful numbers. The t of the sample was calculated for the mean (Mean/ (SD/ square root N)), the lower confidence interval (Lower CI/ (SD/ square root N)), and the upper confidence interval (Upper CI/ (SD/ square root N)). The d of the sample mean (t of the sample mean/square root of N), d of the lower bound (t of the lower confidence interval/square root of N), and d of the upper bound (t of the upper confidence interval/square root of N) were then calculated.

The analysis is an unbiased analysis of the effects for each of the measures used to assess performance. No selections based on which task hypothesised to better tap the improvements made, but instead they are all displayed in the plot for appraisal. This fits with our explorative proof-of-concept exploration of the data. Then task effects are grouped so that they can be weighted. While the output resembles a forest plot it is not a forest plot as the task performances are not independent.

A score of 0.5 indicates that the two means differ by 0.5 of a deviation; a score of 1 indicates that they differ by 1 standard deviation. By convention, effects sizes for Cohen's d are: small=>0.2=0.5; medium=>0.5-0.8; large->0.8. A large effect indicates that the difference between these two groups is large enough *and* consistent enough within the sample to be important.

In addition to the sample mean the upper and lower bounds, or the confidence interval are also plotted. Assuming a normal distribution for our values, the confidence interval is a range of scores around our sample mean that with a specified degree of certainty (e.g. 95% probability – corresponds to the values covered by this amount of the normal distribution) will include the population mean. Additionally, as the confidence interval is in this instance set to 95%, if in the plot the lower bound of the confidence interval is to the right of zero this indicates that the improvement is significant with a $p < 0.05$.

10 Results

10.1 Results

The results presented in this chapter are a comparison of the pre- and post-training assessment data gathered for (i) gaze control tasks explicitly trained in the training intervention, (ii) gaze control tasks not trained, and (iii) standard assessment tasks.

10.1.1 Results for Trained Tasks

Effect sizes, with confidence intervals were computed for each measure, across participants (see figure 35 and table 6). While there were large positive effect sizes for most of the tasks confidence intervals were also large. The lower bound of the confidence interval lying to the right of zero indicates a significant positive effect for the measure (N = 8).

For the timing task we see an increase for all three time durations; short, medium and long. An increase indicates an increase in the temporal accuracy of timed saccades in assessment two compared to assessment one. The lower bound of the confidence interval for the medium and long durations are positive indicating that the improvement seen is significant ($p < 0.05$) despite the small sample size (N = 8).

For the sudden onset distractor task the coefficient of variation, mean reaction time, reaction time variability, and the proportion of correct trials all increase. The improvement in both the proportion of correct responses and the mean RT suggest that the improvements seen reflect a greater ability to perform the task as opposed to a trade-off between speed and task performance. Of these only the lower bound of the confidence interval for the coefficient of variation is a negative number.

For the anti-saccade task we see an increase for the coefficient of variation, the mean reaction time, and the proportion of correct responses. The improvement in both the proportion of correct responses and the mean RT suggest that the improvements seen reflect a greater ability to perform the task as opposed to a trade-off between speed and inhibition. The lower bound for all three measures is below zero indicating that these effects are not significant.

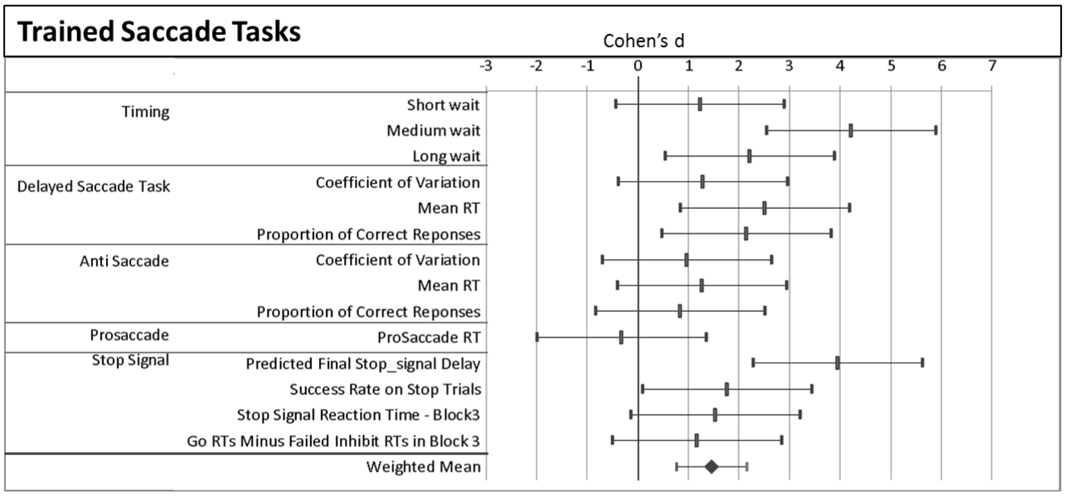


Figure 35. The graph displays Cohen's d effect sizes and the upper and lower bounds for a 95% confidence interval. The effect sizes represent changes in indices of task performance between assessments one and two. Positive values indicated improved performance. Multiple parameters are displayed for each of the Trained Saccade Tasks; the Timing, Delayed Saccade, Anti-Saccade, and Stop-Signal tasks. A weighted mean effect size for all the Trained Saccade Tasks is also given. Lower bound values greater than zero indicated a significant effect for that parameter (p <0.05) for the sample (N = 8).

For the stop signal task we see a slight decrease in the prosaccade reaction times (prosaccade constituted block 1 of the stop signal assessment task). The tracking algorithm that altered the difficulty of the stop signal task altered the stop signal delay (SSD) based on performance, therefore the SSD is a measure of performance. A first degree polynomial curve (y = ax + b) was fitted to the SSD performance parameter. Based on the SSD values for all 120 trials this fitted curve provided an estimate of the predicted SSD value for the 121st trial. A Cohen's d effect size in the order of 4 is seen. This indicates that within the task's set response window (the same window is used in assessment one and assessment two) participants increase the duration of the time they waited before responding. We also see that this improvement is accompanied by an improvement in the success rate, that is, the number of successful inhibits on 'stop' trials. For the stop-signal reactions time (SSRT), an inferred measure of the time taken to cancel a planned action, we see an increase indicating a shorter amount of time needed to cancel a response. There is also an increase in the "Go RT's minus failed inhibit RT's" parameter.

Mean effect size was pooled across measures, weighted to give equal weight to each task, was also calculated, and indicated a statistically significant positive effect on these trained tasks, with a medium-to large effect size.

10.1.2 Results for Pupil Dilation for Trained Saccade Tasks

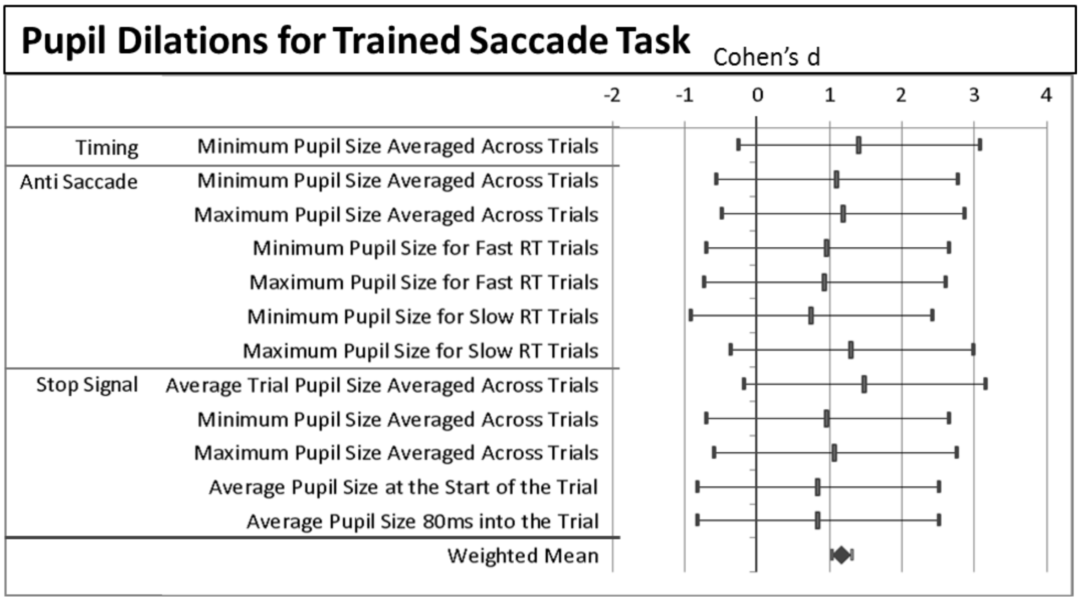


Figure 36. The graph displays Cohen's d effect sizes, and the upper and lower bounds for a 95% confidence interval. The positive effect sizes represent increases in pupil dilations for assessment two compared to assessment one. A single pupil parameter is displayed for the Timed Saccade Task, and multi pupil parameters are displayed for the Anti-saccade and Stop-signal tasks. A weighted mean effect size for changes in pupil dilations between assessments is also given**.**

Effect sizes and confidence intervals were also calculated for the pupil dilation measures. For three of the trained saccade tasks, namely the timing, anti-saccade, and stop-signal tasks, pupil dilations were examined. For the timing task the smallest dilation for each participant for each trial was averaged across all trials. The positive effect size indicates that across participants the smallest pupil dilation per trial was greater during assessment two than during assessment one. A similar effect size is seen for the anti-saccade task for both the largest and smallest pupil size. Similar pupil dilation increases in assessment two are seen in the anti-saccade task for the smallest and largest trial dilations for both slow (lower quartile) and fast (upper quartile) RT trials. In the stop-signal task an increase in pupil dilation is seen for the average trial dilation, the smallest and largest dilation, and the dilation at start of the trials and 80 ms into the trial.

10.1.3 Results for Non-trained Eye-tracking Tasks

Saccade and fixation duration data was extracted for the non-trained eye-tracking tasks, i.e., the reading and spot the difference tasks, and again, effect sizes and confidence intervals were calculated. For the reading task the number of forward saccades made per word increased for assessment two compared to assessment one. This effect was larger when the backward saccades were subtracted. There was also an increase in the duration of the fixations made between saccades. For the spot the difference task there was a decrease in the number of small and large saccades made, and an increase in the duration of fixations during saccades.

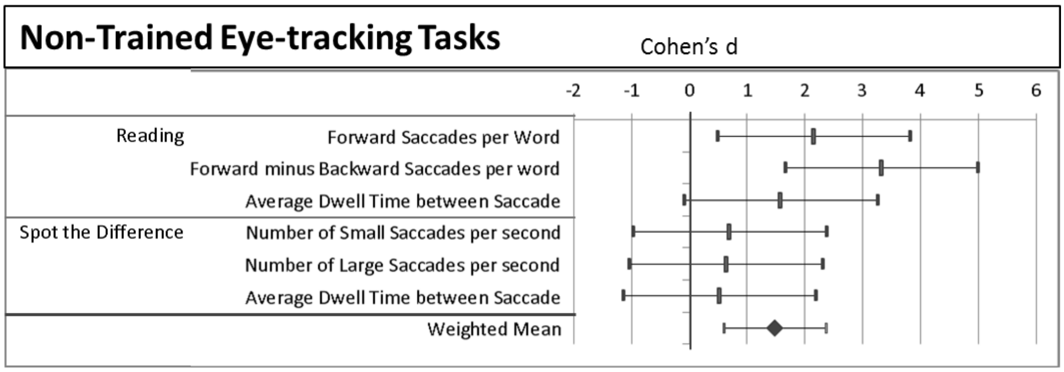


Figure 37. The graph displays Cohen's d effect sizes and the upper and lower bounds for a 95% confidence interval for the Non-trained eye-tracking tasks.

For the reading task a positive value for the "Forward saccades per word" parameter indicates an increase in the number of forward saccades made while reading on-screen text during assessment two compared to assessment one. The "forward minus backward saccade" parameter is the same measure controlling for the number of backward saccades made. Also given is the dwell time between saccades (fixation duration). For the spot the difference positive values indicate a reduction in the number of small and large saccades made per second and an increase in the dwell time made between saccades (fixation durations). A weighted mean effect size for both the Non-trained eye-tracking tasks was also calculated, and was significantly positive, with a large effect size.

10.1.4 Results for the Standard Assessment Tasks

An increase in the number of digits correctly remembered was seen for both the forward and backward digit span. The effect size is slightly larger for the backward digit span. Participants increased the number of letters they crossed out in the cancellation task. An increase is seen for the number of correctly number coloured words in the stroop task. A slight decrease in participants' scores is seen in both the WRAT4 reading and arithmetic. A very small increase is seen for the number of TOWRE non-words read but a large increase is seen for the number of words participants read.

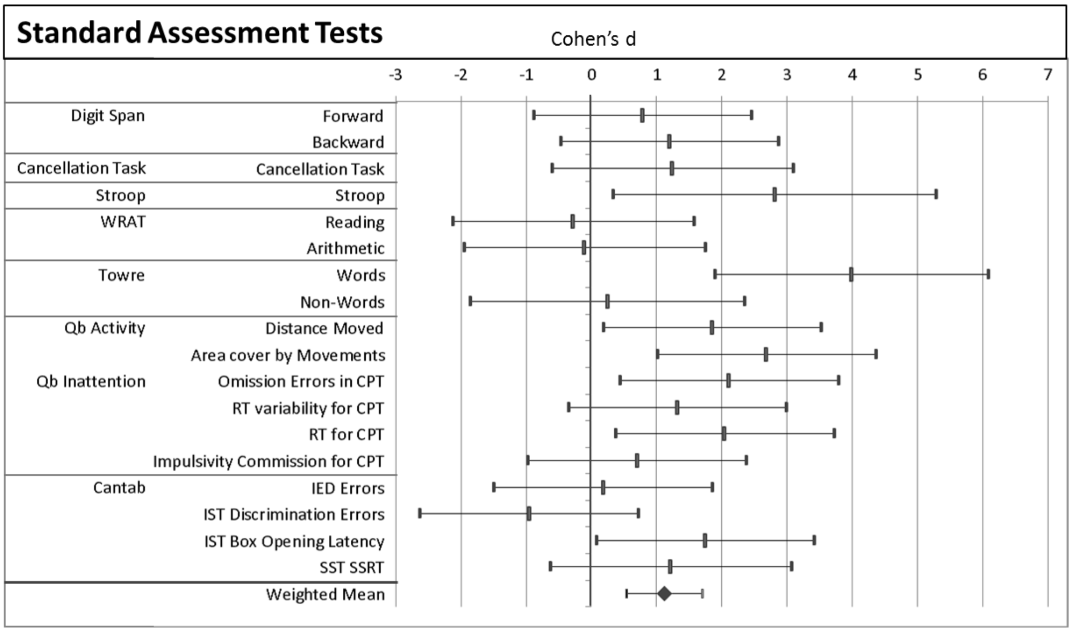


Figure 38. The graph displays Cohen's d effect sizes and the upper and lower bounds for a 95% confidence interval. The effect sizes represent changes in indices of task performance between assessments one and two. Positive values indicated improved performance. A weighted mean effect size for all the Standard Assessment Tests is also given. Lower bound values greater than zero indicated a significant effect for that parameter (p <0.05) for the sample (N = 8).

Table 5. The effect sizes and lower and upper confidence interval (95%) for the change in parameter values between assessment one and two. The output has been modified so that positive values indicate an improvement in performance. The results are grouped into trained saccade tasks, pupil dilations for eye-tracking tasks, non-trained eye-tracking tasks, and standard assessment tasks. For each of these task groups a weighted mean effect is also given.

Task	Task Parameter	Effect	Lower	Upper
Trained Saccade Tasks				
Timing	Short wait	1.22	-0.45	2.89
	Medium wait	4.21	2.54	5.88
	Long wait	2.20	0.53	3.87
Delayed	Coefficient of Variation	1.28	-0.39	2.96
	Mean RT	2.50	0.83	4.18
	Proportion Correct Reponses	2.15	3.82	0.48
Anti-Saccade	Coefficient of Variation	0.96	-0.71	2.63
	Mean RT	1.26	-0.41	2.94
	Proportion Correct Reponses	0.84	2.51	-0.84
Prosaccade	Prosaccade RT	-0.33	-2.00	1.34
Stop Signal	Predicted Final Stop-Signal Delay	3.94	5.61	2.27
	Success Rate on Stop Trials	1.75	3.43	0.08
	Stop Signal Reaction Time -	1.53	-0.14	3.20
	Go RT Minus Failed Inhibit RT	1.16	2.83	-0.51
	Weighted Mean	1.46	0.76	2.16
Pupil Dilations During Eye-Tracking Tasks				
Timing	Minimum Pupil Size	1.40	3.07	-0.27
Anti-Saccade	Minimum Pupil Size	1.10	2.77	-0.57
	Maximum Pupil Size	1.19	2.86	-0.49
	Minimum Pupil Size for Fast RT	0.97	2.64	-0.71
	Maximum Pupil Size for Fast RT	0.93	2.60	-0.74
	Minimum Pupil Size for Slow RT	0.75	2.42	-0.92
	Maximum Pupil Size for Slow RT	1.30	2.97	-0.37
Stop Signal	Average Pupil Dilation	1.48	3.15	-0.19
	Minimum Pupil Size	0.97	2.64	-0.70
	Maximum Pupil Size	1.07	2.74	-0.60
	Average Pupil Size at Start of the	0.84	2.51	-0.84
	Average Pupil Size 80ms into the	0.84	2.51	-0.83

	Weighted Mean	1.17	1. 03	1.31
Untrained Eye-Tracking Tasks				
Reading	Forward Saccades per Word	2.15	3.82	0.48
	Forward minus Backward per	3.32	4.99	1.65
	Average Dwell Time between	1.58	3.25	-0.10
Spot the	Number of Small Saccades	0.70	-0.98	2.37
	Number of Large Saccades	0.63	-1.04	2.30
	Average Dwell Time between	0.52	2.19	-1.16
	Weighted Mean	1.48	0.60	2.37
Standard Assessment Tasks				
Digit Span	Forward	0.78	2.45	-0.89
	Backward	1.20	2.87	-0.48
Cancellation Task	Cancellation Task	1.24	3.09	-0.61
Stroop	Stroop	2.81	5.29	0.32
WRAT	Reading	-0.28	1.57	-2.13
	Arithmetic	-0.11	1.74	-1.96
Towre	Words	3.99	6.08	1.89
	Non-Words	0.24	2.34	-1.86
Qb Activity	Distance Moved	1.85	0.18	3.52
	Area cover by Movements	2.68	1.01	4.36
Qb Inattention	Omission Errors in CPT	2.11	0.44	3.78
	RT variability for CPT	1.32	-0.35	2.99
	RT for CPT	2.04	0.37	3.72
	Impulsivity Commission for	0.70	-0.98	2.37
Cantab	IED Errors	0.18	-1.50	1.85
	IST Discrimination Errors	-0.96	-2.63	0.71
	IST Box Opening Latency	1.74	0.07	3.41
	SST SSRT	1.21	-0.64	3.06
	Weighted Mean	1.12	0.55	1.70

10.2 Results Discussion

Large effect sizes were seen for all trained eye-tracking tasks, with the exception of the prosaccade RTs. For many of the parameters the lower bound of the confidence interval is greater than zero indicating that the effect is significant at $p < 0.05$ despite the small sample of 8 participants.

For the timed saccade task the effect size is largest for the medium duration (1275 ms), however it should be noted that for the timing assessment task the medium duration was always completed first (followed by the short (901ms), then long duration (2023 ms). As a result the larger improvement for the medium duration likely reflects the lack of familiarity with the task at the initial assessment, that is, during the medium duration of the first assessment participants were still learning the task, as a result, some of the improvement seen at assessment two can be attributed to this. There is a larger effect for longer durations compared to shorter durations indicating that the intervention had a greater effect on improving timed saccades of longer durations. This may reflect a ceiling effect for shorter durations. We see that in the pilot study conducted with children during the Summer Scientist Week that a greater degree of competency for shorter durations in the timed saccade task is achieved at an earlier age. It may be that the production of consistently timed behaviour at shorter durations is partly achieved by anchoring the timing of the behaviour to the intrinsic time properties of the behaviour production processes. When a longer delay is required the system may be more dependent on additional processes such as the explicit use of an internal clock. The use of additional systems introduces noise. As a result of this extra noise there is thus more room for an improved performance for longer durations.

In interpreting the SSD or derived SSD values it is important to also consider the mean inhibition rate. Participants could improve their SSD performance through the use of a strategy that prioritised 'stop' trials and ignored 'go' trials. This would result in the appearance of an improvement but would only reflect a shift in strategy. However, results show that participants increase both the length of time they could wait before responding and also increased their success rate for 'stop' trials. They waited longer before responding and improved their rate of inhibiting responses when needed. An improvement on both parameters indicated a performance improvement. This improvement could be achieved in a number of ways. The shorter SSRT observed suggests that participants decreased the time it took to cancel the planned 'go' response upon the arrival of a stop signal. This is the preferred measure of stop signal performance in the literature (Logan, Schachar, & Tannock, 1997). Reported here is an improvement in SSRT for the third block but a similar improvement was also seen when all three stop-signal task blocks were included. In addition to the improvement in SSRT there is also an improvement in the "Go RTs minus failed inhibit RT's in block 3". Based on the rational put forward by Liddle et al. (2009) this suggests that participants also became more efficient at clustering the planned Go RT's within the "sweet spot" producing a leptokurtic distribution that maximised the trade-off between success on the 'go' trials and 'stop' trials. Such an improvement may in part reflect greater temporal accuracy in the execution of the processes involved.

For both the anti-saccade task and delayed saccade task reductions are seen for RT and variability of RT, and an increase in the proportion of correct responses. Participants got faster, more consistent in the length of the RTs after controlling for the size of the RT (using the coefficient of variation controls for the size of the RT), but also increased the number of responses they got correct. An improvement in the proportion of correct responses is important as it demonstrates that the faster RTs are not the result of a strategy that prioritised fast RTs at the expense of performance. The improvements seen for the delay saccade task are greater than those seen in the anti-saccade task. The successful completion of both tasks requires the deployment of multiple functions in addition to inhibitory control. As we do not see improvement in the speed of the prosaccades RT we can tentatively conclude that the faster RTs do in fact reflect an improvement of inhibitory control or related supporting functions.

The goal of the intervention was to improve attentional processes in addition to improving timing and inhibitory control processes. One proxy measure of attention or mental effort is pupil dilation. If the pupil is more dilated it may indicate that the participant is expending more cognitive resources while completing the task. There are many reasons that the pupil may dilate, however participants were exposed to similar conditions in assessments one and two; the room lighting was consistent across sessions, as was the distance from the screen, and the brightness and contrast of the on-screen stimuli presented. It is likely that the increases in the pupil dilations observed for assessment two compared to assessment one reflect some component of the intervention as opposed to environmental variables. One interpretation is that it reflects greater cognitive effort by participants while completing the tasks. As all three tasks utilised tracking algorithms, therefore the better performances observed may indicate an increase in task difficulty and cognitive load. This increase in pupil size was seen for all three tasks for which it was examined - the timing, stop-signal, and anti-saccade tasks. This effect was seen irrespective of whether the minimum, maximum or average size of the pupil averaged across trials was examined, or whether the pupil size was extracted at the start of the trial or after 80ms. A similar increase in pupil size was also seen for the anti-saccade task irrespective of whether the participant responded quickly (upper RT quartile latency trials) or slowly (lower RT quartile latency trials). Taken together these changes in pupil dilation suggest a tonic increase in pupil dilation across the train saccade tasks suggesting an increase in the deployment of cognitive resources during assessment two. The increased deployment of cognitive resources could reflect multiple factors, for example, greater motivation and improved attention. Furthermore, greater deployment of cognitive resources could reflect an increase in the capacity of the functions being deployed (having greater functional capacity increasing the potential for capacity expenditure).

Karatekin et al. (2009) reported that pupil dilations are larger for the antisaccade task compared to the prosaccade task in controls, but not in an ADHD sample. They suggest this may indicate a deficit in the regulations of tonic levels of arousal. They also report smaller dilations in an ADHD sample for the n-back task. The current finding of increased pupil dilations across tasks and trial-types may reflect greater control over levels of arousal in the post-training assessment. Better regulation of physiological arousal may underlie a readiness to response quickly to task demands and contribute to the performance improvements observed.

The analysis of the non-trained eye-tracking tasks was more explorative than the other tasks. These tasks were included to have a more ecologically valid measure of gaze performance more behaviourally relevant for day to day functioning. The hypothesis was that individuals with ADHD have poor inhibitory and attentional control and as a result their direction of gaze will tend to jump around. The analysis sought to establish whether more gaze stability was seen after the delivery of the training intervention. For the reading task the number of saccades made and the duration of fixations were analysed. The thesis pilot study examining school children demonstrated that better performance on the gaze control tasks correlated with an increased number of forward saccades during reading. Similarly, after completing the training participants demonstrated an increase in the number of forward saccades made per word. This effect was even great when controlling for those forwards saccades that were made following backward saccades. In addition we also see that participants also had longer dwell times between saccades (fixation duration). One interpretation of this data is that participants are making smaller more controlled saccades while reading and that they fixate for longer following a saccade, that is, they demonstrate more control and greater gaze stability. However, contra to this, Rayner (1998) reports that dyslexic and beginning readers exhibit shorter saccades with longer dwell times relative to more competent readers (Ashby, Rayner, & Clifton, 2005).

The spot the difference task was also used as a more ecologically valid measure of gaze behaviour. Participants had to identify the difference that existed between two images presented simultaneously on screen. The effect sizes for this task were smaller and the lower confidence interval was approximately minus one for all three spot the difference parameters. As with the reading task longer fixation duration was seen. The second measure of performance was the number of saccades made per second. The positive effect size value reflects a decrease in the number of saccades made per second. This effect is seen for both short and long saccade distances. Taken together with the longer fixation durations this suggests increased gaze stability when performing the tasks.

For both the reading task and spot the difference task it should be noted that the text and images presented were not counter-balanced across participants. The stimuli used were also not analysed to ensure that the image and text used were comparable across assessments. This raises the possibility that the effects seen reflect difference between the stimuli presented. Rayner (1998) reports that as the difficulty of the text increases so does the duration of fixations and the size of saccades decreases. Further evidence contra to the interpretation presented is the finding that greater accuracy in landing position while reading is correlated with reduced dwell time. Increased processing cost equivalent to 20 ms is added for every letter that the eyes deviate from the optimal viewing position in a word. In addition, poorer accuracy is associated with an increased number of saccades as readers are more likely to refixate words (O'Regan et al., 1984).

A number of standard assessment tests were delivered to assess whether any transfer occurred. Also using standard assessments that have reported test-retests effects allowed us to attempt to disentangle the effects of the intervention and practice effects. For the digit span task effect sizes of 0.78 and 1.20 are seen for the forward and backward subtests respectively, this reflected an increase in digits remembered of 0.63 for the forward and 1.5 for the backward tests. While these improvements are greater than the test-retest improvements seen in the literature, a cautious interpretation is needed; we can see in figure 39 that the lower confidence bound extends into negative numbers. Small or negligible test-retest practice effects seen for both the forward and backward digit span are reported in the literature. For 36 typically developing participants completing the RBANS Digit Span, a forward digit span test, no practice effects were observed. At baseline participants scored 10.8 (*SD* =2.1), after 2/3 weeks the mean score was10.3(*SD* =1.8) and after 6 weeks the mean was 10.9 (*SD* =1.9) (Bartels, Wegrzyn, Wiedl, Ackermann, & Ehrenreich, 2010). Another study examining both forward and backward digit span improvements found that after a three day period the forward digit span had improved by 0.3 digits and the backward digit span by 0.45 digits. A third study examining only backward digit span observed that 18 – 30 year olds scored 6.2 (*SD* =1.2) at baseline and 6.7 (*SD* =1.1) at follow-up, and 50-59 year olds score 6.2 (*SD* =1.5) at baseline and 6.4 (*SD* =1.2) at follow-up (Waters & Caplan, 2003).

The cancellation task, in which participants must search and cancel particular visual stimuli, was self-paced, with two targets, and was a pencil and paper version. The cancellation task is a measure of vigilance and gaze control. For this task an effect size of 1.2 was observed. No normative sample comparison was available for this task.

There is a degree of disagreement in the literature as to whether test-retest improvements are seen for the Stroop task. This ambiguity is in part attributable to the multiple versions and scoring methods used for this task. Connor et al. (1988) had a similar test set-up as used in this experiment, that is, 45 seconds to name as many of the ink colours as possible. They reported no practice effect. The nature of this procedure decreases the length of the test compared to more standard procedures and may lower the possibility for practice effects. After a four week gap between assessments Lowe and Rabbitt (1998) found no improvement in the stoop test. Jensen & Rohwer (1966) reported an improvement of 23% in colour naming; other estimates are as high as 25%. An effect size of 2.8 was observed for this study, this reflected a performance improvement of 4.8 words, an improvement of 14%, and therefore this improvement may be wholly attributable to practice effects.

No improvement is seen for the WRAT reading or arithmetic test. Improvements were not expected for these tasks as the function trained (inhibitory gaze control and supporting functions) are not implicated in the successful completion of WRAT tasks. The lack of improvement on these tasks does however support the assertion that the gains made on other tasks reflects a genuine improvement as improvements due to greater effort by participants at assessment two would also likely lead to improvement on the WRAT tasks.

The TOWRE test score stability was assessed by the test developers (Torgesen et al. 1999) with a test-retest method over a period of two weeks. A sample of seventeen 19 to 24 year olds scored a mean standardised score of 102 (*SD* =13) at time point one and scored 102 (*SD* =12) at time point two for the single word efficiency, and 102 (*SD* =14) and 105 (*SD* =15) for the phonemic decoding efficiency. For this study an effect size of 3.99 for single word efficiency and 0.24 for phonemic decoding efficiency was observed. This reflected an improvement of 9 words and 0.5 words respectively. An improvement of 9 words far exceeds what might be expected at retest. This improvement could reflect improved gaze control when reading down the column of words. The lack of improvement in the phonemic decoding most likely reflects the fact that the most limiting factor for improved performance is the phonemic decoding, a function the training does not address. This differential improvement is at least consistent with the hypothesis that the improvements seen are the result of the training intervention.

Strong effects are seen for the QbTest. Participants reduced the amount of movement and the distance they covered. These activity measures are designed to assess the hyperactive symptoms of ADHD. Further, we see improvement for the inattentive measures also. While completing the continuous performance task participants make less omission errors, have faster and less variable RTs at assessment two. This suggests that participants demonstrated improved vigilance during assessment two. A reduction in commission errors, an impulsivity measure, was also seen, however the size of this effect was smaller and its lower confidence bound extended into the negative numbers.

Vogt & Williams (2011) used the QbTest to evaluate the effects of a single dose on methylphenidate in 13 to 18 year olds with ADHD (N = 20). Table 7 below lists baseline and methylphenidate scores (standard deviations) and t-values. This provides a comparative data set. Note that a number of the participants taking part in the training intervention were on medication during the pre- and post-assessments, this most likely elevated the mean baseline scores achieved.

An examination of Table 6 illustrates large effect sizes are seen for both interventions. Greater effect sizes are seen for all parameters for the methylphenidate intervention versus the training intervention. The larger effect sizes in the methylphenidate intervention for Omission Error, RT variability, and Commission error are in part attributable to the relatively poor baseline scores for this sample. The relatively better baseline scores for current study may reflect that a number of the participants were taking ADHD medication. However, in all instances with the exception of Commission errors the post intervention scores are lower for the methylphenidate intervention. Greater parameter variability is generally seen in the proof-of-concept study, however, interestingly not for RT and RT variability parameters.

Interpretation of the effects observed is limited by the small sample sizes and the varied use of ADHD medication in the proof-of-concept assessments. "Distance" is comparable at baseline, but a greater reduction is seen for the methylphenidate intervention. A similar area score is seen post intervention for both data sets. A greater reduction and lower post intervention score for omission is seen for the methylphenidate intervention. RT variability is comparable between data sets post intervention. The training intervention RT is similarly comparable to the baseline RT for the methylphenidate intervention. This along with a longer RT at baseline seen in the training data is a strong indicator of differences between the samples used in both studies. Fewer commission errors and less between subject variability in commission errors are seen for the training data set.

Table 6. Qb output from the (Vogt & Williams, 2011) study and for this training intervention. The baseline and methylphenidate/post training scores (standard deviations) and effect size for the Qb test parameters.

	Vogt & Williams, 2011			Current study effects		
	Baseline (SD)	MPH (SD)	Effect size	Baseline (SD)	Post Training (SD)	Effect Size
Distance (m)	22.9 (16.4)	11.4 (14.4)	2.5	24.0 (39.6)	22.1 (41.79)	1.85
Area (cm^2)	90 (56.7)	38.3 (37.6)	3.7	70.4 (79.3)	41.7 (47.49)	2.68
Omission error (%)	23.5 (23)	6.6 (13.3)	2.9	20.9 (14.7)	12.8 (15.32)	2.11
RT variation (ms)	214.1 (62.5)	159.4 (62.7)	3.3	189.3 (43.7)	162.9 (45.41)	1.32
RT (ms)	551.5 (116.4)	489.8 (151.2)	2.5	652.4 (112.6)	547.5 (89.60)	2.04
Commission error (%)	5.7 (6.4)	3 (5.2)	2.3	2.31 (3.1)	1.8 (3.16)	0.70

For the Cantab tasks we see both positive and negative effect scores. There is a minimal effect for error made in the intra-extra dimensional set shifting task. We see a negative retest performance with respect to the number of discrimination errors made compared to the normative population in the information sampling task. That is, the participants scored worse in assessment two compared to the normative population. There is an improvement in the opening box latency for the information sampling task. This combination of faster box opening latency and increased errors would suggest a performance speed trade-off. Most importantly, we see an improvement in and positive effect for the stop-signal reaction time for the Cantab stop-signal tasks. The positive effect size of 1.21 indicated that participants increased the speed at which they could cancel or inhibit a response. It is possible that this improvement is the result of a practice effect, however Barch, Braver, Carter, Poldrack, & Robbins (2009) reported that no practice effects were observed for the CANTAB stop-signal task. An improvement for this task would be in line with the improvement seen in the inhibitory control eye-tracking tasks and would suggest transfer of enhance inhibitory motor control from inhibitory gaze control to manual inhibitory control.

The standard assessments that show consistent improvement are those designed specifically to assess and monitor ADHD symptoms. Looking at individual profiles (see below in case studies) we see that individual participant Qb scores approach that of the typically developing population following the intervention.

11 Case studies

Before examining and interpreting participant's individual scores I first provide some notes on how to interpret the case study results presented.

Participants completed the Connors' Adult ADHD self-report short version (CAARS-S: S). This is an assessment instrument designed to help inform consideration of an ADHD diagnosis and related problems. The scale has a normative sample of 1026 adults. The score of an adult who completes the scale can be compared to the normative sample and provides a profile of scores that will indicate the subscales that are elevated. Table 8 can be used to interpret an individual's scores across the five subscales:

1. **Inattention / memory problems:** Difficulties may include trouble concentrating, difficulty planning or completing tasks, forgetfulness, absent-mindedness, being disorganised.
2. **Hyperactive / restlessness:** Difficulties may include problems with working at the same task for long periods of time, feeling more restless than others seems to be, fidgeting
3. **Impulsivity / emotional lability:** Difficulties may include engaging in more impulsive acts than others do, low frustration tolerance, quick and frequent mood changes, feeling easily angered and irritated by people.
4. **Problems with self-concept:** Difficulties may include poor social relationships, low self-esteem and self-confidence.
5. **ADHD index:** Identifies individuals "at risk" for ADHD

Table 7. Interpreting the CAARS T- scores

45 - 55	Typical score (should not raise concerns)
56 - 60	Slightly elevated (borderline: should raise concern)
61 - 65	Mildly atypical (possible significant problem)
66 - 70	Moderately atypical (indicates a significant problem)
70 +	Markedly atypical (indicates a significant problem)

Participants completed the Autism Spectrum Quotient-10 (AQ-10) questionnaire (Woodbury et al., 2005). This is a brief screening questionnaire. It is suggested that an individual who scores 7 or greater should be considered for a referral for a specialist diagnostic assessment. Given that only participant 1016 had a score of 7 or greater autism symptoms were not considered a confound for the training and assessment of participants.

Interpreting the Training Performance and Different Graphs

These graphs provide information on individual participant's performances while completing the training intervention, that is, the training between the pre- and post-assessments. For each participant there are five graphs showing the five main training tasks, i.e., timing task, sudden distractor task, anti-saccade task, stop signal task, and jumping bomb task. The Y-axis is timing in milliseconds and the x-axis is the number of the training session. A repeated number on the x-axis indicated that this task was completed more than once for that training session.

The Timing Task figure: shows saccade timing accuracy (red) (temporal proximity to the target duration) and the target duration (blue). When interpeting this graph it must be noted that the timing accuracy is effected by the target duration, the longer the duration the greater the inaccuracy. However, near the start and end of the training intervention participants were given a repeat of the 1500 ms duration. This allows us to compare their performance for a specif duration near the start of training and near the end of the training. Examined was the distance between the target duration and accuracy at these two training sessions to see if there has been an improvement as a result of training.

The Sudden Distractor Task: shows the response window which I changed across the sessions to encourage participants to respond quicker, and the reaction time, which shows the saccade latency in response to the appearance of the 'go' signal (that is the second bomb stimulus).

The Anti-Saccade Task: shows the response window which changed across sessions to encourage faster RTs and RT's for correct responses.

Stop Signal Task: shows the response window (period within which successful responses must fall) and stop signal delay. Both were changed across training sessions to increase the difficulty. Also shown are the SSRT and the Go RT.

The Jumping bomb Task: the main performance indicator here is the mean jumping RT which is the reaction time in response to the 'go' stimuli. The other parameters are measures of task difficulty that were manipulated across training sessions. The "jumping distractor duration" is the period of time distracter bombs appear for, the "final jumping distractor duration" is the period of time the final distractor appears for and is thus also a cue to prepare for a saccade to the target, and the "target duration" is the period of time the target appears for (response window).

Interpreting the Assessment Tables

Individual participant's assessment score tables (tables 9 – 19) provide a breakdown of the participant's scores on the pre- and post-training assessment tasks. Given the speculative nature of the pupil dilation data, the reading, and spot the difference data these were not included in these individual tables. Also removed from the case study assessment task results tables are those measures for which we do not see group improvements: the WRAT reading and arithmetic, and the CANTAB IED and IST. The interpretation of these measures at the individual case level would be inappropriate given that no group effect was observed.

Some tasks have more than one performance parameter listed. For each performance parameter listed their raw score and Z score is given for assessment one, assessment two, and the improvement (difference between assessment one and two). A positive raw score indicates better performance in all cases. The Z-score for any single performance parameter (e.g. Timing task – Short wait) is calculated by first obtaining the mean and standard deviation for all participants' scores for assessments one and two for that performance parameter. An individual score (e.g. Timing task – Short wait – Assessment one for participant 1016) is then calculated by subtracting the mean from this score and then dividing it by the standard deviation, i.e. Z = (data point – mean) / standard deviation.

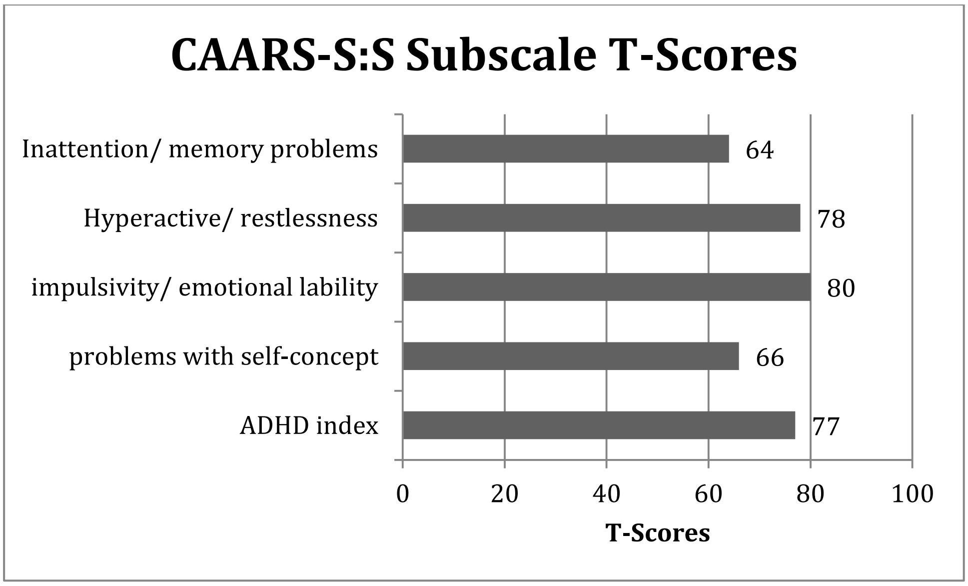
The z-score provide an indication of how a participant performed compared to the other participants and how much he or she improved between assessments. Also in the table in the final column is the overall z-score improvement and standard deviation for the group, this indicates how much participants improved on average between assessments one and two and how much variability there is between participants with regard to this improvement. As the individual z-scores are based on the pooled scores from assessment one and two, if there is an overall improvement between assessments one and two it is more likely to see negative z-scores for assessment one.

For the Qb score instead of raw score the Qb Q-scores are provided. The Q-scores is the participant's z-score for that parameter using the normative sample data set. A negative score indicates a better than average score (compared to the noramtive data set).

11.1 Participant 1016

Gender	Female
Age	19
Diagnosis	Combined
Medication	Strattera (25 mg per day)
Weight	48.3 Kg
Comorbid diagnosis	No
Other issues	Sleep problems and anxiety but not serious
Notes	Had a tendency to stay up late playing video games. Arrived at some sessions tired. Insisted on a tea at the start of each session and typically needed a cigarette break during sessions. Accompanied by her mother who seems eager that she participates.

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
64.00	78.00	80.00	66.00	77.00
IQ estimate	97	Autism Spectrum Quotient		7



Participants 1016 had an average IQ and an elevated autism spectrum quotient. No autistic symptoms or behaviours were apparent during delivery of the intervention or assessments. She turned up to a number of training session tired having been awake until late the night before. She had a diagnosis of ADHD (combined type) and took 25mg of Strattera per day, including during all the training and assessment sessions. Her CAARS scores were markedly atypical. Her scores indicate a mildly atypical inattention and memory problems, moderately atypical problems with self-concept, and markedly atypical scores for hyperactivity / restlessness, impulsivity/emotional lability, and ADHD index.

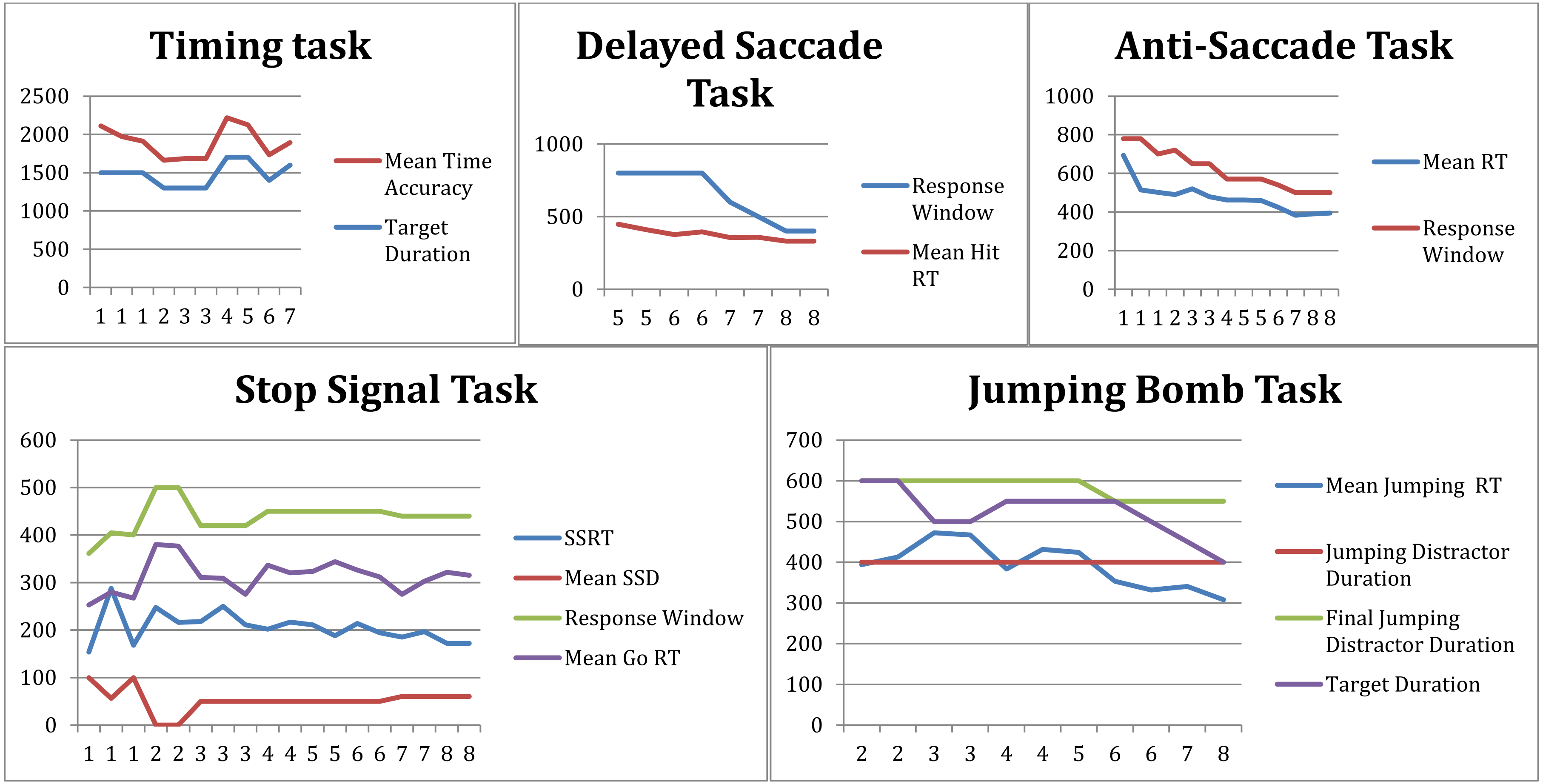


Figure 39. Trainng performance and difficult across the training sessions for participants 1016. Y-axis is time in milliseconds and the x-axis is the number of the training session

Evaluation of performance during training

Participants 1016 started each session with a tea with three sugars, and typically took a cigarette break in the middle of a training session. During the training she really disliked negative feedback. She appeared frustrated with her performance during the early sessions. As a result a higher success rate threshold was set before the task difficulty parameters were increased, thus reducing the difficulty of the tasks. She appeared to grow in confidence and resilence in the face of negitive feedback as the training progressed and her levels of frustration appeared to reduce. Over the course of the training the typical tresholds for increasing task difficulty were introduced. See was generally motivated to beat her old scores but appeared to find the tasks mildly unpleasent. On occasions she half-jokingly complained about the tasks. Her training sessions were typically shorter (40-45 minutes) compared to other participants (50-60 minutes) as she often became fatigued towards the end of a training session, and also to limit her frustraction with the tasks.

Participant 1016 demonstrates improvement across all five tasks displayed in figure 39 above. For the timing task we can see the the distance between the red and blue lines decrease between session 1 and session 7 indicating improved temporal accuracy in the timing of saccade production. She also reduced her mean hit RT for the delayed distractor task, anti-saccade task and jumping bomb task. For the stop-signal task we see a reduction in the SSRT.

She was poor at the fixation tasks but usually managed to successfully complete these tasks. She performed well at the jumping bomb and anti-saccade tasks, but had a tendency to produce early responses for the jumping bomb task and timing task, and tended to look at the distracter for the anti-saccade task. She particularly disliked the stop-signal task early in training as she though it "unfair".

Personal Reflection

I felt that this participant in particular would have benefitted more from further training sessions. I felt that the early sessions were dominated by issues around learning to control her frustration in response to negative feedback. Additionally, I would have preferred if her training sessions, which were spread out over four weeks, had been closer together.

Evaluation of pre- and post-assessment performance

For the three timing task durations participant 1016 displayed greater gains than the other participants on average; the Z-score improvement for the short, medium, and long durations are 1.27, 1.5, and 2 compared to the group average improves of 0.4, 1.43, and 0.86. For both the delayed and anti-saccade tasks 1016 made extremely large gains on the proportion of correct responses improving 2.22 (37%) and 3.9 (38%) repectively. These large improvements are in part driven by the low initial score (Z scores of -1.62 and -3.23 at assessment 1), however her performance in assesssment two was very good (90% and 100% correct). She also improved her reaction times for both these tasks, and reduced the variation of her RT for the delayed saccade task. She increased the speed of her prosaccade RT. She made extremely large gains on all the stop-signal parameters compared to the average improvement for the group. For the SSRT and predicted final stop-signal delay this improvement largly reflects the low score at assessment one but she scored well for success rate and Go RTs minus Failed Inhibit RT during assessment two.

We see a two digit improvement for the backward digit span and a slight improvement for the stoop task. She also made large improvements for the TOWRE word and moderate improvements for the non-word tasks. For the Qb test we see very slight reduction in the the amout of activity. For the Qb continiuos performance task she increased her errors and reduced her RT and RT variability, suggesting a trade-off of speed for performance during the second assessment compared to the first. This reduction in RT variability is the most obvious change in the Qb summary results below (See figure 40 She makes gains in the Cantab IST errors and speed, and a slight gain in the stop signal SSRT.

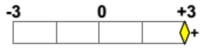
Table 8. Participants 1016: the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	28.00 (-1.41)	18.00 -0.13)	10.00 (1.27)	0.40 (0.65)
	Medium wait	16.00 (-0.84)	8.00 (0.65)	8.00 (1.50)	1.43 (0.68)
	Long wait	39.00 (-1.40)	17.00 (0.60)	22.00 (2.00)	0.86 (0.78)
Delayed Saccade	Mean RT	121.75 (-0.48)	75.46 (1.48)	46.29 (1.97)	0.99 (0.79)
	Coefficient of Variation	0.41 (-0.72)	0.22 (1.11)	0.19 (1.83)	0.72 (1.13)
	Proportion Correct Reponses	0.53 (-1.62)	0.90 (0.60)	0.37 (2.22)	1.19 (1.11)
Anti-Saccade	Mean RT	370.11 (-0.01)	308.36 (0.77)	61.75 (0.78)	0.80 (1.27)
	Coefficient of Variation	0.31 (-0.22)	0.32 (-0.34)	-0.01 (-0.12)	0.68 (1.48)
	Proportion Correct Reponses	0.62 (-3.23)	1.00 (0.74)	0.38 (3.90)	0.64 (1.53)
Prosaccade	Prosaccade RT	632.00 (-0.31)	528.00 (0.80)	104.00 (1.11)	-0.12 (.75)
Stop Signal	Success Rate on Stop Trials	0.39 (-2.33)	0.66 (0.87)	0.27 (3.20)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	342.20 (-2.28)	193.29 (0.21)	148.91 (2.49)	0.99 (1.30)
	Predicted Final Stop-signal Delay	40.61 (-1.47)	145.61 (0.14)	105.00 (1.60)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	-173.95 (-3.10)	77.92 (1.20)	251.87 (4.30)	0.91 (1.58)
Digit span	Forward	10.00 (0.39)	9.00 (-0.02)	-1.00 (-0.41)	0.26 (0.66)

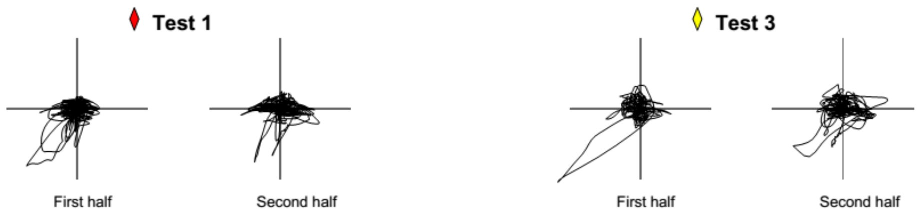
	Backward	4.00 (-1.64)	6.00 (-0.67)	2.00 (0.97)	0.73 (1.22)
Cancelation Task	Cancellation	20.00 (-0.19)	19.00 (-0.32)	-1.00 (-0.13)	0.45 (0.80)
Stroop	Stroop	47.00 (1.42)	50.00 (1.77)	3.00 (0.35)	1.19 (1.40)
Towre	Words	94.00 (-0.07)	110.00 (0.86)	16.00 (0.93)	0.39 (0.33)
	Non-Words	64.00 (0.32)	71.00 (0.83)	7.00 (0.52)	0.03 (0.26)
Qb Activity	Distance Moved	3.70 (-0.96)	3.50 (-0.87)	0.20 (0.09)	0.32 (0.35)
	Area cover by Movements	3.30 (-0.93)	3.20 (-0.88)	0.10 (0.06)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	2.00 (-0.74)	2.70 (-1.31)	-0.70 (-0.58)	0.78 (0.74)
	RT variability for CPT	2.10 (-1.36)	1.50 (-0.76)	0.60 (0.60)	0.66 (1.00)
	RT for CPT	1.60 (-1.13)	1.40 (-0.94)	0.20 (0.19)	0.97 (0.95)
	Impulsivity Commission for CPT	-1.30 (1.33)	-1.30 (1.33)	0.00 (0.00)	0.25 (0.72)
Cantab	SST SSRT	113.62 (1.30)	107.77 (1.43)	5.85 (0.12)	1.02 (2.02)

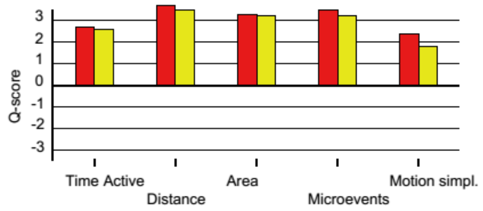
Participant 1016 shows large gains as a result of the training for the trained saccade tasks. She also demonstrates improvement on a number of the standard assessment tasks for which we would expect to see improvement, and a lack of improvement for tasks for which we would not expect to see improvements; e.g improvement on the backward digit span and the stroop task, a greater improvement on the TOWRE words versus non-words. She however shows little improvement with regard to her level of activity and impulsivity during the Qb test, and her improved RT appears to have been achieved at the expense of performance. The small improvement seen for the Cantab manual response stop-signal task suggests poor transfer of the gains made for inhibitory gaze control.

Activity



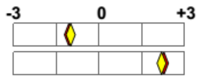
	Q-score		Percentile	
	Test 1	Test 3	Test 1	Test 3
QbActivity	3.2	3.0	99	99



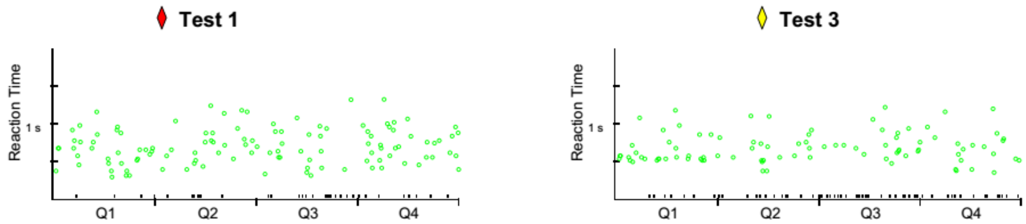


	Measure		Q-score		Percentile	
	Test 1	Test 3	Test 1	Test 3	Test 1	Test 3
Time Active:	49	47	2.7	2.6	99	99
Distance:	26	23	3.7	3.5	99	99
Area:	99	91	3.3	3.2	99	99
Microevents:	13	11	3.5	3.2	99	99
Motion simpl.:	61	54	2.4	1.8	99	96

Attention & Impulse Control



	Q-score		Percentile	
	Test 1	Test 3	Test 1	Test 3
QbImpulsivity	-1.1	-1.0	15	16
QbInattention	2.3	2.2	99	99



	Measure		Q-score		Percentile	
	Test 1	Test 3	Test 1	Test 3	Test 1	Test 3
Omission Error:	26	45	2.0	2.7	98	99
ReactionTime Var:	239	206	2.1	1.5	98	93
Reaction Time:	731	705	1.6	1.4	95	92
with Outliers:	731	705	1.6	1.3	95	90
Normalised Var.:	33	29	1.2	0.6	88	73
LongestPassivity:	5	4				

	Measure		Q-score		Percentile	
	Test 1	Test 3	Test 1	Test 3	Test 1	Test 3
NormCommission:	0.0	0.0	-1.3	-1.3	10	10
Commission:	0.0	0.0	-1.3	-1.3	10	10
DprimeMod:	5.1	5.6	-0.2	0.3	42	62

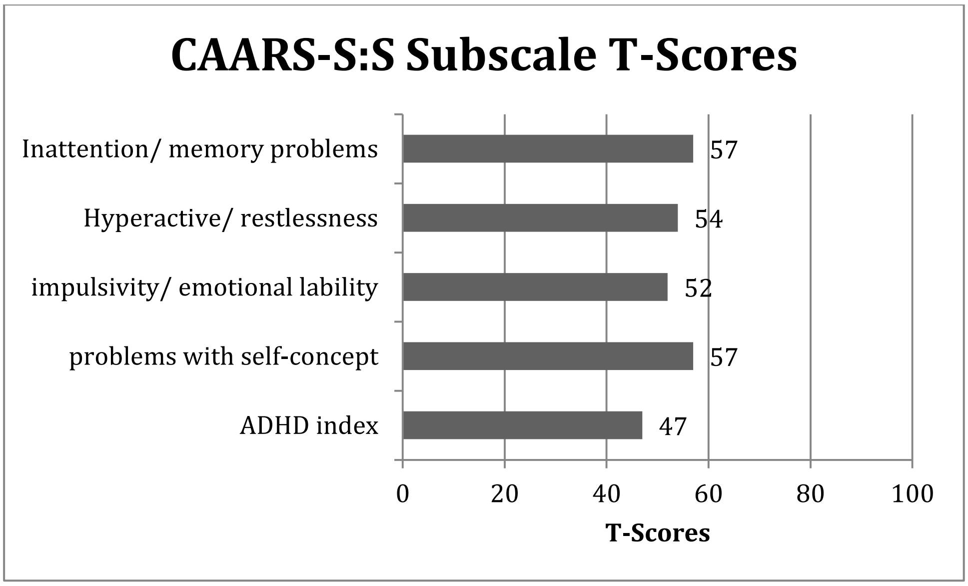
4c8135aa037f408d8b5dbf69f29531fc
0.0 - 0.0 - 600 - 3.4 / 0.0 - 0.0 - 600 - 3.9

Figure 40. Qb pre and post-assessment summary for 1016 (note output mistakely states that this was test three instead of test 2).

11.2 Participant 1087

Gender	Male
Age	28
Diagnosis	No ADHD – reports attention problems
Medication	Sertraline for attention and anxiety problems (100mg per day)
Weight	83 kg
Comorbid diagnosis	Attention problems
Other issues	Reports some depressive symptoms and sleep problems
Notes	Not native English speaking but highly proficient

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
57.00	54.00	52.00	57.00	47.00
IQ estimate	No IQ measure as he is not a native English speaker			
Autism Spectrum Quotient	2			



The CAARS scores for participant 1087 indicate that he has slightly elevated scores for attention/ memory problems and self-concept, but he was in the normal range for hyperactivity/restlessness, impulsivity/emotional liability, and ADHD index. The questionnaire consistency score was 10 indicating potential problems with the reliability of the results. He did not have a diagnosis of ADHD and most likely does not have the condition; however he was included in the intervention because he reported having attention problems. He was on medication (Sertraline) for attention and anxiety problems which he took for the duration of the training. He also reported some depressive symptoms and sleep problems. For some of the sessions (particularly 4 and 5) he suffered some flu like symptoms and he reported that this did impact on his ability to focus. He scored 2 on the Autism Spectrum Quotient which is below the threshold for a suggested referral for assessment. The participant was a non-native English speaker. As a result an IQ estimate was not obtained. The WRAT and Towre reading scores were also not gathered.

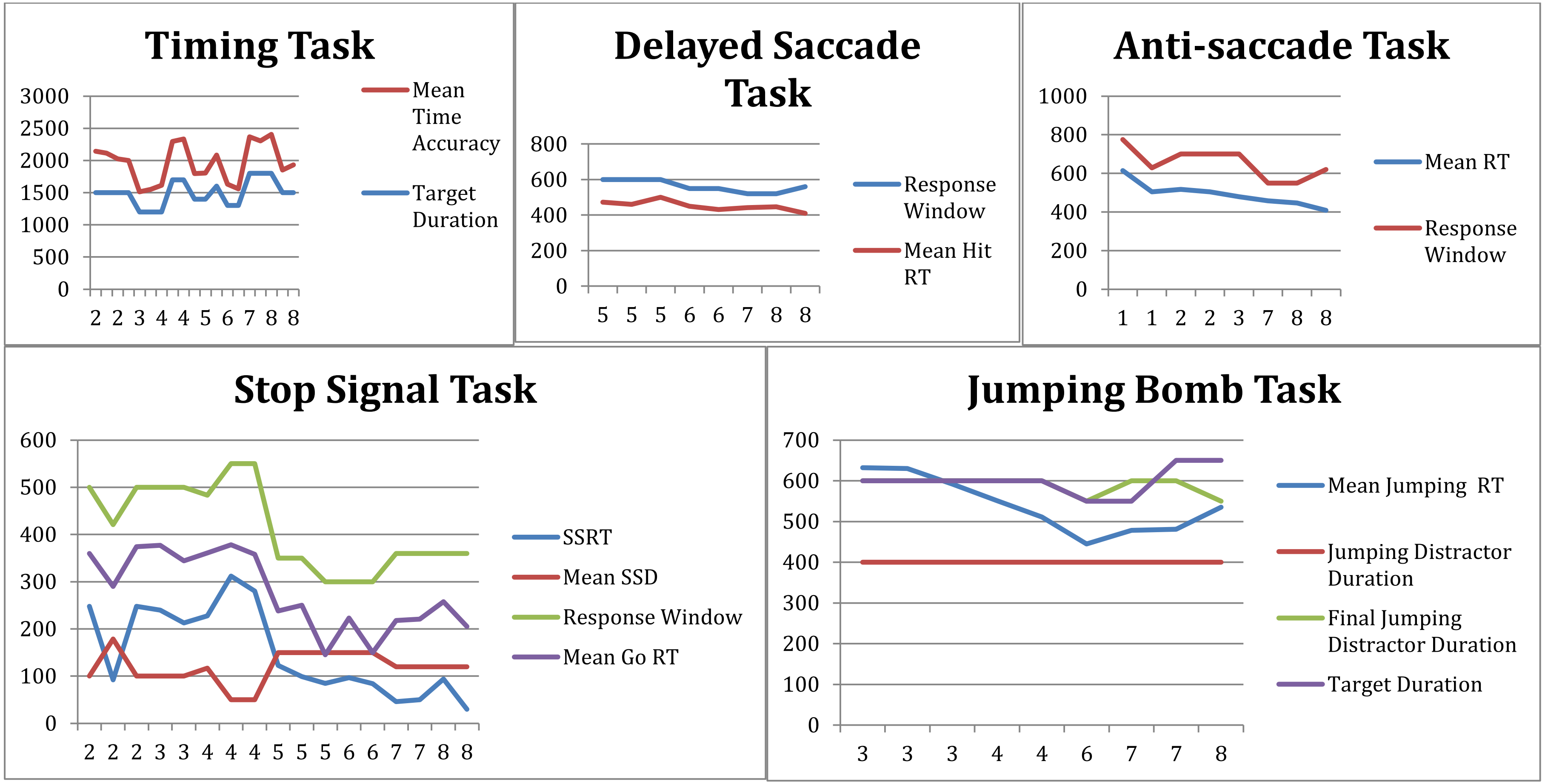


Figure 41. Trainng performance and difficult across the training sessions for participants 1087. Y-axis is time in milliseconds and the x-axis is the number of the training session

Evaluation of performance during training

During training participant 1087 typically appeared eager to finish the training, both each particular session and his study participation generally. Between training tasks he often asked "how many tasks are left". He was however insistent that he would complete all training and assessment sessions and that he was participating in the study because he was interested in research. His training sessions were close together and he was eager to finish study participation before his college exams started.

Participant 1087 made a general improvement in task performance over the course of the training intervention. There is a slight improvement for the timing task. His mean RT improved across sessions for both the delayed saccade and anti-saccade tasks. This was a sizeable drop of approximately 200ms for the anti-saccade task. Improvements are also seen for the SSRT in the stop signal task. In the jumping bomb task steady improvement are seen across sessions until the end of session 7 and in session 8.

Evaluation of pre- and post-assessment performance

Participant 1087 performed poorly on the timing task both at the pre- and post-training assessments. No improvement was made for the short duration and an improvement similar to the group average improvement was seen for the long duration, but given the poor score observed at the initial assessment this post training assessment score is still low. Larger improvements are seen for the less reliable medium duration interval (less reliable as it is the first duration completed at both sessions and therefore the most likely to benefit from practice effects). He performed poorly at both the anti-saccade and delayed saccade task at the initially assessment but made large gains reducing the RT variation in both tasks at the post training assessment. Reflecting the improvement seen in the training tasks there is a fast anti-saccade RT for the second assessment. While the proportion of correct trial for the anti-saccade was near ceiling in the pre-test large gains were made for the proportion of correct trials for the delayed saccade task, going from 49% to 86% correct responses. A small reduction in speed is seen for the pro-saccade task. His performance on the stop signal task is below that of the other participants. Some modest improvements, below the average group improvements, are seen for the stop-signal task. However, large gains are seen for the Go RTs minus Failed Inhibit RT parameter.

Participant 1087 performed poorly at the WM task but did improve by 2 digits in the backward digit span task, a slight larger than average improvement. For the Qb test he had very low movement scores at pre-test and even smaller scores at post-test. For the continuous performance task he reduced his error rate but became more variable and slower in his reaction times. This suggests an adoption of a more cautious strategy. The amount of commission errors remained high across assessments. He performed worse in assessment two at the IED and stop-signal tasks, and increased his box opening latency in the IST while maintaining a perfect discrimination score.

Participant 1087 was one of the least engaged participants during assessment and training. He also did not have ADHD. While he made some gains for some tasks overall his performance was poor at the initial assessment and remained relatively poor at the post-training assessment. He reported that he had attention problems. He produced a poor performance on the intra-extra dimensional set shift test (IED), a measure of rule acquisition and reversal task analogous to the Wisconsin Card Sorting test. He was the only participant who appeared to have difficulties with this task. His performance compared to the other participants produced a Z score of -2.15 and -2.44 at pre and post training assessments respectively. A poor performance on the IED test is indicative of abnormalities in the fronto-striatal substrate.

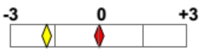
Table 9 For participants 1087 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	27.00 (-1.28)	27.00 (-1.28)	0.00 (0.00)	0.40 (0.65)
	Medium wait	22.00 (-1.96)	8.00 (0.65)	14.00 (2.62)	1.43 (0.68)
	Long wait	45.00 (-1.94)	35.00 (-1.04)	10.00 (0.91)	0.86 (0.78)
Delayed Saccade	Mean RT	113.41 (-0.13)	122.38 (-0.51)	-8.97 (-0.38)	0.99 (0.79)
	Coefficient of Variation	0.64 (-2.93)	0.41 (-0.72)	0.23 (2.21)	0.72 (1.13)
	Proportion Correct Reponses	0.49 (-1.85)	0.86 (0.36)	0.37 (2.22)	1.19 (1.11)
Anti-Saccade	Mean RT	555.02 (-2.35)	285.75 (1.05)	269.27 (3.40)	0.80 (1.27)
	Coefficient of Variation	0.46 (-2.02)	0.26 (0.38)	0.20 (2.41)	0.68 (1.48)
	Proportion Correct Reponses	0.90 (-0.31)	0.92 (-0.10)	0.02 (0.21)	0.64 (1.53)
Prosaccade	Prosaccade RT	528.00 (0.80)	568.00 (0.37)	-40.00 (-0.43)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.53 (-0.67)	0.54 (-0.55)	0.01 (0.12)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	245.86 (-0.67)	214.38 (-0.15)	31.48 (0.53)	0.99 (1.30)
	Predicted Final Stop-signal Delay	66.14 (-1.07)	89.66 (-0.72)	23.52 (0.36)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	-91.38 (-1.69)	27.64 (0.34)	119.02 (2.03)	0.91 (1.58)
Digit span	Forward	8.00 (-0.43)	7.00 (-0.84)	-1.00 (-0.41)	0.26 (0.66)

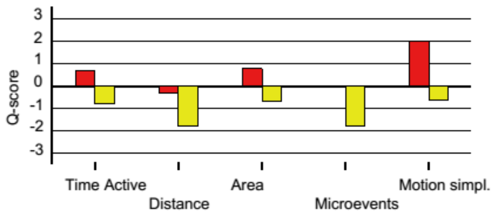
	Backward	5.00 (-1.16)	7.00 (-0.19)	2.00 (0.97)	0.73 (1.22)
Cancelation Task	Cancellation	11.00 (-1.35)	12.00 (-1.22)	1.00 (0.13)	0.45 (0.80)
Qb Activity	Distance Moved	-0.30 (0.79)	-1.80 (1.45)	1.50 (0.66)	0.32 (0.35)
	Area cover by Movements	0.80 (0.51)	-0.70 (1.38)	1.50 (0.87)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	2.70 (-1.31)	2.10 (-0.82)	0.60 (0.49)	0.78 (0.74)
	RT variability for CPT	0.20 (0.54)	1.30 (-0.56)	-1.10 (-1.10)	0.66 (1.00)
	RT for CPT	0.20 (0.23)	0.40 (0.04)	-0.20 (-0.19)	0.97 (0.95)
	Impulsivity Commission for CPT	3.30 (-1.84)	3.40 (-1.91)	-0.10 (-0.07)	0.25 (0.72)
Cantab	IED Errors	62.00 (-2.15)	68.00 (-2.44)	-6.00 (-0.30)	0.03 (0.35)
	IST Discrimination Errors	0.00 (1.01)	0.00 (1.01)	0.00 (0.00)	-0.51 (1.07)
	IST Box Opening Latency	1025.80 (-0.22)	587.12 (0.50)	438.68 (0.71)	0.74 (0.85)
	SST SSRT	186.28 (-0.24)	204.30 (-0.63)	-18.02 (-0.38)	1.02 (2.02)

Activity

QbActivity



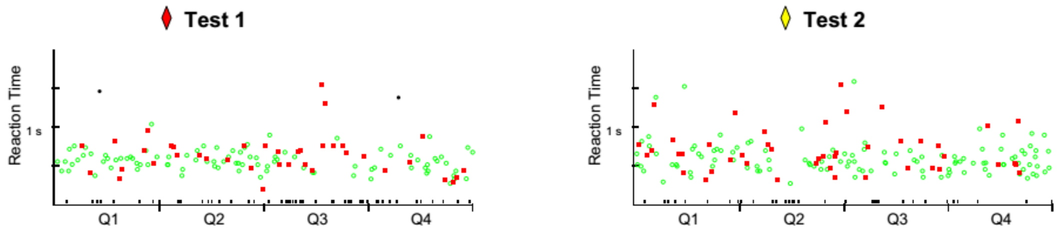
	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbActivity	0.0	-1.8	51	4



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Time Active:	7	1	0.7	-0.8	75	21
Distance:	3	2	-0.3	-1.8	38	3
Area:	13	4	0.8	-0.7	78	24
Microevents:	2	0	-0.0	-1.8	49	3
Motion simpl.:	51	26	2.0	-0.6	97	27

Attention & Impulse Control

	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbImpulsivity	3.6	3.4	99	99
QbInattention	1.0	1.2	83	89



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Omission Error:	40	24	2.7	2.1	99	98
ReactionTime Var.	137	184	0.2	1.3	58	90
Reaction Time:	561	579	0.2	0.4	58	66
with Outliers:	573	579	0.3	0.3	62	62
Normalised Var.:	24	32	-0.1	1.2	46	88
LongestPassivity:	4	6				

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
NormCommission:	15.3	12.5	3.5	3.4	99	99
Commission:	9.2	9.5	3.3	3.4	99	99
DprimeMod:	8.4	8.0	3.5	3.0	99	99

a42b075fbd08455bb545647664894e07
0.0 - 0.0 - 600 - 11.1/ 0.0 - 0.0 - 599 - 7.4

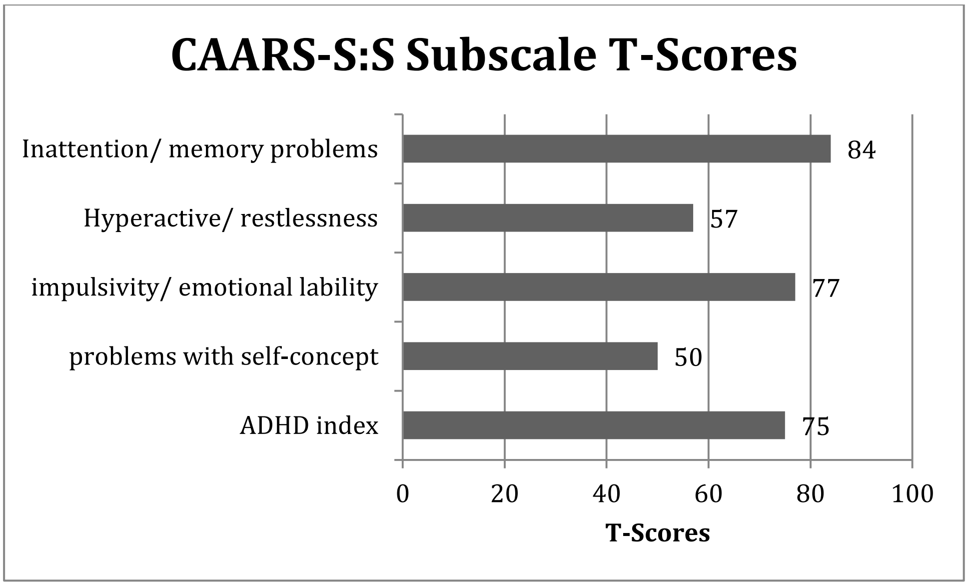
Figure 42. Qb rsults for 1087

11.3 Participant 1134

Gender	Female
Age	37
Diagnosis	Combined
Medication	Concerta XL (18 mg per day, only weekdays)
Weight	60.3 kg
Comorbid diagnosis	Dyslexia, dyspraxia, auditory processing disorder
Other issues	
Note	Both assessments were conducted on weekends, the participants was off her medication on the weekends. Reported that when completing tasks she often used movement or fidgeted as a way to maintain focus.

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
84.00	57.00	77.00	50.00	75.00

IQ estimate	121
Autism Spectrum Quotient	4



Participant 1134 had an above average IQ of 121. She had a disagnosis of ADHD Combined-Type for which she was medicated with 18mg per day (weekdays only) of Concerta XL. She took her medication for all training sessions but as both assessment sessions were at weekends she was not on medication for these. She had a number of comorbidities; dyslexia, dyspraxia, and auditory processing disorder. Her CAARS scores indicated a typical score for self-concept, a slightly elevated score for hyperactivity/restlessness, and markedly atypical scores for inattention/memory problems, impulsivity/emotional liability, and ADHD index.

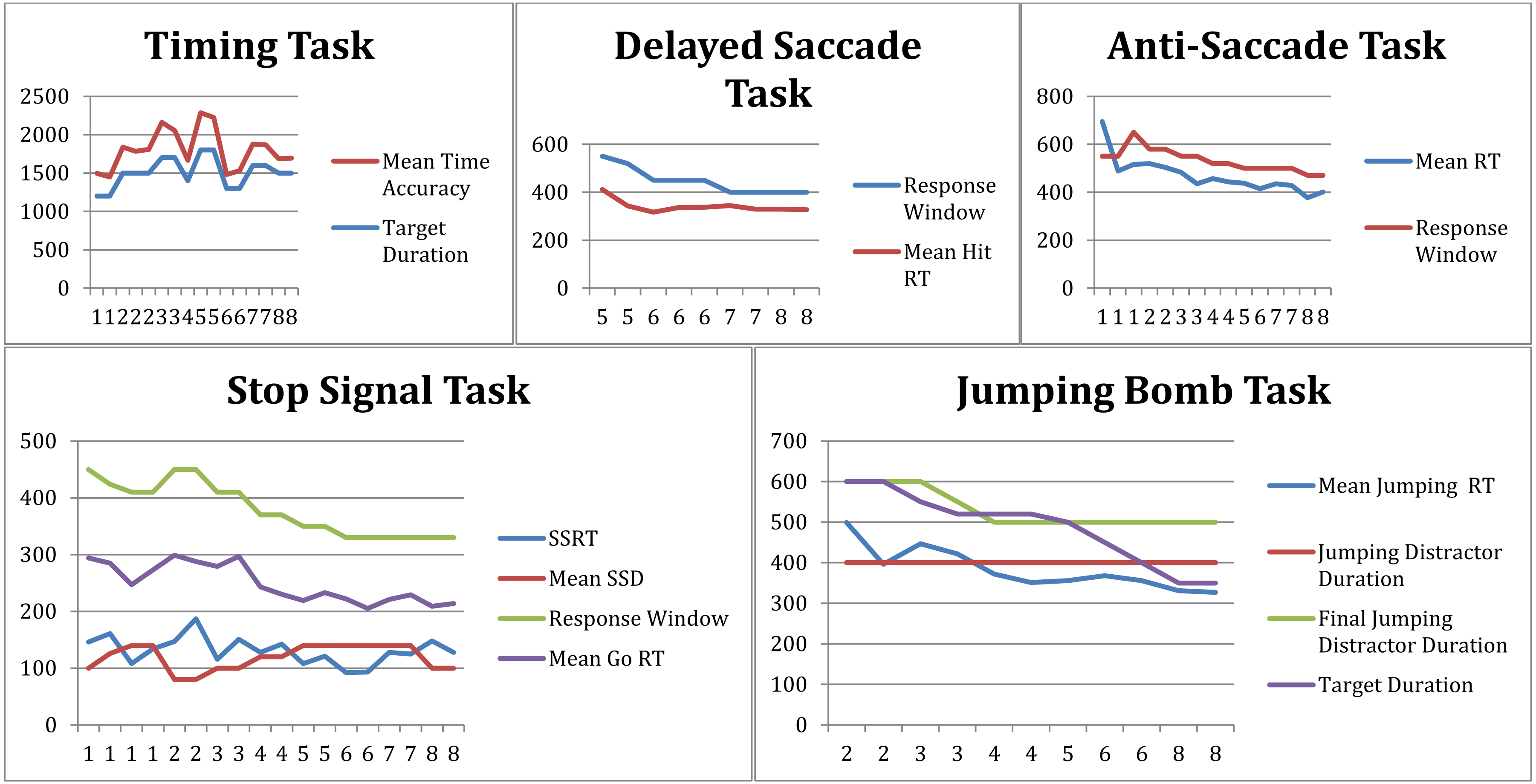


Figure 43. Trainng performance and difficult across the training sessions for participants 1134. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

Participant 1134 typically attended the training sessions straight after she had finished her work. She was typically provided with a small meal before starting each session. She was very motivated and consistently tried to beat her old scores, but did not get annoyed when she performed poorly. Initially she found that she was over stimulated by all the stimuli on the screen moving around and that it was distracting, but she reported that she got used to this in the early session. She liked having the game mechanics and technology explained to her. She felt that the order of the tasks affected their difficulty, e.g. she found that the timing task which requires waiting followed by the anti-saccade task which requires fast responses is a difficult combination.

For the timing task a target duration of 1500 ms was implemented in training session 2 and 8. The reduction in distance between the red and blue line in the timing task graph in figure 43 indicates greater temporal accuracy in the generation of saccades. The mean Hit RT reduced for the delayed saccade task early on in sessions 5 and 6 but did not improve for sessions 7 and 8. Consistent small improvements are seen for the anti-saccade task RT. While there is some improvement for the Go RTs in the first half of the training for the stop-signal task, the SSRT did not improve as a result of the training. A consistent improvement is seen in the jumping bomb task for the mean Jumping RT.

Participant 1134 was highly motivated. She welcomed feedback and sought to improve her performance on all tasks. Her improvements on the trained tasks are however mixed. While some improvements are seen in the timing, anti-saccade and jumping bomb task, no significant improvement was seen in the stop-signal task, and the improvements seen for the delayed saccades task are only seen for the early sessions. Participant 1134's dyspraxia may be an important confound as it may have hindered the learning of gaze control. She also reported that she found her work demanding, particularly during the period in which the training sessions were conducted. In addition she reported that the beneficial effects of her medication tended to wear off by the time the training session began. These factors may have limited the effectiveness of the training interventions.

Evaluation of pre and post assessment performance

Participant 1134 made large improvements on the timing task. Particularly for the short (1.53) and long (1.91) durations where her improvement far exceed the average group improvement (0.4 and 0.99). She made large gains to the proportion of correct response and mean RT for both the anti-saccade and delayed saccade tasks. For both tasks she made large reductions in her RT variability, much higher than the group average. Her prosaccade RT was similar at pre- and post-assessments. While some improvements are seen in the stop-signal task she maintained a poor success rate of just over 50% in assessment two. Her improvement for Go RTs minus Failed Inhibit RTs may reflect the large timing improvements seen.

For the standard assessment tasks we see large gains for both digit span tasks, the gains in the forward digit span (1.23) far exceed the average group improvement (0.26). Small gains are made for the cancellation task, moderate gains for both WRAT tasks, and large gains for the stoop task.

Participants 1134 made large improvement on the Qb test (see figure 44 before for her summary sheet). While only a moderate decrease in area covered and a small increase in the distance moved is seen, large gains are seen for the Qb inattention parameters. We see large improvements in the number of errors in the RT and RT variability. There is also a large reduction in the number of commission errors made. The improvement in all attention measures is above the average group improvements. The lack of improvement for the movement parameters likely reflect the participants strategy of moving / rocking as an aid to maintain focus. Small improvements are seen for the Cantab tasks.

Table 10 For participants 1134 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

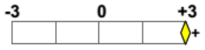
Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	23.00 (-0.77)	11.00 (0.76)	12.00 (1.53)	0.40 (0.65)
	Medium wait	12.00 (-0.09)	7.00 (0.84)	5.00 (0.93)	1.43 (0.68)
	Long wait	31.00 (-0.67)	10.00 (1.24)	21.00 (1.91)	0.86 (0.78)
Delayed Saccade	Mean RT	90.06 (0.86)	68.38 (1.79)	21.68 (0.92)	0.99 (0.79)
	Coefficient of Variation	0.40 (-0.62)	0.20 (1.30)	0.20 (1.92)	0.72 (1.13)
	Proportion Correct Reponses	0.79 (-0.06)	0.91 (0.66)	0.12 (0.72)	1.19 (1.11)
Anti-Saccade	Mean RT	332.92 (0.46)	292.62 (0.97)	40.30 (0.51)	0.80 (1.27)
	Coefficient of Variation	0.39 (-1.18)	0.24 (0.62)	0.15 (1.80)	0.68 (1.48)
	Proportion Correct Reponses	0.85 (-0.83)	0.98 (0.53)	0.13 (1.36)	0.64 (1.53)
Prosaccade	Prosaccade RT	428.00 (1.86)	452.00 (1.61)	-24.00 (-0.26)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.53 (-0.67)	0.55 (-0.43)	0.02 (0.24)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	173.46 (0.54)	193.00 (0.21)	-19.54 (-0.33)	0.99 (1.30)
	Predicted Final Stop-signal Delay	95.96 (-0.62)	111.37 (-0.38)	15.41 (0.24)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	-8.40 (-0.27)	46.00 (0.66)	54.40 (0.93)	0.91 (1.58)
Digit span	Forward	9.00 (-0.02)	12.00 (1.21)	3.00 (1.23)	0.26 (0.66)

	Backward	8.00 (0.30)	10.00 (1.27)	2.00 (0.97)	0.73 (1.22)
Cancelation Task	Cancellation	33.00 (1.49)	35.00 (1.75)	2.00 (0.26)	0.45 (0.80)
Stroop	Stroop	23.00 (-1.36)	31.00 (-0.43)	8.00 (0.93)	1.19 (1.40)
Qb Activity	Distance Moved	5.40 (-1.70)	5.50 (-1.74)	-0.10 (-0.04)	0.32 (0.35)
	Area cover by Movements	4.90 (-1.86)	4.10 (-1.40)	0.80 (0.46)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	0.90 (0.17)	-1.30 (1.98)	2.20 (1.81)	0.78 (0.74)
	RT variability for CPT	0.40 (0.34)	-0.90 (1.64)	1.30 (1.30)	0.66 (1.00)
	RT for CPT	0.40 (0.04)	-0.80 (1.21)	1.20 (1.17)	0.97 (0.95)
	Impulsivity Commission for CPT	2.90 (-1.56)	0.40 (0.16)	2.50 (1.73)	0.25 (0.72)
Cantab	SST SSRT	148.70 ()0.56	135.15 (0.84)	13.55 (0.29)	1.02 (2.02)

It is curious that participant 1134 improved on tasks for which improvements were expected but also for tasks for which we did not expect to see improvement. For example, improvements were seen for the forward digit span and for both WRAT tasks, which were unexpected. However the participant also did not improve on some tasks for which we would expect to see improvements such as the trained and manual stop-signal tasks. The gains made in addition to the timing improvement appear to relate to attention. Improvements are seen for RTs and RT variability for the anti-saccade, delayed saccade and Qb continuous performance task. For the QB test we also see improved commission and omission scores.

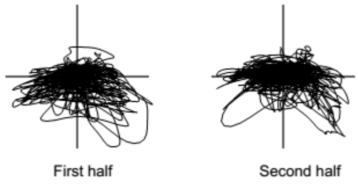
Activity

QbActivity

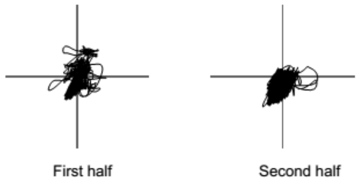


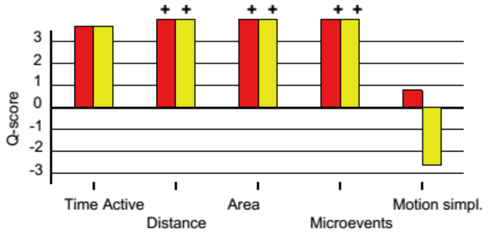
Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
4.8	4.8	99	99

Test 1



Test 2



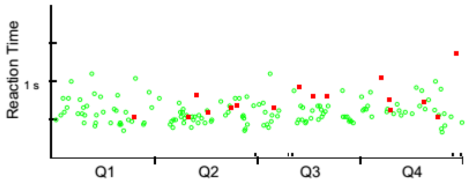


	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Time Active:	95	100	3.7	3.7	99	99
Distance:	120	124	5.4	5.5	99	99
Area:	251	136	4.9	4.1	99	99
Microevents:	34	38	6.0	> 6	99	99
Motion simpl.:	39	13	0.8	-2.6	78	1

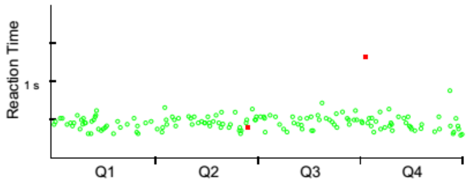
Attention & Impulse Control

	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
QbImpulsivity	2.9	0.4	99	66
QbInattention	0.8	-1.0	79	15

Test 1



Test 2



	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Omission Error:	6	0	0.9	-1.3	82	10
ReactionTime Var.	141	92	0.4	-0.9	66	18
Reaction Time:	592	470	0.4	-0.8	66	21
with Outliers:	592	470	0.4	-0.9	66	18
Normalised Var.:	24	20	0.1	-0.6	54	27
LongestPassivity:	2	0				

	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
NormCommission:	4.8	0.6	2.8	0.4	99	66
Commission:	4.5	0.6	2.9	0.4	99	66
DprimeMod:	6.8	3.2	1.9	-1.0	97	16

2765fa4d5f7c47aa8ecb580f616e7daa
0.1 - 0.0 - 600 - 14.3/ 0.0 - 0.0 - 600 - 0.0

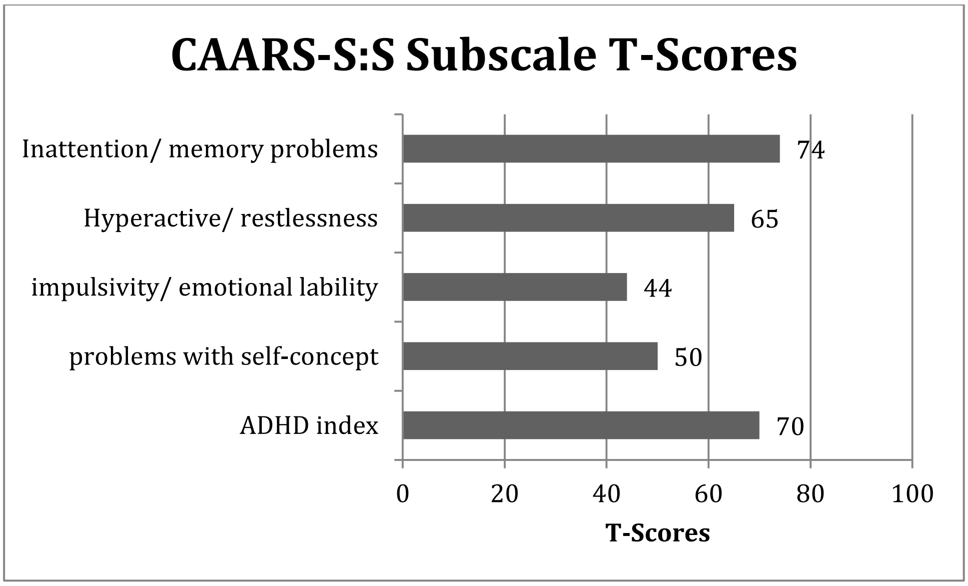
Figure 44. Qb results for participant 1134

11.4 Participant 1358

Gender	Female
Age	20
Diagnosis	Combined
Medication	Methylphenidate
Weight	53.3
Comorbid diagnosis	Dyslexia, dyspraxia, dyscalculia
Other issues	N/A
Note	Assessments completed on weekdays while participants was taking her medication

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
74.00	65.00	44.00	50.00	70.00

IQ estimate	123
Autism Spectrum Quotient	4



Participant 1358 had a high IQ score of 123. She had a diagnosis of combined ADHD for which she was medicated 16 mg of Equasym (sustained-release methylphenidate) per day on weekdays. All training and assessment sessions occurred on weekdays. She had comorbid dyslexia, dyspraxia, and dyscalculia. Her CAARS scores revealed a typical score for impulsivity and emotional lability, and for problems with self-concept. She had a moderate atypical score for hyperactive / restlessness, and a markedly atypical score for inattention / memory problems, and ADHD index.

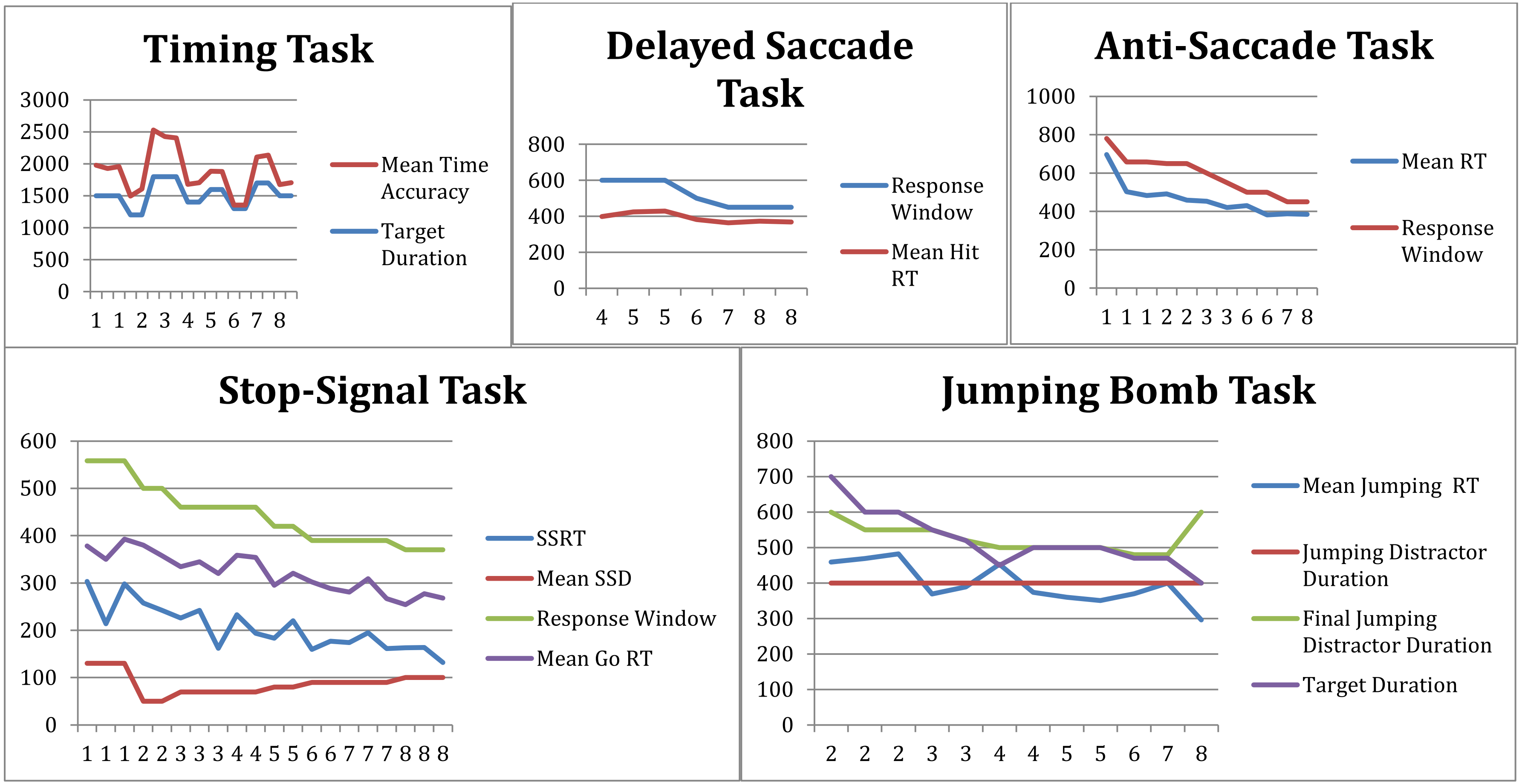


Figure 45. Trainng performance and difficult across the training sessions for participants 1358. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

Participant 1358 was motivated but very uncompetitive. She began the training with a high level of competency on many of the training tasks. She was very good at the anti-saccade, jumping bomb, and fixation tasks. She performed quite poorly at the timing task initially but after a few sessions developed a tactic for enhancing her performance and improved dramatically. In the last training session she was tired as he was up late the night before drinking red bull in order to finish her final year undergrad thesis.

She made dramatic improvement to her timing accuracy in sessions 4 and 5. This appears to be the result of the adoption of a new strategy. Different potential strategies had been discussed with the participant during the sessions, these included (i) counting numbers as a means of estimating duration, (ii) playing a short tune in her head, or (iii) waiting as long as possible until it felt that waiting any longer would lead to a late response. She reported using the latter strategy improved her performance. A very small improvement was seen for the delay saccade task. Large and consistent improvements were seen for the anti-saccade task. Large and consistent improvements were also seen for the stop-signal task; for the SSRT and mean Go RT. Improvements were seen for the jumping bomb task Mean RT. For participant 1358 various changes were made to the final jumping distractor duration parameters that were not made for other participants. This was exploratory to gauge the effect it would have on participants' performance.

Participants 1358 was highly motivated and engaged fully with the training. She was very responsive to feedback and did not become frustrated or fatigued during the training. Apart from the delayed saccade task she responded well to the training intervention and showed improvement across the range of tasks. These improvements were seen despite the relatively high level of performance she demonstrated early on in the training. While improvement were seen for the timing task it is felt that additionally training with a specific focus on timing would have been beneficial for participant 1358.

Evaluation of pre and post assessment performance

Participant 1358 improved by an amount similar to that of the average group improvement for the short and medium time intervals. A small decrease in performance was seen for the long duration timing accuracy. Better than group average (0.64 and 1.19) increases in the proportion of correct responses was made for both the anti-saccade (0.83) and the delayed saccade task (2.88). These performance improvements were combined with faster RTs for both tasks. Additionally, for the anti-saccade task a large reduction (1.56) was seen for the variability of the anti-saccade RTs. A moderate improvement was seen for the prosaccade task. Large improvements, slightly better than the average group improvements (0.93, 0.99, and 1.07) were seen for the success rate (1.19), the SSRT (1.12) and Predicted Final Stop-signal Delay (1.34). No change was seen for the Go RTs minus Failed Inhibit RTs. The lack of change for this parameter may relate to the difficulties she experienced with respect to timing.

We see a two digit improvement for the forward and a three digit decrease for the backward digit span task. No change is seen for the cancellation task, a slight improvement is seen for the Stroop task, and little change is seen for the WRAT task. In the Towre task a moderate increase is seen for the words and a slight decrease for the non-words.

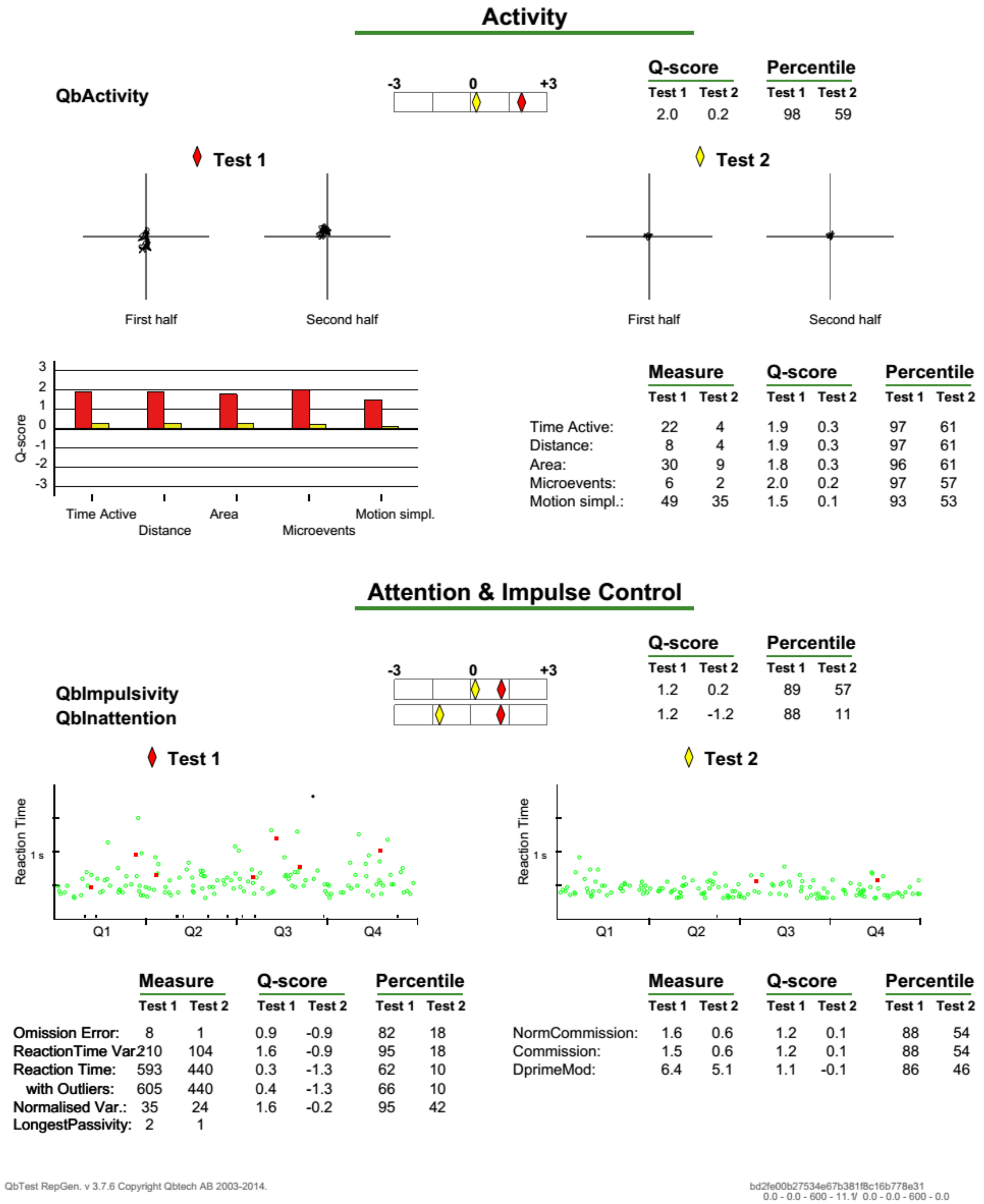
For the Qb test we see a decrease in the distance moved (0.7) and the area covered by these movements (0.87) above that of the group average (0.32 and 0.51). Large gains were made to all attention and impulsivity measures. While completing the continuous performance task at the post-training assessment her RT became faster, less variable, but she also made less errors and less commission errors. These trends can be seen in figure 46 below. Little change was seen for the Cantab tasks with the exception of the number of discrimination errors for the IST task.

Table 11 For participants 1358 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	18.00 (-0.13)	14.00 (0.38)	4.00 (0.51)	0.40 (0.65)
	Medium wait	18.00 (-1.22)	9.00 (0.47)	9.00 (1.68)	1.43 (0.68)
	Long wait	31.00 (-0.67)	33.00 (-0.85)	-2.00 (-0.18)	0.86 (0.78)
Delayed Saccade	Mean RT	103.19 (0.31)	80.70 (1.26)	22.49 (0.96)	0.99 (0.79)
	Coefficient of Variation	0.28 (0.53)	0.28 (0.53)	0 (0)	0.72 (1.13)
	Proportion Correct Reponses	0.46 (-2.03)	0.94 (0.84)	0.48 (2.88)	1.19 (1.11)
Anti-Saccade	Mean RT	348.96 (0.25)	257.30 (1.41)	91.66 (1.16)	0.80 (1.27)
	Coefficient of Variation	0.34 (-0.58)	0.21 (0.98)	0.13 (1.56)	0.68 (1.48)
	Proportion Correct Reponses	0.92 (-0.10)	1.00 (0.74)	0.08 (0.83)	0.64 (1.53)
Prosaccade	Prosaccade RT	688.00 (-0.91)	624.00 (-0.22)	64.00 (0.68)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.58 (-0.08)	0.68 (1.11)	0.10 (1.19)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	179.43 (0.44)	112.36 (1.56)	67.07 (1.12)	0.99 (1.30)
	Predicted Final Stop-signal Delay	127.77 (-0.13)	215.31 (1.21)	87.54 (1.34)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	23.94 (0.28)	22.93 (0.26)	-1.01 (-0.02)	0.91 (1.58)
Digit span	Forward	6.00 (-1.25)	8.00 (-0.43)	2.00 (0.82)	0.26 (0.66)
	Backward	9.00 (0.78)	6.00 (-0.67)	-3.00 (-1.45)	0.73 (1.22)

Cancelation Task	Cancellation	33.00 (1.49)	33.00 (1.49)	0.00 (0.00)	0.45 (0.80)
Stroop	Stroop	30.00 (-0.55)	32.00 (-0.31)	2.00 (0.23)	1.19 (1.40)
Towre	Words	85.00 (-0.59)	96.00 (0.05)	11.00 (0.64)	0.39 (0.33)
	Non-Words	57.00 (-0.20)	56.00 (-0.27)	-1.00 (-0.07)	0.03 (0.26)
Qb Activity	Distance Moved	1.90 (-0.17)	0.30 (0.53)	1.60 (0.70)	0.32 (0.35)
	Area cover by Movements	1.80 (-0.07)	0.30 (0.80)	1.50 (0.87)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	0.90 (0.17)	-0.90 (1.65)	1.80 (1.48)	0.78 (0.74)
	RT variability for CPT	1.60 (-0.86)	-0.90 (1.64)	2.50 (2.50)	0.66 (1.00)
	RT for CPT	0.30 (0.14)	-1.30 (1.69)	1.60 (1.56)	0.97 (0.95)
	Impulsivity Commission for CPT	1.20 (-0.39)	0.10 (0.37)	1.10 (0.76)	0.25 (0.72)
Cantab	SST SSRT	171.15 (0.08)	179.82 (-0.11)	-8.67 (-0.18)	1.02 (2.02)

The improvements seen for participant 1358 largely related to attention and inhibitory control, with moderate improvements for timing. We see large improvements for all trained tasks, except for timing for which no improvements are seen for the long duration. For the standard assessment tasks the strongest improvements are seen for the Qb tests, both in the reduction in movement, the RT and RT variability, but also a reduction in the amount of errors made.


Activity

QbActivity

	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbActivity	2.0	0.2	98	59

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Time Active:	22	4	1.9	0.3	97	61
Distance:	8	4	1.9	0.3	97	61
Area:	30	9	1.8	0.3	96	61
Microevents:	6	2	2.0	0.2	97	57
Motion simpl.:	49	35	1.5	0.1	93	53

Attention & Impulse Control

	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbImpulsivity	1.2	0.2	89	57
QbInattention	1.2	-1.2	88	11

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Omission Error:	8	1	0.9	-0.9	82	18
ReactionTime Var:	210	104	1.6	-0.9	95	18
Reaction Time:	593	440	0.3	-1.3	62	10
with Outliers:	605	440	0.4	-1.3	66	10
Normalised Var.:	35	24	1.6	-0.2	95	42
LongestPassivity:	2	1				

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
NormCommission:	1.6	0.6	1.2	0.1	88	54
Commission:	1.5	0.6	1.2	0.1	88	54
DprimeMod:	6.4	5.1	1.1	-0.1	86	46

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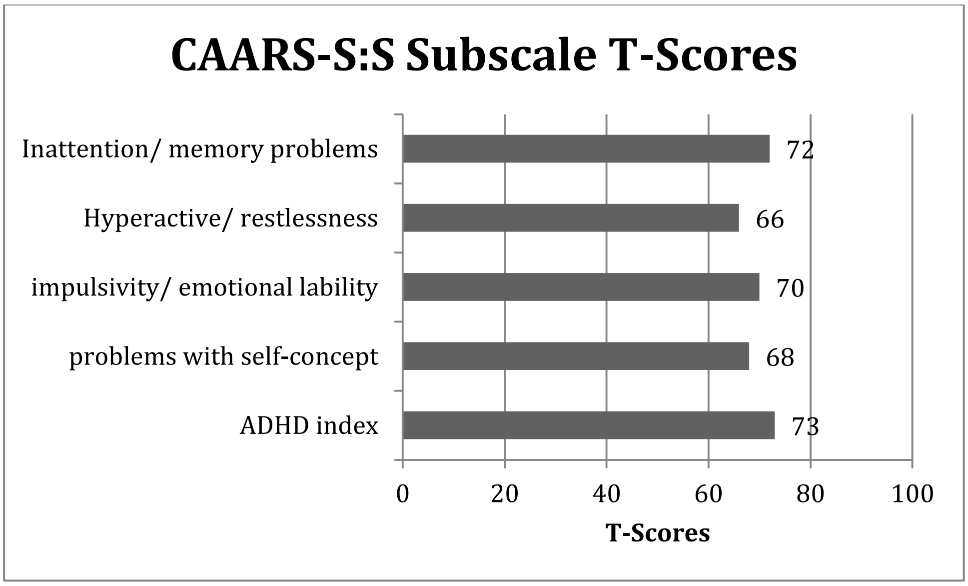
Figure 46. QB results for 1358

11.5 Participant 1434

Gender	Male
Age	16
Diagnosis	Combined
Medication	Not on medication
Weight	N/A
Comorbid diagnosis	No
Other issues	Some anxiety and sleep problems but not serious
Note	Very Eager, tried hard

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
72.00	66.00	70.00	68.00	73.00

IQ estimate	112
Autism Spectrum Quotient	6



Participant 1434 was the youngest participant (16 years old). He had a diagnosis of combined ADHD but was not on medication. He had an IQ of 112 and a Austism Spectrum Quotient just below the 7 point cut off that suggests an assessment be sought. He had no comorbidities but reported some low level sleep and anxiety issues. On the CAARS he scored moderately atypical for hyperactivtiy / restlessness, impilsivity / emotional lability, and problems with self-concept, and markedly atypical for inattention / memory problems and ADHD index.

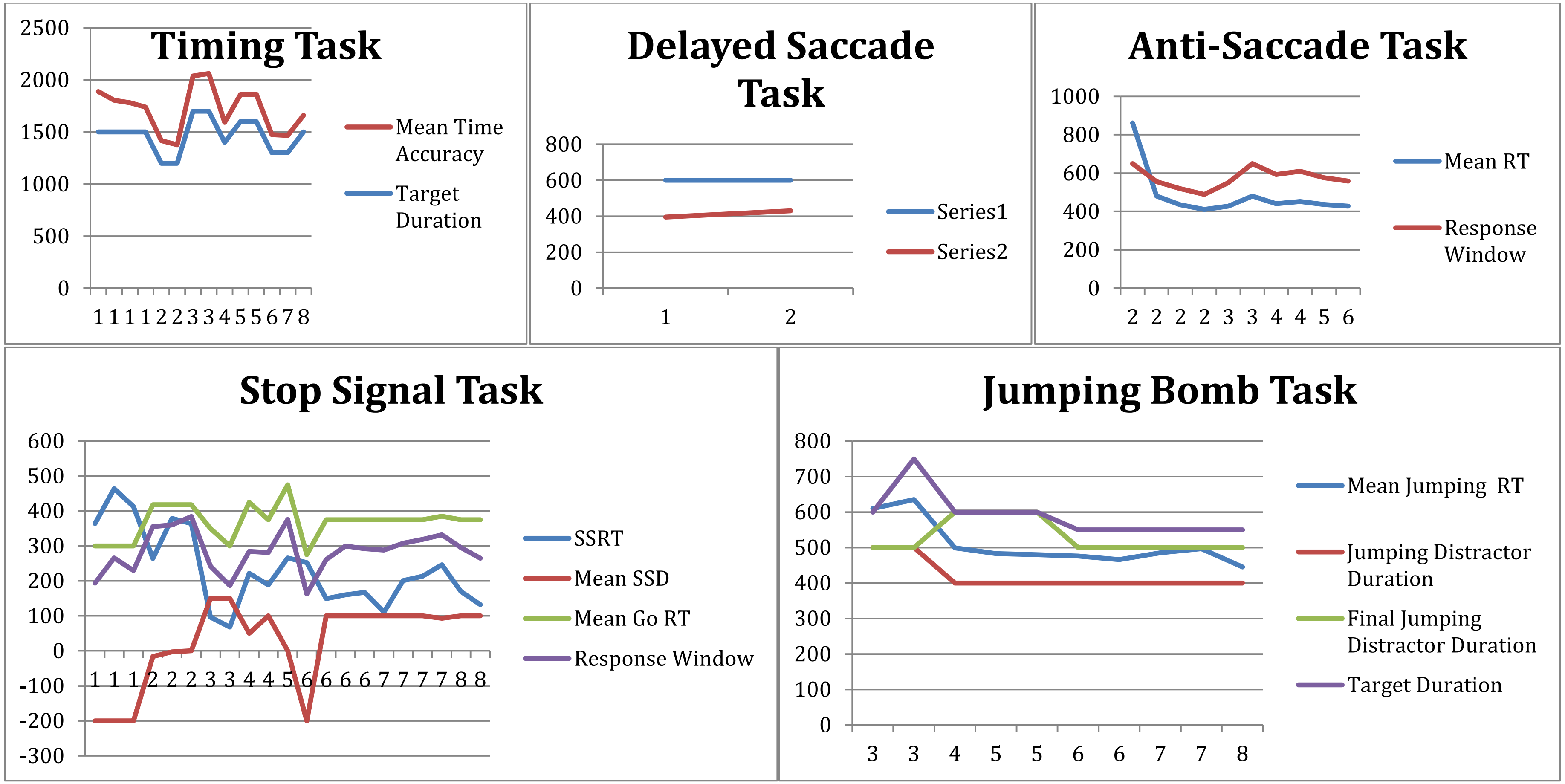


Figure 47. Trainng performance and difficult across the training sessions for participants 1434. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

He was a highly motivated and competitive participant. His engagement with the tasks increased greatly when performance targets were set for him, or when he was attempting to beat his old score on a task. He disliked performing poorly and tended to dislike tasks on which he performed poorly. However he said he liked these tasks as his performance improved. It was found that giving him the same task back to back was an effective strategy for motivating him as he was eager to beat the score he had just achieved. He liked the forward timing task and I typically gave him this task at the start of the session as it appeared to settle him. He was quite reflective on his performance and the tasks, for example he stated "delayed onset task requires vigilance" and he drew parallels between some of the tasks and the starting gun for the 100 meters sprint. Related to his competitiveness he had some minor issues around becoming frustrated with a poor performance. Being as competitive as he was he thought "Sometimes when I get a few wrong I'm like 'forget this'" and he wanted to stop the current block and start a new block. However he reported this was less of an issue over the course of the training. He also described his experience of his inattention, "sometimes I zone out and just stare at the centre for a few bombs".

He made large improvements in the timing task. Too few delayed saccade task blocks were delivered during training to see improvements. He made early gains on the anti-saccade and jumping bomb task but not in the later training sessions. For the stop-signal task the performance did improve across trials but was highly variable as can be seen for the SSRT in figure 47.

Evaluation of pre- and post-assessment performance

Performance on the timing tasks for the short and long intervals was good at the initial assessment, particularly for the short interval. The lack of improvement for the short duration likely reflects a ceiling effect, however improvements were made for the medium and long interval blocks. A moderate improvement was seen for delayed saccade task RT and the proportion of correct trials, and a small increase was seen for RT variability. A ceiling effect was seen for the anti-saccade performance, but a slower RT and small increase in RT variability were seen for assessment two. A moderatly slower prosaccade RT was seen in assessment two. For the stop-signal task he increased his success rate and the predicted stop-signal delay, but contrary to the average group change on the SSRT he produced a worse SSRT performance and Go RTs minus Failed Inhibit RTs on assessment two compared to assessement one.

For the standard assessment task a two digit increase was seen for the forward digit span, and no change for the backward digit span. The cancellation and stoop tasks were not completed at assessment one. A slight and moderate decrease in performance was observed for the WRAT reading and arithmetic respectively. A small improvement was seen for the Towre words and a small decrease in performance was seen for the non-words.

Table 12 For participants 1434 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	6.00 (1.39)	7.00 (1.27)	-1.00 (-0.13)	0.40 (0.65)
	Medium wait	13.00 (-0.28)	7.00 (0.84)	6.00 (1.12)	1.43 (0.68)
	Long wait	17.00 (0.60)	6.00 (1.60)	11.00 (1.00)	0.86 (0.78)
Delayed Saccade	Mean RT	136.65 (-1.12)	120.20 (-0.42)	16.45 (0.70)	0.99 (0.79)
	Coefficient of Variation	0.25 (0.82)	0.29 (0.43)	-0.04 (-0.38)	0.72 (1.13)
	Proportion Correct Reponses	0.88 (0.48)	0.98 (1.08)	0.10 (0.60)	1.19 (1.11)
Anti-Saccade	Mean RT	400.56 (-0.40)	475.09 (-1.34)	-74.53 (-0.94)	0.80 (1.27)
	Coefficient of Variation	0.27 (0.26)	0.29 (0.02)	-0.02 (-0.24)	0.68 (1.48)
	Proportion Correct Reponses	0.97 (0.42)	0.97 (0.42)	0.00 (0.00)	0.64 (1.53)
Prosaccade	Prosaccade RT	728.00 (-1.33)	800.00 (-2.10)	-72.00 (-0.77)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.66 (0.87)	0.73 (1.70)	0.07 (0.83)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	187.00 (0.31)	252.00 (-0.77)	-65.00 (-1.09)	0.99 (1.30)
	Predicted Final Stop-signal Delay	180.95 (0.68)	234.20 (1.49)	53.25 (0.81)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	25.14 (0.30)	-5.96 (-0.23)	-31.10 (-0.53)	0.91 (1.58)
Digit span	Forward	8.00 (-0.43)	10.00 (0.39)	2.00 (0.82)	0.26 (0.66)
	Backward	8.00 (0.30)	8.00 (0.30)	0.00 (0.00)	0.73 (1.22)
Cancelation Task	Cancellation		18.00 (-0.45)		0.45 (0.80)

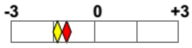
Stroop	Stroop		32.00 (-0.31)		1.19 (1.40)
Towre	Words	80.00 (-0.89)	84.00 (-0.65)	4.00 (0.23)	0.39 (0.33)
	Non-Words	50.00 (-0.72)	46.00 (-1.01)	-4.00 (-0.30)	0.03 (0.26)
Qb Activity	Distance Moved	-1.10 (1.14)	-2.00 (1.53)	0.90 (0.39)	0.32 (0.35)
	Area cover by Movements	-0.30 (1.15)	-1.20 (1.67)	0.90 (0.52)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	0.80 (0.25)	-0.40 (1.24)	1.20 (0.99)	0.78 (0.74)
	RT variability for CPT	0.90 (-0.16)	0.20 (0.54)	0.70 (0.70)	0.66 (1.00)
	RT for CPT	2.80 (-2.30)	0.00 (0.43)	2.80 (2.73)	0.97 (0.95)
	Impulsivity Commission for CPT	-0.10 (0.51)	-0.50 (0.78)	0.40 (0.28)	0.25 (0.72)
Cantab	SST SSRT	275.88 (-2.15)			1.02 (2.02)

For the Qb test participant 1434 did not move much during the continuous performance task. For distance moved his z-score compared to the normative sample at assessment one was z =-1.1 and for assessment two he moved less, z = -2. A similar reduction was seen for the area covered by the movements and was again low compared to the normative sample. For the attention and impulsivity parameters his improvements are greater than the group average. His particularly slow RT at assessment one (2.8, -2.3) may reflect an overtly cautious strategy, however both his performance and RT improved for assessment two.

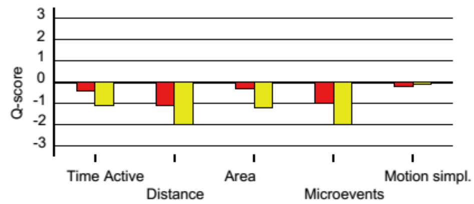
A moderate improvement was seen for the Cantab IED errors. For the IST task a faster box opening latency and an increase in the discrimination errors suggests a performance speed trade-off. The Cantab stop-signal task was not completed due to equipment failure.

Activity

QbActivity



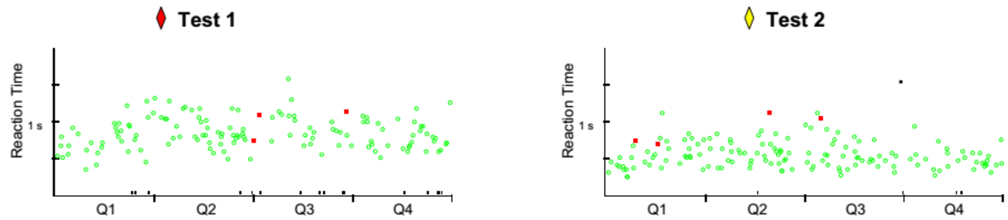
Q-score		Percentile	
Test 1	Test 2	Test 1	Test 2
-1.0	-1.4	15	9



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Time Active:	3	1	-0.4	-1.1	34	13
Distance:	3	2	-1.1	-2.0	13	2
Area:	9	4	-0.3	-1.2	38	11
Microevents:	1	1	-1.0	-2.0	15	2
Motion simpl.:	34	35	-0.2	-0.1	42	46

Attention & Impulse Control

	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbImpulsivity	-0.6	-0.5	29	32
QbInattention	2.1	0.1	98	52



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Omission Error:	12	4	0.8	-0.4	79	34
ReactionTime Var.:	203	169	0.9	0.2	82	58
Reaction Time:	866	552	2.8	0.0	99	50
with Outliers:	866	561	2.8	0.1	99	54
Normalised Var.:	23	31	-1.0	0.3	16	62
LongestPassivity:	2	1				

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
NormCommission:	1.0	0.6	-0.1	-0.6	46	27
Commission:	0.9	0.6	-0.1	-0.5	46	31
DprimeMod:	6.4	5.7	0.4	-0.2	66	42

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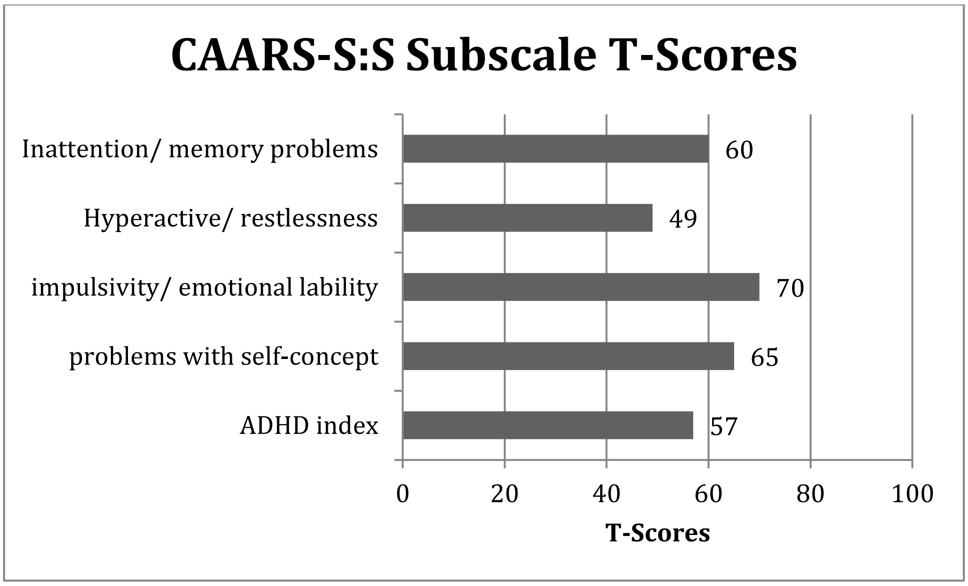
0.0 - 0.0 - 600 - 0.0 / 0.0 - 0.0 - 600 - 25.0

Figure 48. Qb results for 1434

11.6 Participant 1523

Gender	Male
Age	20
Diagnosis	Combined
Medication	Methylphenidate (10mg in the morning and 5mg in the evening)
Weight	73 kg
Comorbid diagnosis	No
Other issues	No
Note	

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
60.00	49.00	70.00	65.00	57.00
IQ estimate	136			
Autism Spectrum Quotient	5			



Participant 1532 had a particularly high IQ score of 136. He had recently received a diagnosis of ADHD Combined-Type for which he was prescribed methylphenidate, 10 mg in the morning and 5 mg in the evening. He was on medication for the duration of all training sessions but not for the pre- and post- assessments. His CAARS scores were typical for hyperactivity / restlessness, slightly elevated for inattention / memory problems, problems with self-confidence, and ADHD index, and markedly atypical for impulsivity / emotional lability.

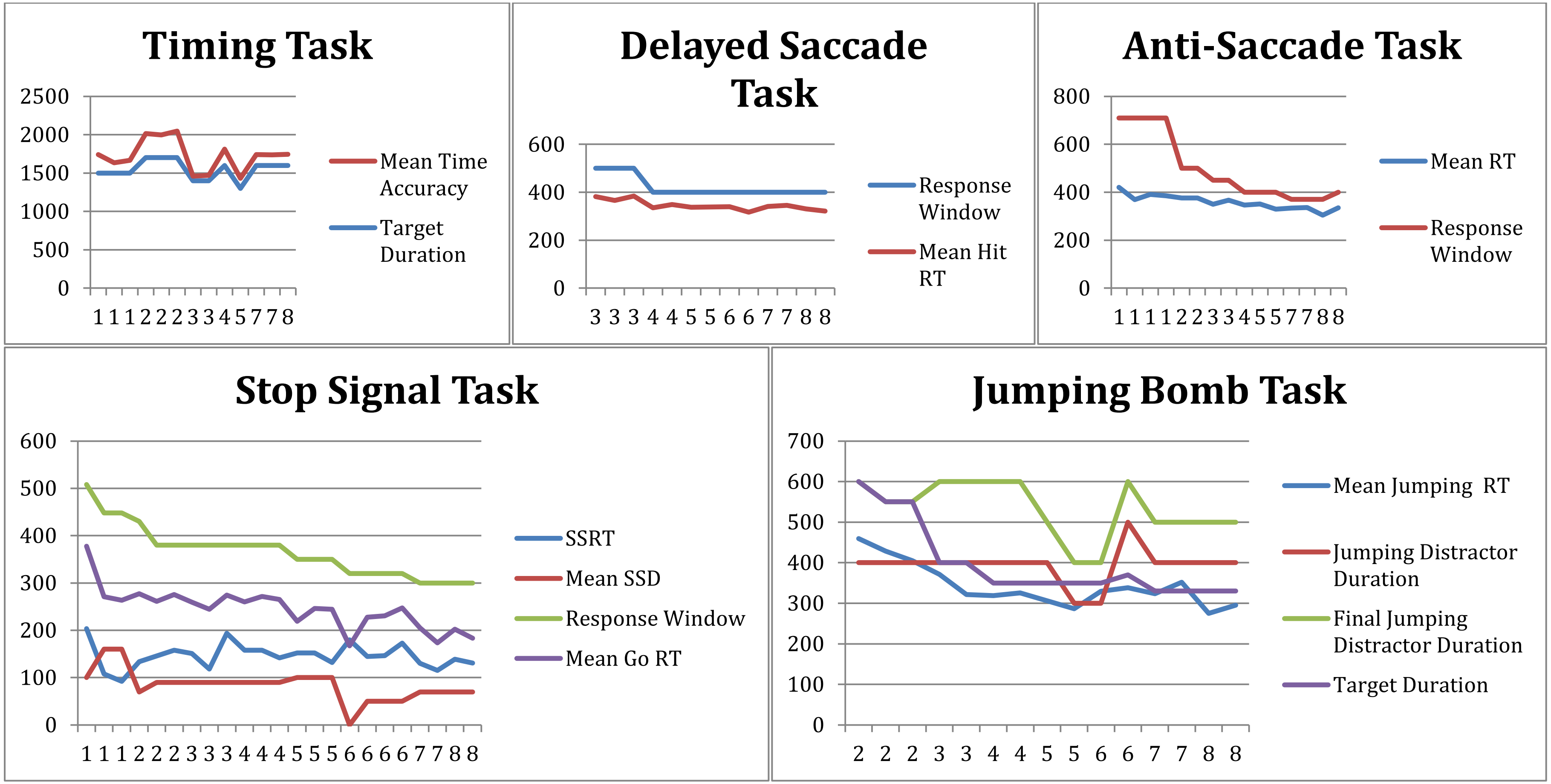


Figure 49 Trainng performance and difficult across the training sessions for participants 1523. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

Participant 1523 was an extremely high performer. He did very well on the initially assessment task and thus ceiling effects for performance may be an issue. He was highly motivated and eager to improve and to beat his old scores. He reported that he did find the tasks mentally demanding and that they also placed a strain on his visual focus. He was reflective with regard to his performance and took an interest in the game mechanics. He made many remarks on the task, for example, noting that the increasingly difficult time constraints on the anti-saccade task made him more likely to look at the distractor. He felt that the delayed saccade task was the most difficult; however he performed well on all training tasks. He reported liking the game sounds and found them useful for achieving a good performance. He also reported that focusing on the spatial accuracy of his saccade helped to improve his performance.

No gains were made for the timing task as performance was high from the initial training session. Improvements were seen for the mean RT for the anti-saccade task and the delayed saccade task. Early gains were made in the jumping bomb task mean RT. For the stop-signal task faster RTs are seen for Go RTs but not for the SSRT which remained relatively stable throughout.

Overall participant 1523 was highly motivated but performance gains during training were likely muted due to his high level of proficiency at the start of the training.

Evaluation of pre- and post-assessment performance

Participant 1523 performed well during assessment one and two. His better than average performance at assessment one reduced the degree of improvement possible at assessment two. While his performance on the timing task was good at the initial assessment a number of the other participants who did worse in the timing task at the initial assessment outperformed him at assessment two. The size of his improvements, while positive for the medium and long duration, are small, below that of the group average. We see greater gains for the other eye-tracking tasks. In the delayed saccade and anti-saccade task the proportion of correct responses was high at the initial assessment and we see a small reduction for the delay saccade task. However, we see large reductions in the mean RT and RT variability for both tasks. In the stop-signal task a similar success rate is seen across assessments but a faster SSRT and Go minus failed inhibit RT are seen. There is also a longer predicted SSD, an indicator of improved performance.

For the standard assessment task as small improvement for the forward digit span (0.41) and a large improvement for the backward digit span (2.42) are seen above the group average (0.26 and 0.73). Improvements are also seen for the cancellation and stroop tasks. A slight increase is seen for the Towre word and slight decrease for the non-word tasks.

For the Qb test we see a small increase in the distance moved and no change to the area covered by movements. Small improvements are seen for the three Qb attention parameters and no change for the impulsivity parameter. Similar to other participants there is an increase in the number of errors and speed at which boxes are open in the Cantab IST task. For the Cantab manual stop-signal task we see a medium sized improvement of 0.45, less than the group mean improvement of 1.02.

Table 13 For participants 1523 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

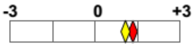
Task	Parameter	Assessment 1 (Z score)	Assessment 2 (Z score)	Improvement (Z score)	Group mean Improvement Z Score (SD)
Timing	Short wait	12.00 (0.63)	12.00 (0.63)	0.00 (0.00)	0.40 (0.65)
	Medium wait	10.00 (0.28)	5.00 (1.22)	5.00 (0.93)	1.43 (0.68)
	Long wait	17.00 (0.60)	14.00 (0.87)	3.00 (0.27)	0.86 (0.78)
Delayed Saccade	Mean RT	136.97 (-1.13)	86.97 (1.00)	50.00 (2.12)	0.99 (0.79)
	Coefficient of Variation	42.39 (-0.34)	32.70 (0.33)	9.69 (0.67)	1.02 (0.78)
	Proportion Correct Reponses	0.96 (0.96)	0.9 (0.6)	-0.06 (-0.36)	0.72 (1.13)
Anti-Saccade	Mean RT	351.44 (0.22)	246.81 (1.55)	104.63 (1.32)	0.80 (1.27)
	Coefficient of Variation	0.31 (-0.22)	0.16 (1.59)	0.15 (1.80)	0.68 (1.48)
	Proportion Correct Reponses	0.98 (0.53)	0.97 (0.42)	-0.01 (-0.10)	0.64 (1.53)
Prosaccade	Prosaccade RT	608.00 (-0.05)	576.00 (0.29)	32.00 (0.34)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.67 (0.99)	0.65 (0.75)	-0.02 (-0.24)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	196.60 (0.15)	114.00 (1.53)	82.60 (1.38)	0.99 (1.30)
	Predicted Final Stop-signal Delay	164.50 (0.43)	253.37 (1.79)	88.87 (1.36)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	-16.88 (-0.42)	16.33 (0.15)	33.21 (0.57)	0.91 (1.58)
Digit span	Forward	13.00 (1.62)	14.00 (2.03)	1.00 (0.41)	0.26 (0.66)
	Backward	7.00 (-0.19)	12.00 (2.24)	5.00 (2.42)	0.73 (1.22)

Cancelation Task	Cancellation	14.00 (-0.96)	16.00 (-0.71)	2.00 (0.26)	0.45 (0.80)
Stroop	Stroop	40.00 (0.61)	49.00 (1.66)	9.00 (1.04)	1.19 (1.40)
Towre	Words	118.00 (1.33)	125.00 (1.73)	7.00 (0.41)	0.39 (0.33)
	Non-Words	80.00 (1.50)	78.00 (1.35)	-2.00 (-0.15)	0.03 (0.26)
Qb Activity	Distance Moved	1.20 (0.14)	1.50 (0.00)	-0.30 (-0.13)	0.32 (0.35)
	Area cover by Movements	1.70 (-0.01)	1.70 (-0.01)	0.00 (0.00)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	0.50 (0.50)	0.20 (0.74)	0.30 (0.25)	0.78 (0.74)
	RT variability for CPT	-0.40 (1.14)	-0.80 (1.54)	0.40 (0.40)	0.66 (1.00)
	RT for CPT	-0.30 (0.72)	-0.40 (0.82)	0.10 (0.10)	0.97 (0.95)
	Impulsivity Commission for CPT	-0.70 ()0.92	-0.70 (0.92)	0.00 (0.00)	0.25 (0.72)
Cantab	SST SSRT	130.95 (0.93)	109.78 (1.38)	21.17 (0.45)	1.02 (2.02)

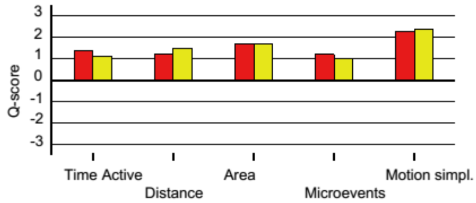
Overall, participant 1523 did demonstrate improvement in the trained saccade tasks as well as the standard assessment tasks. The sizes of the improvements were slightly smaller than the group mean improvements and this in part reflects the high performance at the initial assessment. Added to this, participant 1523, based on his CAARS scores the severity of his ADHD symptoms may not be as severe as those of a number of the other participants and it is a possibility that there were fewer gains to be made as a result.

Activity

QbActivity



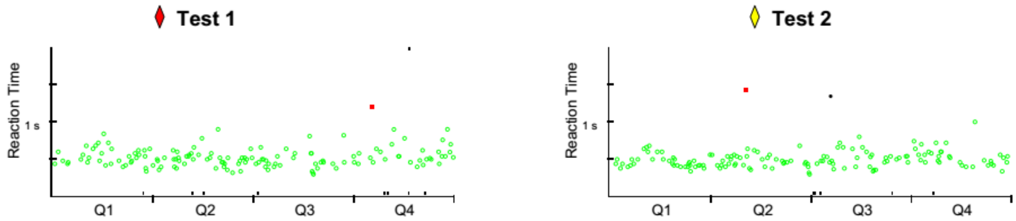
Q-score		Percentile	
Test 1	Test 2	Test 1	Test 2
1.3	1.1	91	86



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Time Active:	16	12	1.4	1.1	91	86
Distance:	6	7	1.2	1.5	88	93
Area:	31	32	1.7	1.7	95	95
Microevents:	4	4	1.2	1.0	88	84
Motion simpl.:	57	58	2.3	2.4	99	99

Attention & Impulse Control

	Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2
QbImpulsivity	-0.6	-0.6	28	27
QbInattention	0.1	-0.1	53	46



	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Omission Error:	6	4	0.5	0.2	69	58
ReactionTime Var.:	123	110	-0.4	-0.8	34	21
Reaction Time:	518	506	-0.3	-0.4	38	34
with Outliers:	518	514	-0.3	-0.4	38	34
Normalised Var.:	24	22	-0.4	-0.7	34	24
LongestPassivity:	1	2				

	Measure		Q-score		Percentile	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
NormCommission:	0.3	0.3	-0.7	-0.7	24	24
Commission:	0.3	0.3	-0.7	-0.7	24	24
DprimeMod:	5.7	5.5	0.2	0.0	58	50

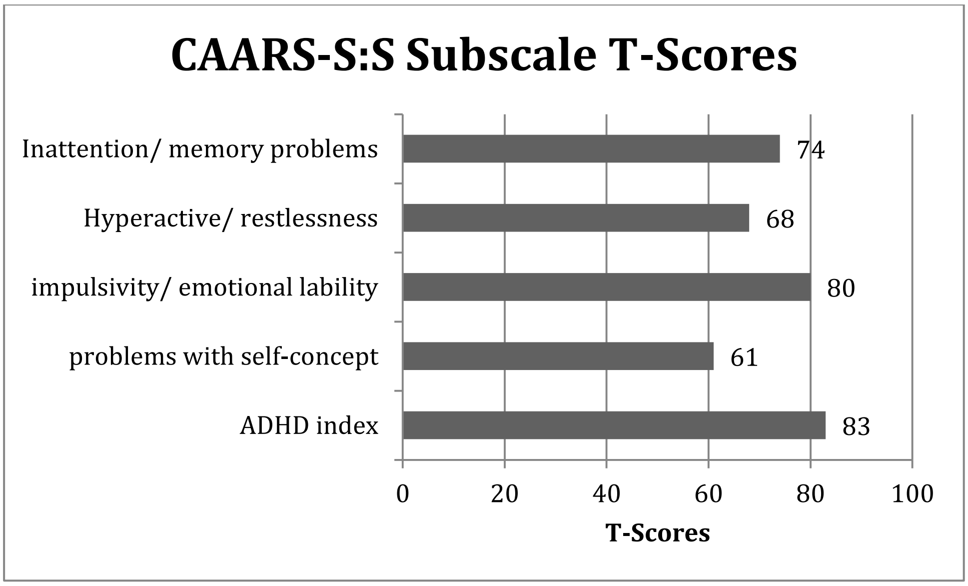
7c1c63c1348e40faada835c63e884b83
0.0 - 0.0 - 600 - 0.0 / 0.0 - 0.0 - 599 - 0.0

Figure 50. Qb result for 1523

11.7 Participant 1633

Gender	Female
Age	28
Diagnosis	No diagnosis
Medication	No
Weight	N/A
Comorbid diagnosis	No
Other issues	Sensory processing problem, some anxiety and depression but not serious
Note	Pregnant at the time of participation

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
74.00	68.00	80.00	61.00	83.00
IQ estimate	123		Autism Spectrum Quotient	4



Participants 1633 had an IQ score of 123. She did not have a clinical diagnosis of ADHD, though felt sure herself that she had ADHD. She was not on any medication. She had no other diagnosis but reported a mild sensory processing problem, and low level anxiety and depression which she did not deem serious. She was pregant for the duration of her participation. For the CAARS she had mildly atypical problems with self-concept, moderately atypical hyperactivity / restlessness, and markedly atypical inattention / memory problems, impulsivity / emotional lability, and ADHD index. She was the only participant to score 80 or above on two of the CAARS subscales.

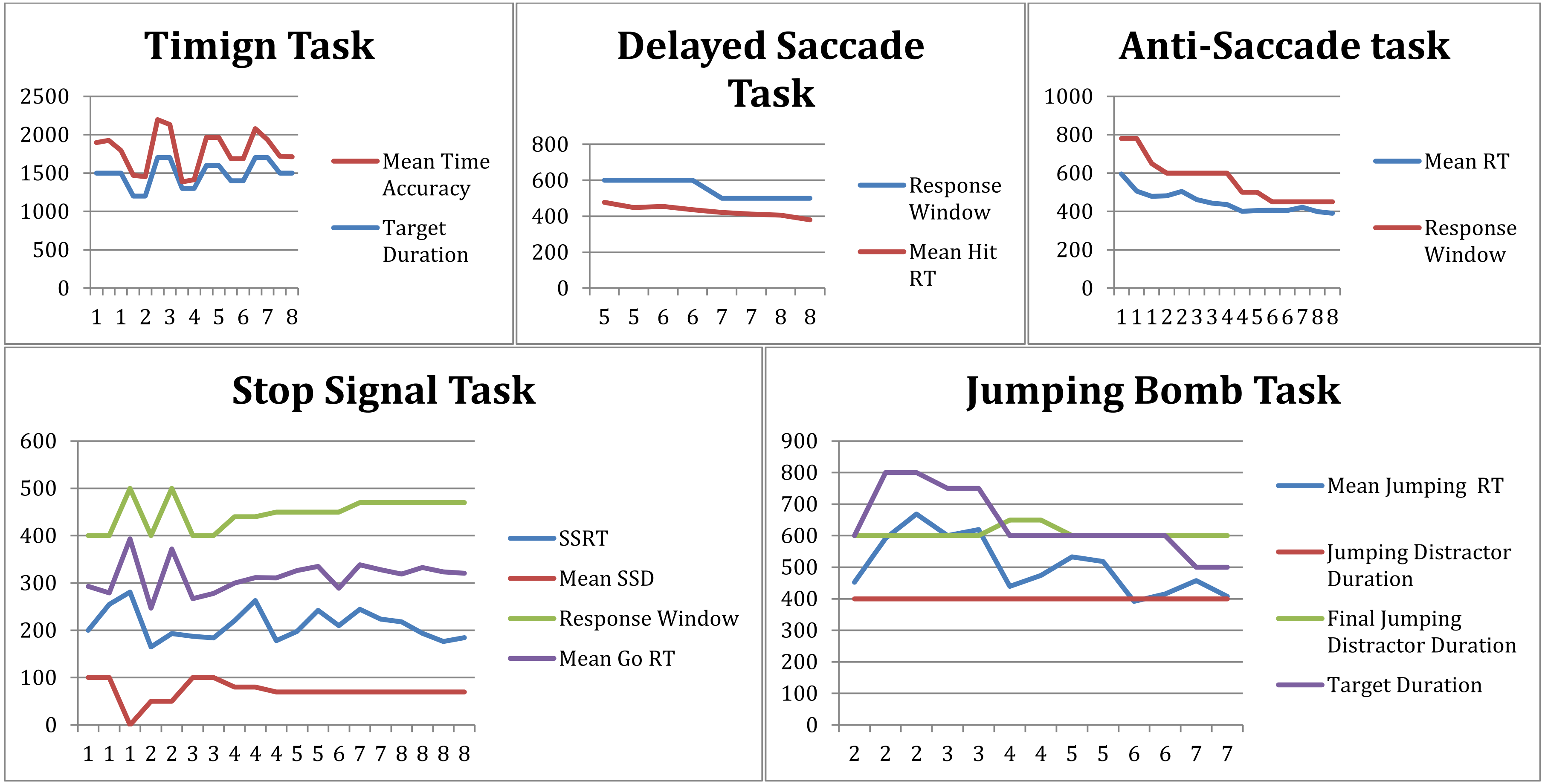


Figure 51. Trainng performance and difficult across the training sessions for participants 1633. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

Participant 1633 appeared motivated to participate in the training intervention but was not very competitive or motivated to excel on the training tasks. She found the jumping bomb and delayed saccade tasks difficult, and she also had some difficulty with the timing task. She reported that the tasks became much more difficult with the removal of additional stimulus cues, for example, the removal of the radioactive sign from distractor bombs in the jumping bomb. She reported that her performance was sometimes poor due to poor attention as she was sometimes drifting off. Her engagement with the tasks was increased when unexpected stimuli appeared. She stated that she really enjoyed novelty. After she produced consistent good performances in session 7 she reported: "I just realised I needed to be quicker". With participant 1633 I felt that even though she was often able to perform at a more difficult level she would have been happy not challenge herself at an easier level. This impressed upon me a need to challenger her to perform at a more difficult level. In session 8 she tried really hard, was very motivated and her performance was much improved and consistent.

Over the course of the training intervention we see a large improvement for the timing task. The distance between the red and blue lines at session one and eight has clearly reduced. A steady improvement is seen for both the anti-saccade RT and the delayed saccade task RT. No improvement is apparent for the stop-signal task. For the jumping bomb task we see a variable performance and a general improvement. We can also see that the RT performance closely maps onto the experimenter defined target durations.

Personal reflections

While engaged with the training intervention participant 1633 appeared at times content with her current level of performance. More so than with other participants, her level of engagement appeared to closely reflect the task demands placed upon her. This tendency did seem to recede across the training session. I feel that more training sessions with 1633 would have been useful as she appeared to progressively try harder as the sessions progressed. She would also have benefitted from a greater variety of training games.

Evaluation of pre- and post-assessment performance

An improvement in the long wait timing task (z = 0.82) in line with the group average (0.86) can be observed. There is a slight improvement in delay saccade task mean RT 26 ms, while this improvement (z = 1.1) is better than the group average (z = 0.99) the mean RT for assessment one was relatively slow (z = -144). A slight improvemet is seen for the anti-saccade mean RT. For both the anti-saccade and delayed saccade task the proportion of correct responses suggests a cautious response style with ceiling effects for the anti-saccade task, but some room for improvement on the delayed saccade task (assessment two score – 88%, an improvement of 13%). The prosaccade is slower for assessent two. An improvment is seen for the stop-signal sucess rate (z = .59). A large improvement is seen for the RT on block three (z = 2.76) and the predicted final stop-signal delay (z = 1.21). Taken together this indicated a substantial improvement on the stop-signal task.

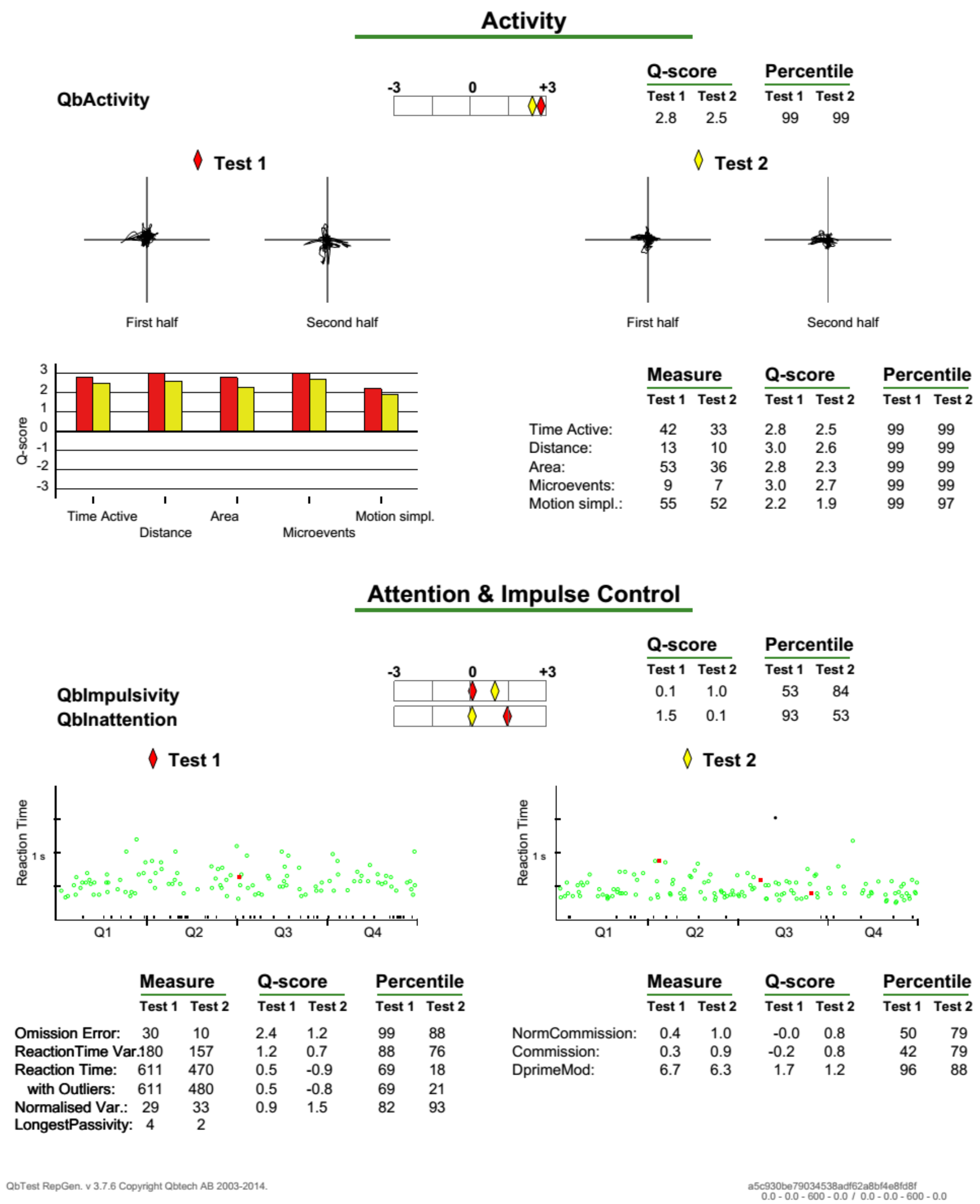
No change was observed for the forward digit span, but a large improvement was seen for the backward digit span (4 digits), an improvement in z scores of 1.94 compared to the group average z score improvement of 0.73. Improvements were also observed for the cancellation, stroop and Towre tasks. For the Towre task a greater improvement was observed for the words than the non-words condition (11 words versus 4 words improvements).

The Qb activity metrics revealed a slight reduction in the distance moved (z = 0.17) and the area covered (z = 0.29) but both metrics were poor at assessment one and assessment two compared to the group. While both reaction times (z = 140) and reaction time variability (z = 0.5) improved this appears to be at the cost of an increase in commissioning errors. An improvement for Cantab SSRT was observed, a reduction from 204 to 163 ms (a z score improvement of 0.88).

Table 14 For participants 1633 - the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	**Parameter**	**Assessment 1 (Z score)**	**Assessment 2 (Z score)**	**Improvement (Z score)**	**Group mean Improvement Z Score (SD)**
Timing	Short wait	18.00 (-0.13)	18.00 (-0.13)	0.00 (0.00)	0.40 (0.65)
	Medium wait	23.00 (-2.15)	12.00 (-0.09)	11.00 (2.06)	1.43 (0.68)
	Long wait	27.00 (-0.31)	18.00 (0.51)	9.00 (0.82)	0.86 (0.78)
Delayed Saccade	Mean RT	143.96 (-1.43)	118.04 (-0.32)	25.92 (1.10)	0.99 (0.79)
	Coefficient of Variation	0.35 (-0.14)	0.27 (0.62)	0.08 (0.77)	0.72 (1.13)
	Proportion Correct Reponses	0.75 (-0.30)	0.88 (0.48)	0.13 (0.78)	1.19 (1.11)
Anti-Saccade	Mean RT	363.04 (0.08)	357.71 (0.14)	5.33 (0.07)	0.80 (1.27)
	Coefficient of Variation	0.26 (0.38)	0.43 (-1.66)	-0.17 (-2.05)	0.68 (1.48)
	Proportion Correct Reponses	0.99 (0.63)	0.99 (0.63)	0.00 (0.00)	0.64 (1.53)
Prosaccade	Prosaccade RT	552.00 (0.54)	640.00 (-0.40)	-88.00 (-0.94)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.58 (-0.08)	0.63 (0.51)	0.05 (0.59)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	289.86 (-1.41)	125.00 (1.35)	164.86 (2.76)	0.99 (1.30)
	Predicted Final Stop-signal Delay	129.55 (-0.11)	208.56 (1.10)	79.01 (1.21)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	33.02 (0.44)	28.47 (0.36)	4.55 (0.08)	0.91 (1.58)
Digit span	Forward	11.00 (0.80)	11.00 (0.80)	0.00 (0.00)	0.26 (0.66)
	Backward	7.00	11.00	4.00	0.73

		(-0.19)	(1.75)	(1.94)	(1.22)
Cancelation Task	Cancellation	17.00 (-0.58)	23.00 (0.20)	6.00 (0.77)	0.45 (0.80)
Stroop	Stroop	28.00 (-0.78)	30.00 (-0.55)	2.00 (0.23)	1.19 (1.40)
Towre	Words	82.00 (-0.77)	93.00 (-0.13)	11.00 (0.64)	0.39 (0.33)
	Non-Words	58.00 (-0.13)	62.00 (0.17)	4.00 (0.30)	0.03 (0.26)
Qb Activity	Distance Moved	3.00 (-0.65)	2.60 (-0.48)	0.40 (0.17)	0.32 (0.35)
	Area cover by Movements	2.80 (-0.65)	2.30 (-0.36)	0.50 (0.29)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	2.40 (-1.06)	1.20 (-0.08)	1.20 (0.99)	0.78 (0.74)
	RT variability for CPT	1.20 (-0.46)	0.70 (0.04)	0.50 (0.50)	0.66 (1.00)
	RT for CPT	0.50 (-0.06)	-0.90 (1.30)	1.40 (1.36)	0.97 (0.95)
	Impulsivity Commission for CPT	-0.20 (0.58)	0.80 (-0.12)	-1.00 (-0.69)	0.25 (0.72)
Cantab	SST SSRT	204.38 (-0.63)	163.02 (0.25)	41.36 (0.88)	1.02 (2.02)



Activity

QbActivity	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
QbActivity	2.8	2.5	99	99

Measure	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Time Active:	42	33	2.8	2.5	99	99
Distance:	13	10	3.0	2.6	99	99
Area:	53	36	2.8	2.3	99	99
Microevents:	9	7	3.0	2.7	99	99
Motion simpl.:	55	52	2.2	1.9	99	97

Attention & Impulse Control

	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
QbImpulsivity	0.1	1.0	53	84
QbInattention	1.5	0.1	93	53

Measure	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Omission Error:	30	10	2.4	1.2	99	88
ReactionTime Var.	180	157	1.2	0.7	88	76
Reaction Time:	611	470	0.5	-0.9	69	18
with Outliers:	611	480	0.5	-0.8	69	21
Normalised Var.:	29	33	0.9	1.5	82	93
LongestPassivity:	4	2				

Measure	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
NormCommission:	0.4	1.0	-0.0	0.8	50	79
Commission:	0.3	0.9	-0.2	0.8	42	79
DprimeMod:	6.7	6.3	1.7	1.2	96	88

QbTest RepGen. v 3.7.6 Copyright Qbtech AB 2003-2014.

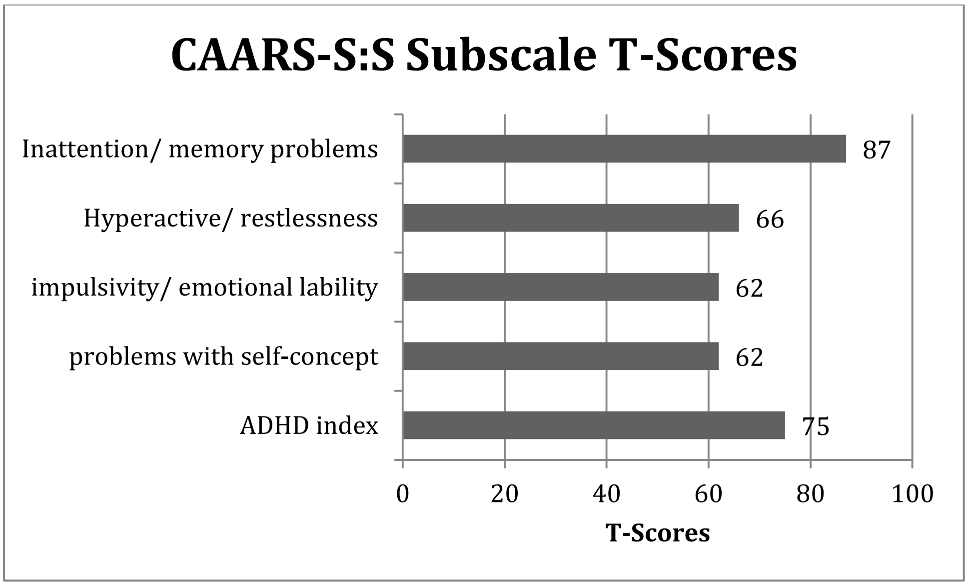
a5c930be79034538adf62a8bf4e8fd8f
0.0 - 0.0 - 600 - 0.0 / 0.0 - 0.0 - 600 - 0.0

Figure 52. Qb results for 1633

11.8 Participant 1864

Gender	Male
Age	38
Diagnosis	No diagnosis
Medication	No
Weight	N/A
Comorbid diagnosis	Depression on and off
Other issues	Some sleep problems
Note	

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
79.00	72.00	58.00	64.00	73.00
IQ estimate	125	Autism Spectrum Quotient		3



Participant 1864 had an above average IQ of 125. He did not have a diagnosis of ADHD and was not on any medication. He reported that he was sure he had ADHD. He stated that he had suffered from depressive for period in his life but currently had no depressive symptoms. He also suffered from some mild sleep problem. His CAARS scores were mildly atypical for impulsivity / emotional lability, and for problems with self-concept, moderately atypical for hyperactivity / restlessness, and marked atypical for inattention / memory problem and ADHD index.

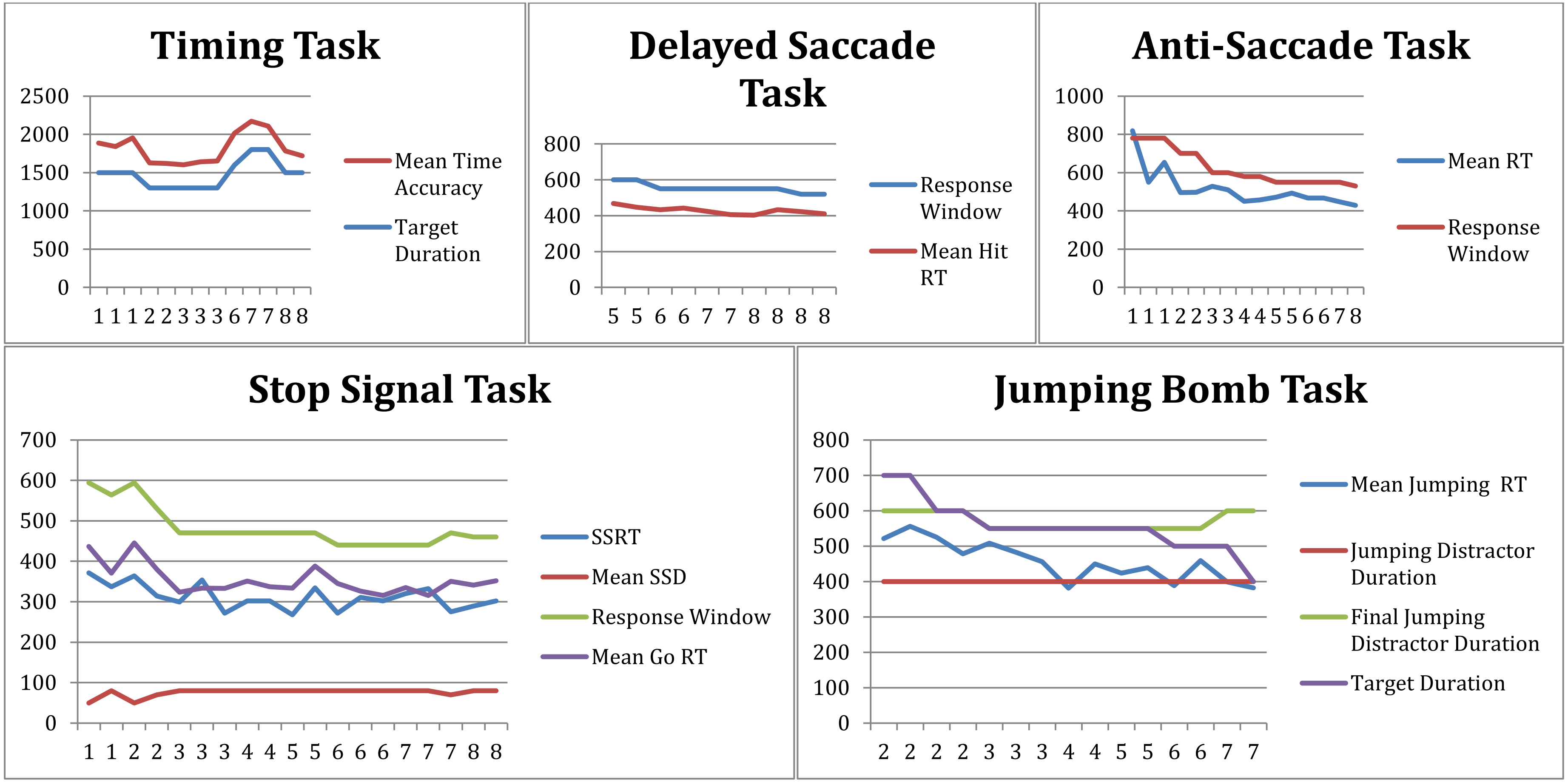


Figure 53. Trainng performance and difficult across the training sessions for participants 1864. Y-axis is time in milliseconds and the x-axis is the number of the training session.

Evaluation of performance during training

Participant 1864 was very competitive and highly motivated. Occasionally he displayed signs of mild irritation upon receiving negative automated performance feedback. He reported liking the challenge of difficult levels and particularly liked to have the same task back to back so that he could try to beat his score. His greatest difficulty was a tendency to move too early when a target appeared, for example, in the jumping bomb task and delay saccade task. When a target appeared he found it difficult to maintain focus on the central fixation point. However, the maintenance of fixation appeared not to be an issue in the fixation task in which no saccade to a target location had to be withheld for a period. He found the variable ITI on the delay saccade task made this task significantly more difficult. In relation to improving his performance he stated, "I feel like there is a skill I am learning and it's one I haven't been able to learn until now. Focusing and only moving when I'm meant to". He was quick to highlight perceived bugs in the programming when he felt the game was not responsive. For a number of training sessions he arrived to the session tired.

Over the course of the training session he made some improvements on the timing tasks. He also increased his RT for the delay saccade task. For the anti-saccade task he made large gains over the first three sessions and continued to make smaller gains across the remaining sessions. For both the stop signal SSRT and jumping bomb RT improvements are seen for the early sessions only and the performance is variable throughout.

Participant 1864, while tired for a number of the training sessions, was highly motivated and engaged with the training. He made improvements in several tasks and reported feeling that he was improving.

Evaluation of pre- and post-assessment performance

In the second assessment session participant 1864 became extremely tired during the eye-tracking tasks. As a result the data collection had to be abandoned after the anti-saccade task. He returned the following day to finish the eye-tracking (stop-signal and delayed saccade tasks) and the Cantab tasks. During this rescheduled post-training assessment he again appeared to be tired but completed the remaining tasks.

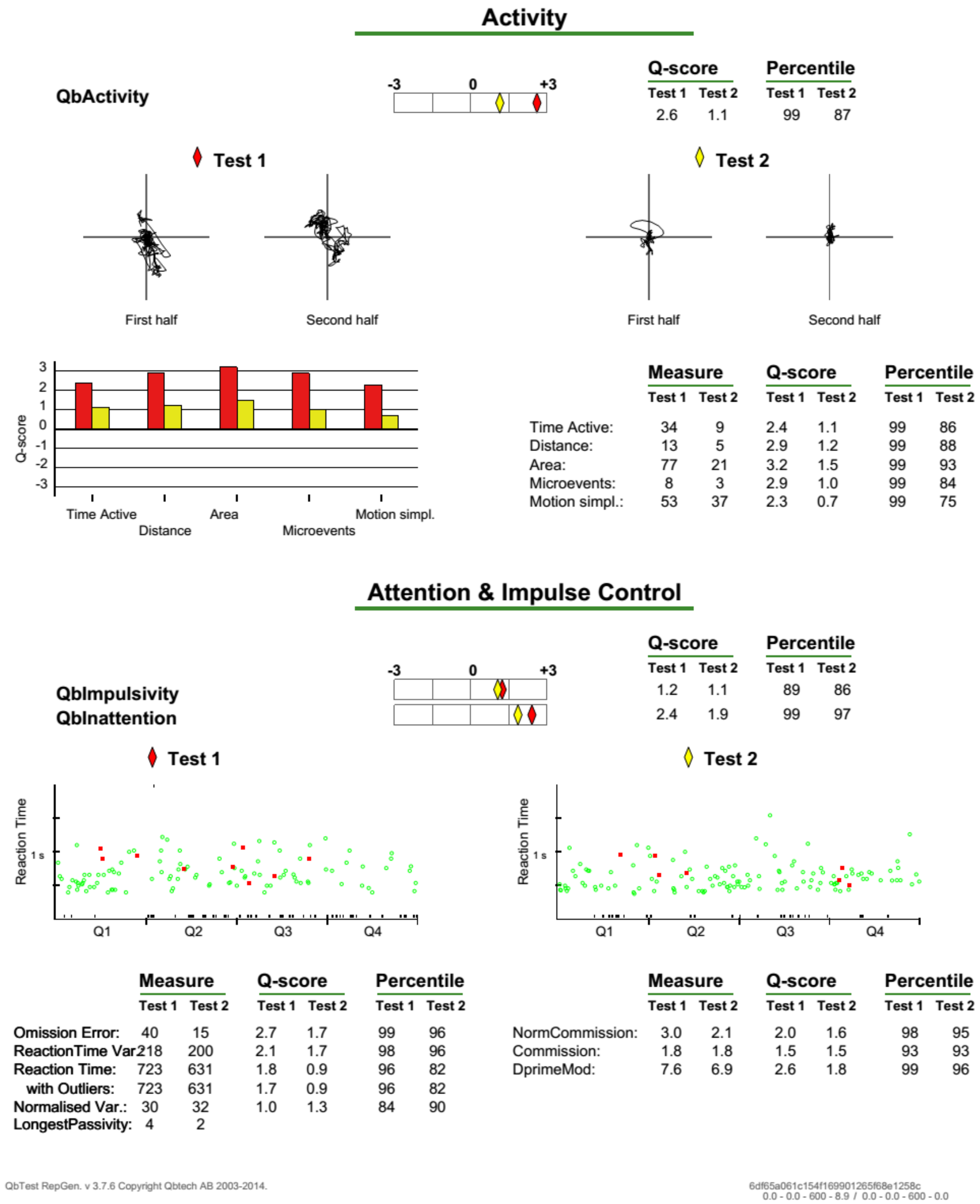
He performed well on the timing task at the initial assessment but still managed to improve on his scores for the medium and long durations. We see some small and medium sized improvements for the RT and RT variability in the anti-saccade and delayed saccade tasks. While he improved on the proportion of correct responses for the delayed saccade task his performance was worse for the anti-saccade task. For the stop-signal task he improved his success rate (1.54) and also his SSRT (1.09) and predicted final stop-signal delay (1.66) to a greater degree than the group mean improvement (0.93, 0.99, and 1.07 respectively).

Table 15 For participants 1864 – the performance scores (Z score) for the task parameters at assessment one and two, and the changes between assessments. A Z score for the mean group improvement is also given (and standard deviation).

Task	Parameter	Assessment 1 (Z score)	Assessment 2 (Z score)	Improvement (Z score)	Group mean Improvement Z Score (SD)
Timing	Short wait	7.00 (1.27)	7.00 (1.27)	0.00 (0.00)	0.40 (0.65)
	Medium wait	8.00 (0.65)	5.00 (1.22)	3.00 (0.56)	1.43 (0.68)
	Long wait	15.00 (0.78)	13.00 (0.96)	2.00 (0.18)	0.86 (0.78)
Delayed Saccade	Mean RT	130.75 (-0.86)	117.58 (-0.30)	13.17 (0.56)	0.99 (0.79)
	Coefficient of Variation	0.34 (-0.05)	0.33 (0.05)	0.01 (0.10)	0.72 (1.13)
	Proportion Correct Reponses	0.74 (-0.36)	0.82 (0.12)	0.08 (0.48)	1.19 (1.11)
Anti-Saccade	Mean RT	412.88 (-0.55)	403.16 (-0.43)	9.72 (0.12)	0.80 (1.27)
	Coefficient of Variation	0.22 (0.86)	0.20 (1.11)	0.02 (0.24)	0.68 (1.48)
	Proportion Correct Reponses	0.96 (0.32)	0.85 (-0.83)	-0.11 (-1.15)	0.64 (1.53)
Prosaccade	Prosaccade RT	644.00 (-0.44)	712.00 (-1.16)	-68.00 (-0.72)	-0.12 (0.75)
Stop Signal	Success Rate on Stop Trials	0.51 (-0.91)	0.64 (0.63)	0.13 (1.54)	0.93 (1.08)
	Stop Signal Reaction Time - Block3	263.20 (-0.96)	198.00 (0.13)	65.20 (1.09)	0.99 (1.30)
	Predicted Final Stop-signal Delay	75.77 (-0.93)	184.34 (0.73)	108.57 (1.66)	1.07 (0.54)
	Go RTs Minus Failed Inhibit RTs in Block 3	48.52 (0.70)	54.73 (0.81)	6.21 (0.11)	0.91 (1.58)
Digit span	Forward	8.00 (-0.43)	7.00 (-0.84)	-1.00 (-0.41)	0.26 (0.66)
	Backward	6.00 (-0.67)	6.00 (-0.67)	0.00 (0.00)	0.73 (1.22)

Cancelation Task	Cancellation	18.00 (-0.45)	18.00 (-0.45)	0.00 (0.00)	0.45 (0.80)
Stroop	Stroop	0.00 (-4.03)	26.00 (-1.01)	26.00 (3.01)	1.19 (1.40)
Towre	Words	77.00 (-1.06)	82.00 (-0.77)	5.00 (0.29)	0.39 (0.33)
	Non-Words	46.00 (-1.01)	45.00 (-1.09)	-1.00 (-0.07)	0.03 (0.26)
Qb Activity	Distance Moved	2.90 (-0.61)	1.20 (0.14)	1.70 (0.74)	0.32 (0.35)
	Area cover by Movements	3.20 (-0.88)	1.50 (0.11)	1.70 (0.98)	0.51 (0.38)
Qb Inattention	Omission Errors in CPT	2.70 (-1.31)	1.70 (-0.49)	1.00 (0.82)	0.78 (0.74)
	RT variability for CPT	2.10 ()-1.36	1.70 (-0.96)	0.40 (0.40)	0.66 (1.00)
	RT for CPT	1.80 (-1.33)	0.90 (-0.45)	0.90 (0.88)	0.97 (0.95)
	Impulsivity Commission for CPT	1.50 (-0.60)	1.50 (-0.60)	0.00 (0.00)	0.25 (0.72)
Cantab	SST SSRT	232.42 (-1.23)	180.22 (-0.12)	52.20 (1.11)	1.02 (2.02)

Little change was seen for the digit span or cancellations tasks. There was a small improvement for the Towre words. On the QB test there was a large decrease in the distance moved and the area covered by movements. While his performance on the QB attention measures was worse than that of the other participants he did improve by an amount similar to the group mean. No change was observed for impulsivity. He demonstrated a large improvement for the Cantab stop-signal SSRT slightly greater than the group mean improvement.



Activity

QbActivity

	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
QbActivity	2.6	1.1	99	87

	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Time Active:	34	9	2.4	1.1	99	86
Distance:	13	5	2.9	1.2	99	88
Area:	77	21	3.2	1.5	99	93
Microevents:	8	3	2.9	1.0	99	84
Motion simpl.:	53	37	2.3	0.7	99	75

Attention & Impulse Control

	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
QbImpulsivity	1.2	1.1	89	86
QbInattention	2.4	1.9	99	97

	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
Omission Error:	40	15	2.7	1.7	99	96
ReactionTime Var:	218	200	2.1	1.7	98	96
Reaction Time:	723	631	1.8	0.9	96	82
with Outliers:	723	631	1.7	0.9	96	82
Normalised Var.:	30	32	1.0	1.3	84	90
LongestPassivity:	4	2				

	Measure Test 1	Measure Test 2	Q-score Test 1	Q-score Test 2	Percentile Test 1	Percentile Test 2
NormCommission:	3.0	2.1	2.0	1.6	98	95
Commission:	1.8	1.8	1.5	1.5	93	93
DprimeMod:	7.6	6.9	2.6	1.8	99	96

6df65a061c154f169901265f68e1258c
0.0 - 0.0 - 600 - 8.9 / 0.0 - 0.0 - 600 - 0.0

Figure 54. Qb result for 1864

11.9 Discontinued participants

1964

Gender	Male
Age	17
Diagnosis	Combined
Medication	No
Weight	N/A
Comorbid diagnosis	No
Other issues	Migraines
Note	Participant withdrew from the study due to competing demands. He did appear eager to continue participation.

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
45.00	57.00	64.00	60.00	58.00
Autism Spectrum Quotient	3			

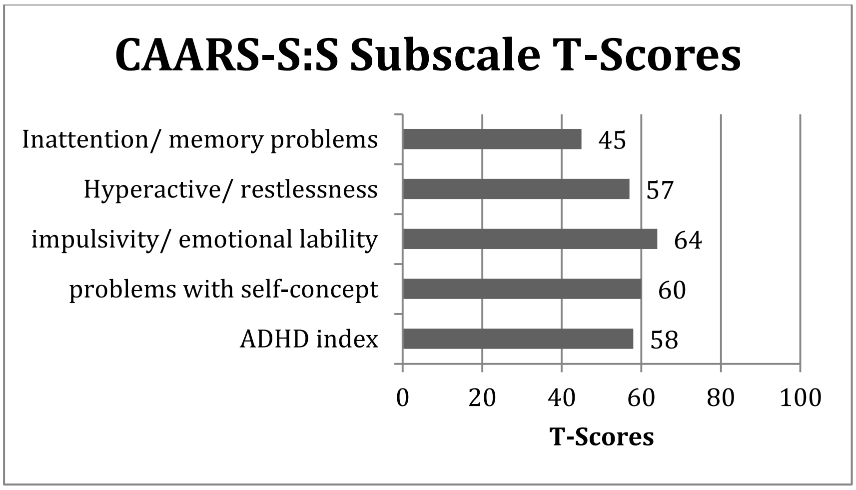


Table 16For participants 1964 - the performance scores for the task parameters at assessment one.

Task	Parameter	Assessment 1
Timing	Short wait	28.00
	Medium wait	14.00
	Long wait	33.00
Sudden Distracter	Mean RT	0.00
	Coefficient of Variation	0.00
	Proportion Correct Reponses	0.00
Anti-Saccade	Mean Correct RT	448.92
	Coefficient of Variation	
	Proportion Correct Reponses	0.00
Prosaccade	Prosaccade RT	592.00
Stop Signal	Success Rate on Stop Trials	0.50
	Stop Signal Reaction Time - Block3	240.80
	Predicted Final Stop-signal Delay	46.99
	Go RTs Minus Failed Inhibit RTs in Block 3	43.69
WM	Forward	5.00
	Backward	7.00
Cancelation Task	Cancellation	19.00
Stroop	Stroop	31.00
Towre	Words	82.00
	Non-Words	42.00
Qb Activity	Distance Moved	-1.40
	Area cover by Movements	-0.60
Qb Inattention	Omission Errors in CPT	0.60
	RT variability for CPT	1.60
	RT for CPT	0.50
	Impulsivity Commission for CPT	0.70
Cantab	SST SSRT	216.60

1779

Gender	Female
Age	37
Diagnosis	No
Medication	No
Weight	N/A
Comorbid diagnosis	No
Other issues	Postural orthostatic tachycardia syndrome (POTTS) and migraines
Note	The reason for withdrawal from the study related to issue with Postural tachycardia syndrome (*PoTS*) and migraines

Inattention/ memory problems	Hyperactive/ restlessness	impulsivity/ emotional lability	problems with self-concept	ADHD index
87.00	66.00	62.00	62.00	75.00

Autism Spectrum Quotient	2

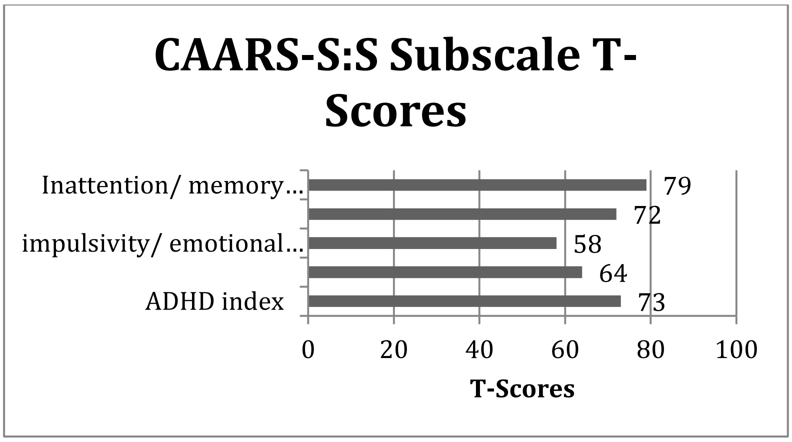


Table 17 For participants 1779 - the performance scores for the task parameters at assessment one.

Task	Parameter	Assessment 1
Timing	Short wait	24.00
	Medium wait	10.00
	Long wait	24.00
Sudden Distracter	Mean RT	0.00
	Coefficient of Variation	0.00
	Proportion Correct Reponses	0.00
Anti-Saccade	Mean Correct RT	433.42
	Coefficient of Variation	
	Proportion Correct Reponses	0.00
Prosaccade	Prosaccade RT	552.00
Stop Signal	Success Rate on Stop Trials	0.53
	Stop Signal Reaction Time - Block3	181.22
	Predicted Final Stop-signal Delay	85.63
	Go RTs Minus Failed Inhibit RTs in Block 3	-16.50
WM	Forward	7.00
	Backward	6.00
Cancelation Task	Cancellation	26.00
Stroop	Stroop	37.00
WRAT	Reading	104.00
	Arithmetic	68.00
Towre	Words	125.00
	Non-Words	81.00
Qb Activity	Distance Moved	1.10
	Area cover by Movements	1.50
Qb Inattention	Omission Errors in CPT	1.10
	RT variability for CPT	0.90
	RT for CPT	0.80
	Impulsivity Commission for CPT	0.40
Cantab	IED Errors	14.00
	IST Discrimination Errors	0.00
	IST Box Opening Latency	499.14
	SST SSRT	211.42

12 Discussion

Building on research suggesting an inhibitory gaze control deficit in ADHD, I set out, in this project, to utilise eye-tracking technology to assess inhibitory gaze control performance in ADHD and to develop an engaging intervention capable of training the inhibitory gaze control system. The primary aim of the project was to develop a training intervention that could subsequently be trialled in a randomised control trial. This was achieved by (i) clarifying the rational for the training intervention, (ii) conducting a literature review to identify the design and delivery features of the intervention, and (iii) developing the intervention through successive iterations by conducting the pilot studies and the proof-of-concept study.

12.1 Project summary

This thesis proposes that individuals with ADHD have an abnormality in the dopamine system. This is manifested at the cognitive level as an altered reinforcement system and will have a wide ranging impact, ranging from the relative saliency of the reinforcement contingencies identified in the environment, to the rate at which skills can be acquired. As a result of this primary deficit in reinforcement a secondary deficit in inhibitory control emerges. Distinguishing between the primary deficits and the secondary consequential deficits is important because for those secondary deficits the relevant system may have latent capacity that is underutilised. In terms of remediation of impairment secondary deficits may represent the low hanging fruit. The intervention targeted inhibitory gaze control because it lies at the intersection of attentional, hyperactive, and possible impulsive symptoms of ADHD. In addition, it has been argued that inhibitory control may be trainable as (i) it is enhanced in the case of Tourette syndrome and bilinguals, (ii) it is a function that naturally develops over the course of development, (iii) we know the brain is highly plastic, and (iv) performance on inhibitory control tasks and the related neural activity normalise in ADHD populations when performance incentives are provided. If the failure to develop inhibitory gaze control is not due to a lack of capacity then it may be possible to create a learning environment with reinforcement contingencies commensurate with the parameters of the abnormal reinforcement system observed in ADHD. The purpose of this project was to create a learning environment in the form of a game that will train inhibitory gaze control in individuals with ADHD.

Drawing on the training, gaming, and design literature I identified design principles that were used in the development of the training intervention. These included: (i) ensuring that the target of the training constitutes the core mechanics of the intervention game (intrinsic integration), (ii) encourage intrinsic motivation, (iii) utilising tracking algorithms to ensure the trainee is operating within their zone of proximal development, (iv) varying task difficulty just below the trainees' maximum capacity to ensure they are challenged to improve but also have capacity to invest in processing the germane load, that is, the development of those skills that will ensure better performance in the future, (v) ensuring that increases in task load relate to germane and not extrinsic load, and (vi) targeting the ability of interest with multiple tasks.

The intervention was programmed in Matlab and utilised the CRS 250 Hz eye-tracker. The pilot studies conducted helped to (i) further refine the assessment tasks and to inform the development of the training intervention, (ii) give me a degree of competency with the equipment and programming in Matlab, (iii) establish robust eye-tracking procedures to ensure the quality of the data, (iv) identify training parameters, (v) validate the Competitive Integration Model that was used to inform the development to the training intervention, and (vi) to establish convergent validity for the assessment tasks used.

A proof-of-concept study was then conducted with an adult ADHD population. This involved the delivery of 8 training sessions with the training intervention and the comparison of a pre- and post-training assessment battery. Both within group comparisons and case study analyses were conducted. The training intervention essentially attempts to present an externalised representation of trainees' inhibitory control system and provides them an opportunity to exercise this system, combined with reinforcement when they train it.

12.2 Proof-of-concept Group Results

For the main proof-of-concept study assessment tasks were delivered before and after the 8 sessions of the training intervention. The changes in performance between assessments were compared. Given the small sample size (N = 8) the effect sizes were analysed. The results are grouped into: 1.) the trained tasks, 2.) the pupil dilations for trained tasks, 3.) the non-trained eye-tracking tasks, and 4.) the standard assessments.

A large positive mean effect size was observed for the trained gaze control tasks. Improved trial accuracy scores combined with faster reaction times on the anti-saccade and delayed saccade tasks suggest a better inhibitory gaze control performance, and this may be consistent with the slight increase in RT on the pro-saccade task. This is similarly suggested by a short SSRT and mean inhibition rate in the stop-signal task. The effect observed for "Go RTs minus failed inhibit RT's" additionally suggests the improved performance on the stop-signal task may be partially attributable to greater temporal precision or less variability in the timing of planned saccade movement. Similarly, a reduction in RT variability is seen in the anti-saccade and delayed saccade tasks. This effect could be the result of improved vigilance, less noise in the system, or improved timing (as suggested by the timing task improvements), and is of interest given the robustness of findings of increased RT variability in ADHD (Kofler et al, 2013).

The improvement in performance parameters are accompanied by a tonic increase in pupil dilations (a phasic analysis of the pupil dilations was not conducted but should be carried out on future data). This increase is likely attributable to a number of factors. It may reflect better regulation of physiological arousal and thus a greater readiness to respond. It could reflect an increase in the deployment of cognitive resources during assessment two. The increased deployment of cognitive resources could reflect multiple factors; for example, greater motivation, improved attention, or a greater deployment of cognitive resources could reflect an increase in the capacity of the functions being deploy (having greater functional capacity increase the potential for capacity expenditure).

In an effort to measure gaze control for more ecologically valid tasks, data was also gathered from reading and spot-the-difference tasks. The analysis of the non-trained eye-tracking tasks was more explorative than the other tasks, and changes observed are interpreted with caution. These tasks were poorly controlled and the analysis completed was rudimentary. The analysis sought to establish whether more gaze stability was seen after the delivery of the training intervention. After completing the training participants demonstrated an increase in the number of forward saccades made per word. In addition we also see that participants also had longer dwell times between saccades (fixation duration). A similar trend with reduced effect sizes was observed for the spot the difference task. One interpretation of this data is that participants are making smaller more controlled saccades while reading and that they fixate for longer following a saccade, that is, they demonstrate more control and greater gaze stability. Given that gaze stability is in part a motor control ability, in ADHD it may be a proxy measure for hyperactivity. If true an increase in dwell time could reflect a reduction in hyperactivity. If as proposed the increased number of forward saccades does reflect greater control of saccade movements this may explain the improved performance seen for the TOWRE single word reading task (effect size = 3.99) and the cancellation task (effect size = 1.2).

While improvements are seen for the trained gaze control tasks it is unclear if these improvement reflect enhanced functional ability as a results of the training intervention or for other reasons. The effects sizes in some instances are so large that a guarded cautious interpretation is the obvious reaction, and effects other than the practice provided must be considered. As gaze control tasks involve the use of the eye-tracker it must be considered that improved performance may reflect an equipment familiarity effect. That is, participants may have improved their ability to supply the equipment and data processing algorithms with gaze data more likely to be interpretable. Efforts were made to guard against this with attempts to ensure performance metrics were not adversely biased by poor or lost data, however, during the course of the training intervention participants received not only feedback on their performance, but were indirectly reinforced for producing gaze data that meets the criteria for processing. In sum, being more apt at producing data surpassing the constraints of the equipment may impact on the performance metric generated.

A better performance at the second assessment may reflect an enhanced level of motivation in the trainees. Such an effect could influence both trained and untrained assessment tasks. We know performance on a number of tasks improves when ADHD participants are more highly motivated. An increase in motivation could occur for a number of reasons. Perhaps trainees are invested in seeing an improvement after having attended multiple training sessions and as a result are more highly motivated during assessment two compared to assessment one. Given the number of assessments and training sessions involved and the experimenter-participant relationship that was established as a result, enhanced motivation could also result from a desire in trainees to please the experimenter. Increased motivation may additionally be seen because trainees - as a result of engaging with the training intervention - have now identified inhibitory control and accurate timing as skill worth expending cognitive resources on. This latter point would not constitute an enhancement of the inhibitory control or timing ability, but instead an effort to use the existing ability to maximum effect.

In addition to practice effect and enhanced motivation, the observed improvements could reflect intra-individual variability. The sample is small and thus is highly susceptible to random variations. In this instance the effects could reflect a randomly determined poor performance at the initial assessment and a regression to the mean on the follow-up assessment. Added to this is the potential impact of extrinsic load at the initial assessment, for example, gaining a familiarity with the environment and the experimenter, apprehension in relation to being assessed, gaining familiarity with the use of the equipment involved.

While remaining conscious of all these caveats, I note that the patterns of improvements observed are in line with our predictions. The improvements observed on a number of the standard assessment tasks are above what would be expected due to practice effects alone. In addition, improvements are not seen for all tasks and a differential pattern of improved performance in line with what might be expected as a result of successful training emerged. The standard assessment tasks were delivered in part to assess whether any transfer occurred but also to have some standardised comparison data sets. The profile of results suggests improved performance in the post-training assessment for tasks that rely on a combinations of functions, namely gaze control, attentional control, inhibitory control, and timing and time estimation.

The measures that showed the greatest effects were in the hypothesised domains:

- Inhibitory control (Stroop, SST, Qb hyperactivity)
- Attention (QbTest commission and omission errors, RT variability)
- Gaze control (TOWRE single word reading, cancellation task, gaze control during reading, including more forward saccades per word and increased dwell time)

Measures that showed the smallest or negative effects were in domains not hypothesised to show marked transfer effects:

- WRAT arithmetic and untimed reading (a range of complex skills involved)
- TOWRE non-words (large phonological component to task)
- Set-shifting

The trend to improved backward digit span (effect size 1.2), was unexpected, and not statistically significant. However, if a real effect it may reflect a greater allocation of cognitive resources in assessment two as suggested by the greater dilation in pupil observed in the gaze control tasks.

One interpretation of the increases in pupil dilations is that there is an increase in the expenditure of cognitive resources while completing the tasks during assessment 2. While we might expect more efficient trained functions to deliver a better performance without the need for an increase in resource expenditure, in this instance we might expect that consolidation of enhanced functional ability is not yet complete. Also, as can be seen from the case study figures participants' learning did not appear to have reached a ceiling, thus greater cognitive expenditure may reflect an investment in the germane task load.

The differential improvements observed in the TOWRE single word and non-word tasks are in line with our predictions. Enhanced gaze control is predicted to facilitate efficient reading of words in the single word task, which primarily taps word-reading speed, but in the non-word version the limiting performance factor is phonological component. The training intervention is not predicted to impact on phonological processing. Differential improvements in line with predictions are similarly seen for the CANTAB tasks. An improvement is seen for the manual stop-signal SSRT suggesting greater efficiency at assessment two for cancelling planned 'go' responses. Conversely, in line with prediction, improvements are not seen for the inter-extra dimensional task or the information sampling task (IST) (while we do see a faster IST box opening latency this is accompanied by an increase in discrimination errors suggesting a strategic shift). While the IST does tap impulsivity, there is no strong evidence that this form of impulsivity (sometimes known as "reflection impulsivity" is related to the impulsivity of ADHD (DeVito et al, 2009).

The improvements observed for the TOWRE word reading task and the results of the reading task are suggestive of improvement in gaze control with a functional relevance. In addition, symptom relevant improvements are suggested by improvements in QbTest measures of hyperactivity and inattention. For assessment two participants reduced the amount of movement and the distance they covered; activity measures are designed to assess the hyperactive symptoms of ADHD. Improvements are also observed for the inattentive measures; participants make fewer omission errors, have faster and less variable RTs. A reduction in commission errors, an impulsivity measure, was also observed.

The evidence presented in this thesis suggests that the gaze-control training intervention may have been successful in remediating cognitive control deficits in ADHD. In addition it also demonstrates the viability of delivering the intervention and thus constitutes a proof-of-concept. Of particular note is that not only did we see improvements in the trained gaze control tasks, there is also evidence of transfer to untrained tasks, including tasks using different response modalities and stimuli, as suggested by the differential improvements in related tasks in line with predictions. Moreover, the current version of the intervention was positively received by the participants. On the whole they reported finding it engaging and compelling. They also reported a subjective experience of improving on the tasks across training sessions.

However, we do not know the extent to which remediation is possible; perhaps when reaching adolescence a critical window has already been missed. While the differential improvement observed across tasks is largely consistent with our prediction and provides a degree of support for the efficacy of the training intervention, these task specific improvements may also be the result of enhanced motivation. It may be the case that enhanced motivation in ADHD normalises only those tasks for which the ADHD population are observed to display a pronounced deficit, for example, inhibitory control. If true the data provided cannot distinguish training effects from the effects of enhanced motivation. This proof-of-concept study cannot disentangle the effect of the potential effects of motivation and the training intervention. The strongest conclusion that can be drawn from the effects observed is that, as has been proposed, a larger RCT needs to be conducted to determine what factors are driving the observed effects.

12.3 Using Eye-tracking

One of the strengths of using the eye-tracker is that it affords a means of ensuring the participants are fixated on the centre of the screen and demonstrating a degree of gaze stability before the start of each trial. If they failed to look at the centre of the screen nothing happened. And if they looked at the centre but looked away too early they were automatically reminded not to do so by an on-screen message. All participants were able to achieve this with a degree of effort; some initiated this automatic reminder more than others. This feature served as a constant anchor for their attention at the start of each trial, thus supporting the maintenance of task focus. This feature of the training would not be possible without the use of an eye-tracker and is seen as one of the strengths of the approach taken.

Eye tracking technology is currently making great strides and is likely to be widely available over the next decade. The technology is increasingly more user-friendly; meaning the use of eye-tracking equipment will be increasingly accessible. The progress currently being made in eye-tracking technology presents an opportunity for researchers and clinicians to harness this technology. Eye-tracking provides an extremely rich source of data that is highly accurate with a high temporal resolution. Systems that utilise two or more cameras, one for each eye, mean that not only are head restraints unnecessary, but head movements can also be monitored and recorded. It can be exploited to provide quantitative assessments and interventions related to visual activity. The challenge for researchers and clinicians in the area of ADHD is to identify visual activity profiles for individuals with ADHD that can facilitate diagnosis, or suggest targets for interventions, or provide a means of monitoring the condition.

Ideally, primary deficits would be identified early in a child's development in order that medication, environmental supports, or other interventions could minimise the emergence of secondary deficits, particularly for those functions for which there is a critical window. In this way the negative impact of the primary deficits may be minimised. However, the identification of endophenotypes at such an early stage may not be possible, and by the time deficits are observable remediation of secondary deficits may prove impossible. However, the combination of a decrease in cost of eye-tracking technology, its increasing ubiquity, and its non-invasive nature suggest a potential for gaze control interventions to be proactively delivered to individuals at risk to ensure the development of cognitive control skills in line with the typical course of development. The use of preventive intervention could reduce the risk of children developing the proposed secondary deficits in cognitive control.

12.4 Limitations

The arrangement of the training sessions and assessment session was determined at the convenience of the trainees. For some trainees the sessions were spread out and for others they were not. While this was not a limitation for the proof-of-concept study as it supplied useful information and guidance regarding participant's desired spread of sessions, during the delivery of a RCT this should be standardised.

In the proof-of-concept implementation of the training intervention all gaze control assessment tasks were explicitly trained, even though the stimuli were different in a number of respects from those in the training tasks. In future RCTs, including a inhibitory gaze control task in the assessment that is not explicitly trained may be useful to clarify that inhibitory gaze control is being training and that the effects for the inhibitory gaze control tasks are not simply the result of practice on the individual tasks.

A limitation with the automated saccade identification algorithm used was that in some instances the overall time window of the task remained static while the internal shifting time parameters of a task shifted in response to the participant's performance. For a minority of trials this resulted in a late response being recorded as a no-response trial dependent on the shifting of internal task parameters. One solution is to have the overall task time window shifting in line with the shifting of internal parameters of the task.

The programming of the task needs to be more robust. This intervention was developed within the Matlab environment which is not designed for this purpose. A more appropriate programming language and a more skilled programmer should be utilised to ensure the program is maximally responsive to participants' gaze and that programming bugs and inefficiencies are minimised.

While the eye-tracker used was appropriate for the current iteration of the task it had some limitations. Newer eye-trackers claim to be able to produce data of equivalent temporal resolution and spatial accuracy but without the need for a chin rest. A head free eye-tracker would increase the ecological validity of the intervention. In addition the eye-tracker was difficult to transport. Newer more portable eye-trackers will increase the accessibility of the intervention. A single laptop and small plug in eye-tracker would allow researchers to more easily collect data from clinics or schools etc. A head free tracker could additionally be used with smaller children who find it difficult to maintain a stable head position which completing the task.

12.5 Continuation of the work

While the ultimate aim in extending the work of this thesis is to conduct a RCT, there are a number of intermediary steps needed before progressing to this stage. The thesis and proof-of-concept study have developed the intervention and assessment tasks, demonstrated the viability of delivering the training intervention, and have suggested that the intervention may remediate the attentional and inhibitory control deficits associated with ADHD. To progress this work further there is a need to conduct a proof-of-concept study that provides more definitive support for the efficacy of the intervention.

To establish the efficacy of the intervention there is a need for the intervention to:

(1) be trialled with a more representative ADHD population. For example, the ADHD population recruited for the thesis proof-of-concept study have a high average IQ, and in addition were predominantly recruited for an adult ADHD support group. To avoid a similar selection bias the recruitment of a community same with high scores on an ADHD screen tool could be considered, possible base on a school sample. Alternatively, recruitment of participants via ADHD clinics could be considered.

(2) There is a need to establish clear criteria with respect to a diagnosis of ADHD. Of the adult ADHD population recruited (N = 8) only five had a diagnosis of ADHD, and one had attention problems but was unlikely to have ADHD. Subsequent trials of the intervention will benefit from only recruiting participants with a confirmed diagnosis of ADHD.

(3) Given the discussions within this thesis pertaining to the potential for critical learning periods during development, the consolidation of compensatory strategies and functions over time, and the remittance of hyperactive symptoms with age within the ADHD population, there is a need to ensure subsequent trials of the intervention recruit a homogeneously aged population of ADHD. Given the large gain seen in inhibitory control function between the ages of 6 to 10 years and subsequent continued improvement and maturation of the associated substrate (see section 1.1.2) a child ADHD population between the ages of 10 to 12 years are considered ideal for evaluating the training intervention. Children with ADHD at this age are predicted to evidence a failure to develop age appropriate inhibitory control function, yet will not have developed compensatory skills potentially present in adolescents. (The recruitment of an ADHD sample was one of the main challenges of the current proof-of-concept study and will likely continue to be one of the main challenges facing subsequent trials of the intervention. There is a need for a considered approach to address this issue. The involvement of clinicians at a early stage may be beneficial.)

(4) A considered position on whether ADHD participant are taking medication at the time they receive the intervention needs to be adopted. If the training intervention is effective the benefits may be more readily observable if participants are not taking

medication. However, given that ADHD participants are less likely to be able to focus their attention during the delivery of the intervention if not taking medication, interventions gains may be less likely without medication. There are also ethical and practical complications associated with either medication naive participants or taking participants off medication for the duration of the intervention. One possible approach is to ensure participants are not taking medication for the completion of the assessment tasks (ensuring a sufficient wash our period) but are taking medication for the duration of the delivery of the training interventions.

(5) There is a need to utilise a control intervention in subsequent trials. A wait list design with a control intervention would allow all participants to receive the intervention while ensuring a control intervention can be delivered to the wait list group. The control intervention should control for contact with the experimenter. Given that it has been hypothesised that the positive results of the current intervention may be the result of an enhanced level of motivation to perform well during the post-intervention assessment as a result of the degree of effort exerted during the completion of the training, there is a need to ensure that the control intervention in future trials are equally motivating and allow the participant to invest in improving at the control tasks. Related to this there is also a need to have the conditions blinded, participants should be unaware of being in the experimental or control condition. The Cogmed or a similar training program may prove to be a useful control intervention.

(6) While it poses some logistical and procedural difficulties, ideally the delivery of the intervention would be double blinded to ensure the experiment is unaware of which condition the participants are randomly assigned. The proof-of-concept study conducted in this thesis required that the experimenter made manual adaptations to task parameters in order that aspects of the tasks were adaptively modified to reflect the participant's level of ability, however, having completed this process of adapting the parameters these procedures can now be programmed to occur automatically and more standardization procedures across participants can be established. A partial solution to the issue of blinding is firstly, as suggested above, have the training largely automated, and secondly, to have the delivery of the training

managed by research assistants who are themselves unaware of whether the gaze control intervention or control intervention is the intervention being trialled.

(7) If gains can be establish there is additionally a need to the degree to which they are maintains. The inclusion of a follow-up assessment after three months could be introduced to the procedures.

12.6 Future developments

If robust gains can be established there is a need to examine the degree to which they are maintained. In addition, there is a need to establish to what degree gains transfer to behavioural functioning. There is also a need to establish the likelihood of making functional gains both on and off medication, and additionally the degree to which gains are maintained based on medication.

It may be necessary that further interventions are established in facilitate the translation of the cognitive gains made into functional everyday behaviours. This is likely to be especially true in instances in which individuals have developed compensatory mechanisms or strategies that circumvent the need to rely on the underdeveloped function. The loss of gains seen overtime may relate to the degree to which the enhanced functions can be integrated in a useful way into daily behaviour.

There are a number of directions that could be pursued in future trials:

- A trial that controls for experimenter contact (control matched only for experimenter time - research examining the effectiveness of therapy has identified that one of the best predictors of success is the patient's commitment to the therapist (Ardito and Rabellino, 2011).
- It would be useful to explore to what degree the efficacy of the intervention relates to inhibitory gaze control versus inhibitory control. This could be examined with the use of an equivalent manual response training intervention.
- A study comparing the gains made or the impact on ADHD symptoms compared to an alternative intervention, for example, Cogmed, would be useful.

- Studies examining potential changes in neural activity as a result of training would also be useful.
- Patent and teacher ratings of ADHD symptoms are an obvious outcome measure to record in future studies. Academic performance would also be a useful measure to establish if the gains made translate in a practical manner to everyday functioning.

A number of potential task improvement and modification are brainstormed in appendix 1.

12.7 A wider discussion of the issues raised

12.7.1 Cognitive training

A major challenge when training and assessing cognitive functions is that they are inferred, cognition cannot be observed directly. In fact, we cannot even be sure that the functions we profess to train truly exist. Within the field of psychology there is no agreed upon cognitive structure or architecture. Instead there are loosely assembled patchworks of theories that span multiple levels of analysis. Rival schools of thought can be isolationist, and terms common to different theories can have very different meanings. Research is based upon a positivistic bias and the predilection that a unitary cognitive architecture with a physiological instantiation can be identified. The goal of establishing something akin to a Platonic Archetypal cognitive structure within which to organise or contextualise the derivative empirical reality may however not be achievable. While science by its nature would posit that the creation of an objective empirical model of cognitive function is theoretically achievable, in practice the complexity of modelling the dynamic multifaceted cognitive system may be beyond that capacity of what is practicable. Any unifying theory would need to account for the cognitive system's ability to be self-aware/self-reflective, and to redefine and shape its own structure.

There is a tendency to think there is a blue print of how the brain is structured, something that will state what function should go where and how different structures should interconnect. The regional allocation of these gross functions is likely to be largely genetically determined, but there is also a large amount of variability between individuals' neural wiring. While the allocation of gross functions to particular regions is largely predetermined the detail of the allocation is stimulus or environmentally driven. We can see extreme examples of this when we look at the case of congenital blindness resulting from damage to the visual apparatus and not to neurological abnormality. In such cases there is surplus neurological real estate available. How does the brain know to allocate it to other functions? It does not because as such this region was not pre-allocated to any function. In most cases, as a result of evolution, the occipital lobe is preferentially placed to become a visual processing area, and the rough structure of the regions are optimised to serve this function but it is not pre-allocated. Allocation is determined by the stimulation that the system receives, it is determined by the problems the system must resolve. This issue is of interest when we think of developmental disorders. Are they the result of the sub optimal allocation of space to different sub-functions, possibly due to the lack of the necessary stimulation at a critical period, maybe due to an over exposure to a particular set of stimuli, or possibly due to an abnormal global structure? Some functions may simply not be possible to learn once a critical period has passed. Also, comparisons between "health" and "abnormal" brain structures and functioning are of limited utility because different brains have simply developed along different paths (Karmiloff-Smith, 2002).

There are a number of issues to bear in mind when training and assessing cognitive functions. In instances where an individual reaches the threshold for a diagnosis a default assumption of a deficit cannot be assumed in all cases. While an individual may not act in a way that the majority of society deems appropriate or efficient we cannot assume that a different preferred mode of operating has not been adopted. Many individuals with ADHD are considered highly creative, and in many cases a blunting of this creativity is the reason provided by individuals who discontinue their medication. In such instances it may not be appropriate to refer to worst cognitive performance as a deficit. It may instead be thought of as a preference to excel in one domain which has an impact on functioning in another domain. This is not to suggest ADHD is a choice, but that a poor performance does not necessarily equate to inability or impairment.

We should additionally note that the deficits associated with ADHD are not the defining cognitive or neural features of an individual. Any individual with ADHD will also have numerous idiosyncrasies that are also seen in the typically developing population. However, an abnormal arousal or reinforcement system may have a magnifying effect on some of these tendencies. For example, a child may be shy and introverted, but the addition of an ADHD tendency to not learn social cues could exacerbate his or her's introverted nature.

There is a need to clarify to what processes "cognition" refers to, what we mean by "cognitive deficit", and what the target of cognitive training should be. At a broad level we might think of a cognitive deficit as abnormal cognitive functioning that has a negative impact on behaviour. But a cognitive deficit is more specific - is it an abnormally functioning system, a weakened system relative to the general population, a function that is absent, a failure to coordinate the actions of multiple systems, or perhaps the selection of an inefficient strategy? To what degree should we break down the processes we identify? For example, cognitive control can be addressed at a global motivation or strategy level, or can be broken down into constituent parts, reactivity and regulations. Further still we can divide up the processes involved in regulation. In theory we can divide up behaviour until the symbolic level becomes physiology; this highlights the artificial divide we create between the levels of analysis. What is important is what is useful and informative, usable and practical. For example a useful distinction is to identify the potential for increased functionality in a particular system, that is, is there a missing function or a weakened function with the potential to develop or a typically developed function we are trying to enhance? Is there a deficit because there is no capacity or because an opportunity to learn has not been experienced?

There are likely to be a number of barriers to the acquisition of cognitive function that are not developed within the typical developmental period. Firstly there are maturational considerations and potential critical developmental windows of opportunity for certain functions. But there are also more subtle barriers that do not relate to inability but instead relate to opportunity to develop cognitive functions outside of the typical timeframe of development. As children and teenagers acquire new or more developed cognitive functions they are provided with support. Mistakes are expected and tolerated and the environment is modified in subtle ways to foster the development of these emerging abilities. However, we might expect that these supports and allowances are withdrawn or rejected at some stage, and as a result the acquisition of a new cognitive function is not facilitated to the same degree. It is also likely that an individual who has failed to develop a particular skill within the normal timeframe will develop alternative coping strategies to manage or avoid the demands for which the function in question is intended. This avoidance or use of compensatory strategies will potentially be largely unconscious and engrained. As a result, the remediation of an underlying deficit may not alter an individual's established pattern of behaviour and they may not integrate a newly acquired function into their behavioural or cognitive repertoire, but instead continue utilising established strategies to circumvent specific behavioural or cognitive demands.

There are a number of challenges associated with training a particular function. Firstly, it is difficult to identify the weakened function we should target for training. As mentioned previously no task is function specific. Related to this is the difficulty in finding a method to train the targeted function with some degree of precision. Further, it is important that compensatory strategies are not deployed to circumvent the necessity for utilising the intended target of the training. Trainees will have idiosyncratic preferences that can result in the use of a multitude of different strategies when performing a task. The problem is potentially more difficult if we are trying to strengthen an underdeveloped function. This is because a compensatory system or strategies may have been developed and habitually used. A related problem is incentivising the trainee to utilise the underlying skill. The trainee needs to be focused on the development of the target of the training intervention; if no incentive is provided their attention and engagement may be insufficient for development to occur, but if we introduce an highly desirable incentive the trainee may seek to utilise any available function to obtain the incentive as opposed to utilising the intended target of the training. Using the crude example of an infant who is learning to walk; if a highly desirable target is placed some distance from the infant we might expect that they will revert to the tried and tested method of crawling.

If a new function is developed or strengthened we might expect that it needs to be utilised to be maintained. In addition to the development of ability it may be necessary to additionally train the integration of this ability into everyday behaviour in order that it is maintained. For a training intervention to be maximally effective there is a need for it to be implemented across a number of levels. The amelioration of inhibitory control deficits in a child with ADHD may not be evident at the behavioural level unless additional training is similarly implemented to alter the behaviour. Ideally the trainee will themselves demand more of themselves and utilise newly acquired functions, but there may also be a need for demands to be placed on the trainee until the newly acquired function is consolidated and integrated into their behavioural repertoire. This has particular relevance for children with ADHD for whom the consolidation period maybe protracted. For example, if they have undergone some type of treatment or training intervention their teachers and care givers need to demand improved performance in those areas were improvements would be expected. Having newly acquired skills integrated into the daily routine will ensure they are maintained.

12.7.2 Combining cognitive training with other interventions

When evaluating an intervention it is worth reflecting on the purpose, cost and implications. To what level of dysfunction is the treatment directed (aetiological, biological, cognitive, behavioural); what is the impact of the treatment at the symptom level; does it provide a coping strategy; are the effects tonic or phasic; are the effects immediate, delayed, or cumulative over time; is it applicable to all ages and populations; is the treatment cost effective given the effect size (e.g. neurofeedback requires many sessions for a small effect versus medication which has moderate costs but large effects), does it have an active agent; does it impact on daily function (some alternative treatments are found to have effects on specific outcome measures but little impact on daily function such as academic performance)? It is worth noting that ADHD severity, IQ, parental depressive symptoms have been identified as moderators of treatment outcomes (Hinshaw, 2007; Mathiassen et al., 2012).

12.7.2.1 Medication

ADHD is primarily treated with stimulants. These drugs are thought to enable the individual to more readily hit the brakes and inhibit behaviour when needed (Swanson et al, 1993). Individuals with ADHD will often self-medicate with caffeine, and are more likely to use recreational drugs (Horner and Scheibe, 1997). Methylphenidate and amphetamine stimulate the release and inhibit uptake of catecholamines (dopamine and noradrenalin) and thus enhance the activity of these neurotransmitter systems, reducing symptomatology in ADHD. This suggests that ADHD is therefore the result of a dysregulation of the catecholaminergic pathways (Castellanos & Tannock, 2002). Castellanos et al. (1996) reported that the severity of ADHD symptoms was related to levels of dopamine, but effects were not found for noradrenaline. However, Michelson et al. (2001) reported that drugs that effect both dopaminergic and noradrenergic systems are more effective than more specific drugs. This suggests the involvement of the noradrenergic neurotransmission.

While the effect of these drugs do identify possible mechanisms that cause the deficits of ADHD, the delivery of stimulants to typically developing controls is also found to reduce inattention, activity, and impulsivity. The effects of stimulant medication have been found to have a proportionally larger impact on behavioural ratings than on cognitive performance (Swanson et al., 1998). MPH is effective at reducing the symptoms of ADHD with a large effect size. MRI studies show that MPH up regulates and normalises brain regions known to be under functioning in ADHD and that longer term administration enhances the activation of the basal ganglia and frontal regions (Rubia et al., 2009). The effectiveness of drug treatments has focused research on striato-frontal dopamine regions. These regions have been implicated in the cognitive deficits associated with ADHD. Medication effects have also focused research on dopamine system candidate gene searches, e.g. genes related to dopamine 4 and 5 receptors and transporters (DiMaio, Grizenko, & Joober, 2003). Strong associations for noradrenergic genes have been found (Comings et al., 1999).

The majority of the noradrenergic fibers originate in the locus coerulus, the lateral aspect of the fourth ventricle, and innervate the spinal cord, the cerebellum, the entire cerebral cortex, and hippocampus (Sara & Bouret, 2012). The two main groups of dopaminergic neurons in the brain are the nigrostiatal group, originating in the substantia nigra and innervating with the caudate nucleus and putamen, and the mesocortical group, with cell bodies in the ventral tegmental area and diffuse innervations to the forebrain, including the frontal and cingulate cortex and nucleus accumbens (Chinta & Andersen, 2005). It has been proposed that the cognitive impairments of ADHD are the result of a hypodopaminergic state in the prefrontal cortex, while hyperactivity (and possible impulsivity) are the result of a hyperdopaminergic state in the striatum (Solanto et al., 2001). Stimulants may take effect by normalising levels of dopamine in the prefrontal cortex, which in turn normalises areas secondary to the prefrontal cortex such as the striatum. This would explain why the delivery of a stimulant can still have a positive effect on symptoms despite the fact that the nigrostiatal group of dopamine neurons are hyperactive. An alternative interpretation is that an increase in dopamine within the striatum as a result of stimulant medication may amplify the spontaneous release of dopamine in response to environmental stimulation, and as a result increases the signal-to-noise ratio (Swanson, Baler, & Volkow, 2011).

We do not know if medication is normalising Sagvolden's proposed reinforcement deficit. However as mentioned, MRI studies show that MPH up regulates and normalises brain regions known to be under functioning in ADHD and that longer term administration enhances the activation of the basal ganglia and frontal regions (Rubia et al., 2009).

It is also worth considering our criteria for evaluating the effectiveness of medication. Medication is evaluated based on the reduction of severity of the symptoms observed not on the normalisation of the underlying impairment. Evaluating the effectiveness of medication based on symptoms may be limiting the types of medication developed to treat ADHD. Focusing on symptoms as outcome measure by which to assess medication efficacy in part reflects the current lack of understanding of the underlying impairments, but also reflects a bias for immediate observable results in the treatment of ADHD. However, this focus may create the situation whereby medication does not address the primary deficit but simply manages the "problem" symptoms. Related to this is the potential for medication that would normalise the underlying primary deficit not being readily evident at the symptom level. That is, even if the primary deficit was remediated the benefits of this may not be apparent until secondary deficits and entrenched behavioural responses were altered. The normalisation of the underlying primary deficit may set the context by which secondary deficits can be remediated by supporting the acquisition or development of cognitive functions, but this process of remediation is likely to be slow and may require the explicit targeting of the underdeveloped function. This line of reasoning highlights the importance of the outcome measured used to identify effective medication in ADHD. The identification of endophenotypes, the identification of subgroups within the ADHD population, and the demarcation of primary and secondary deficits may be of benefit in the identification of alternative indicators of medication efficacy. For the purpose of this the intervention proposed in this thesis the ideal medication would not produce a reduction in symptoms but create a normalised reinforcement system and a highly receptive plastic neural system that is responsive to the training attempting to remediate secondary cognitive deficit.

12.7.2.2 Alternative and complements to medication

Despite the large effect sizes and the success of pharmaceutical treatments in ADHD there are a number of reasons why alternative treatments or complementary treatments (treatments that can be combined with pharmaceutical treatment) should be identified. Firstly, the aetiological heterogeneity of ADHD would suggest that different treatments may work for different groups. Despite the large effect sizes, medication may not be equally effective across these subgroups. In addition there are a number of objections raised in relation to taking medication. There is a reluctance to prescribe medication to young children. In some cases there will also be a reluctance to avail of medication due to personal preferences. Some parents have concerns about "mind altering drugs", especially when it is not known for how long their child will need them. It is not known what effects ADHD medications are having on the brain and particularly on brain development. A reluctance to accept medication can be partly fuelled by anti-medication and anti-psychiatric rhetoric prevalent on the internet. Another concern that is raised is that those taking medication can feel that it changes who they are, that is, the medication is suppressing or modifying them in some way; this raises questions about their identity when on medication. The side effects of medication are also problematic; trouble falling asleep, loss of appetite, headaches, dry mouth, nausea, tics, dizziness, mood swings, and reduced creativity. There are also reports that medication can reduce a child's height growth (Conner et al., 1999, Swanson et al., 2007). The discontinuation of medication is commonly observed during adolescence due to the reasons outlined above.

Medication has been found to have a disproportionally larger effect on symptoms than on cognitive deficits (Boonstra, et al., 2005; Swanson et al., 1998). There is a need for treatments that address the cognitive deficits. Cognitive training interventions may offer a low-cost risk-free (no active agent) alternative to medication. The development of low-cost risk-free alternatives to medication may also offer a preventative method that could provide individuals with a predisposition towards ADHD a degree of protection against environmental triggers for the condition. Additionally, there are benefits to identifying and remediating problems during the critical periods within which a cognitive function develops. However, it is a major challenge to identify an early deviation from a typical developmental pathway with a sufficient level of precision, but in instances where the treatment is cheap, with no active agent, and is effective, the degree of precision required of an assessment test is reduced as treatment can be delivered to a broad range of individuals at risk.

There are also a number of arguments in favour of combining mediation with alternative intervention. In the treatment of depression research has shown that the effectiveness of medication combined with other treatments such as therapy is superior to medication alone (Blackburn, Bishop, Glen, Whalley, & Christie, 1981). Additionally, medication and cognitive behavioural therapy interventions for the treatment of depression, while equally effective, involve different brain regions (DeRubeis, Siegle, & Hollon, 2008). This may also be the case if comparing ADHD drug treatment with cognitive training interventions.

The research on medication in ADHD is suggestive that it has a positive normalising effect on the brain (Spencer et al., 2013). Whether medication is normalising a reinforcement deficit or not it potentially creates a more receptive neural system with greater potential to remediate the secondary cognitive deficits that result from an impaired reinforcement system, if given the opportunity. One explanation for the limited impact of medication on cognitive performance is that the cognitive skills concerned are acquired over time, therefore normalising the primary reinforcement deficit (if this is the effect of the medication) does not normalise the secondary cognitive deficits that an impaired reinforcement system produced, at least not in the short term. The acquisition of these cognitive functions will likely take time and opportunity. A cognitive training intervention could provide this opportunity. A useful analogy is that of the hammer and heat. Medication provides the heat by normalising reinforcement learning, and a cognitive training intervention targeting secondary deficits can guide neural plasticity, i.e., the hammer. Medication potentially creates are receptive neural system by which the training intervention may be maximally effective at inducing long lasting neural change.

Work by Wang and colleagues (2013) suggests that the effectiveness of medication may wane over time (also see Crawford, McDougall, Meier, Collins, & Watson, 1998, while Kuczenski & Segal, 2002 report no effect). If true, the reducing effectiveness of medication may constitute a limited time window in which to maximise the benefits of complimentary treatments to be used in conjunction with medication. If a cognitive training intervention effectively enhances cognitive performance and induces lasting neural plasticity changes when combined with medication, then there is a need to deliver such treatments while the medication is still effective. More research is needed in this area.

ADHD constitutes a large burden for the individual with the condition and for society; the development of alternatives to medication and the development of treatments for use in combination with medication have the potential to make a significant contribution to reducing this personal, social, and financial burden. I have suggested that individuals with ADHD fail to learn inhibitory control skills due to an impaired dopamine reinforcement system, but this is also due to a lack of opportunity owing to the fact the socialisation process is biased in favour of the learners with "typical" reinforcement parameters. The education system, and more broadly the socialisation process that our culture has established primarily cater for typically developing children; as a result those with an altered reinforcement system have both a reduced capacity and opportunity to develop a host of cognitive and behavioural functions. The effective management of the condition requires that parenting and the environment are responsive to the altered reinforcement systems observed in ADHD. Medication is posited as normalising to some degree the dopamine dysfunction and while the intervention is attempting to create a learning environment to account for the altered reinforcement parameters, there is also a role for interventions targeting the environmental context of the learner. Below I briefly review parent training and discuss the potential need for societal change.

12.7.2.3 Parent training

Research links parenting with brain development and neurocognitive functioning (Bernier, Carlson, & Whipple, 2010). Children with ADHD tend to have more conflictual parental interactions (Barkley et al., 2001; Deault, 2010; Lange et al., 2005). The parents of children with ADHD are found to exhibit more directive and commanding behaviour, more disapproval, fewer rewards and more negative disciplinary strategies. This in turn contributes to familial disharmony and parental stress which in turn lead to poorer long-term behavioural and treatment outcomes for children with ADHD (Hinshaw et al., 2000; Keown & Woodward, 2002). Reductions in parental negative disciplinary strategies, however, were found to be a significant mediator of better developmental outcomes for children with ADHD (Hinshaw et al., 2000; Tarver, Daley, & Sayal, 2014).

Behavioural management techniques designed to decrease the frequency and severity of troublesome ADHD type behaviours have been taught to both parents and/or teachers. These techniques have been tested in controlled classrooms, psychoeducational groups, and specialised summer camps. These techniques are derived from behaviour modification, social skills training, parent and teacher training and support groups (Pelham & Hoza, 1996). For treatments to be most effective, they need to be implemented in multiple settings, including the home, school, and community (Pelham et al., 2000). Gaining consistency among multiple providers can be difficult.

In terms of the nature of the parenting intervention Halprin suggests that it is important that the quality of the parenting is improved as opposed to learning to control the child. He states that parental warmth is critical. Negative affect leads to negative outcomes (Healey, Flory, Miller, & Halperin, 2011; Halperin, Bédard, & Curchack-Lichtin, 2012). One suggested intervention is to train parents to teach skills to their children, that is, the parent training intervention is training parents to train particular skills in their children. Targets for training include WM, attention control, motor skills, pattern recognition, inhibitory control and physical exercise (Cousins and Weiss, 1993; Erk, 1997; Forgatch et al., 2004; Green and Chee, 1997, Newby et al., 1991).

If the proposed cognitive training of inhibitory control is successful these gains may not be evident at the behavioural level unless additional training is similarly implemented to alter the behaviour. Ideally the trainees will demand more of themselves and utilise newly acquired functions, but there may also be a need for demands to be placed on the trainees until the newly acquired function is consolidated and integrated into their behavioural repertoire. This has particular relevance for children with ADHD for whom the consolidation period maybe protracted. In addition the individuals habitual behavioural repertoire may need to be challenged to ensure they utilise and integrate a newly acquire cognitive function at the behaviour level. For example, teachers and care givers may need to demand improved performance in those areas were improved inhibitory control would be expected. Having newly acquired skill integrated into the daily routine will ensure they are maintained.

12.7.2.4 Societal change

While problem behaviours and symptoms often need to be corrected or managed, and while a combination of medication and interventions (such as the training as proposed in this thesis) can help to correct problem behaviours and symptoms the onus may not solely be on the individual with ADHD. There is also a need for schools, work places and society in general to adapt to the variation seen within the population. In a performance driven society that pushes for greater productivity and efficiency the combination of a socially constructed concept of normal behaviour and the means to modify aspects of behaviour and neural activity to encourage conformity are a dangerous combination.

There are a number of ethical issues that society should reflect upon when attempting to shape the behaviour. To what degree should the individual with ADHD modify their behaviour and to what degree is there an onus on society to be flexible to meet the needs of its people? Perhaps greater flexibility in the school and work environments will allow those with ADHD to enhance their contribution. Research on temperament suggests that the goodness of fit between a child's temperament and the environment (expectations, demands and opportunities) is critical. A better fit leads to fewer behavioural problems (Chess, 1990). When the environment is altered to match the child's temperament, fewer behavioural problems are expected to develop (Mather, 2012).

12.1 Concluding remarks

This thesis has developed an inhibitory control training intervention and a number of assessment tasks to measure it efficacy. The proof-of-concept study supported the viability of delivering the training intervention with an adult ADHD population. There is now a need for a proof-of-concept study to establish the efficacy of the training with respect to enhancing the targeted functions, namely inhibitory control and aspect of timing and attention. To this end a larger sample with a confirmed diagnose of ADHD and a control intervention are required.

The complexity of training cognitive functions, the lack of clarify with respect to the a coherent of account of the deficits that underlie ADHD, and more broadly within psychology the limited accounts of cognition and neurology underscore the need for any ADHD intervention to demonstrate practical gains that translate to everyday function. It is hoped that subsequent trials of this intervention will first demonstrate robust gains on the functions targeted, and subsequently demonstrate functional gains and a reduction in the severity of problematic ADHD symptoms.

I have suggested that this intervention may be useful for the remediation of cognitive deficits associated with ADHD. If the remediation of such deficits can be establish, and if their remediation is found to have a practical relevance for everyday tasks and behaviours, the potential to use this intervention as a preventative measure should be explored. The intervention has no active agent, that is, it is non-pharmacological. In addition, the technology required for the delivery of the intervention, for example eye-trackers, is increasingly available. Interventions such as this could be delivered to those populations with a genetic predisposition or who evidence an endophenotype associated with ADHD, for example an impaired performance on the stop-signal task. The early administration of such measure may serve to minimise the impact of the condition.

While the intervention may be capable of delivering some gains in the functions targeted it is the opinion of the author that such interventions must be delivered as part of a holistic approach to the treatment of ADHD. Discussed above are the potential benefits of combining the delivery of the intervention with medication to ensure training gains are made and consolidated. In addition there is a need to consider the role of the home and school environment. If the capacity to implement new behaviours has been developed with a cognitive training intervention equally important may be the need for parents and teachers to support a child with ADHD to develop and adopt new patterns of behaviour. One approach that is increasing viable is to modify the interventions such that it can be delivered in the home or school environment.

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14 Appendix

14.1 Potential tasks improves

Anti-saccade

The inter-trial interval is currently set to be inconsistent. Having a alternative version in which the inter-trial interval consistent may be a useful way to integrate a longer duration estimation component into the task.

Having a cue fade in may be a useful way to encourage greater sustain vigilance.

One approach that could be taken is to progressively increase the complexity of the tasks and integrate the tasks, for example, a version of the task in which trainees should not made a saccade until a cue is given which appears after the typical anti saccade cue. This cue could be the disappearance of the anti-saccade cue, or the disappearance of the fixation cross, or could be an arrow placed centrally.

Pre-empt the anti-saccade cue with an auditory tone.

The timed saccade task

Consistent production of their own chosen interval

Consistent production of a given interval

Tapping a response button to the swing of an on screen pendulum

The movement of the gaze or tapping a response button to the rhythm of a metronome

Comparison or two stimuli presentation intervals, potentially of different modalities (e.g. auditory / visual)

Encouraging trainees to explore different strategies such as explicitly tell them to count / not to count?

While the time is set to be the same for both the timing tasks in any training session in reality if we want the time to be consist for both there should be a happy middle time duration that would work for both without any need for modifications for each trial. At the moment this is the situation as the participant must respond earlier for one and late (reverse timing task) for the other, thus the time they must wait in each is slightly different.

Stop Signal Task

Version of the task with lots of stop trials (e.g. 66% stop-trials)

Version with a long response window that encourages them to wait (points go to zero if they make a mistake)

For participants who particularly struggle with the stop signal task I could have the stop trials proceeded by an auditory tone – I could then progressively introduce the tone into go trials or fade out the auditory tone for stop trials. It could additionally be useful to fade in or out and auditory tone to either trial-type examine the strength of conditioning.

It should be noted that the stop signal task does require a good sense of timing but the magnitude of the difference between this timing tasks and the explicit timing task may mean that the timing systems are not common to both. This may be worth examining in future

Jumping Bomb Task

After the trainee has establish a degree of competency on this task I could introduce a stop signal (or a distractor). The trainee at this stage will have learn to response very quick to the arrival of the target. They introduction of a stop signal will examine the degree to which the can relearn and adapt.

Delayed saccade task

A fault with the delayed saccade task is that if the participants wants to avoid the slowness of the task they can make a premature saccade to make the trial short. This strategy is eaily detected as a poor performance score but avoiding this preventing participants form potentially avoiding this delay is an easy to fix.

A weakness for the ass2 of the delay saccade task is that this task required participants to learn how the tasks works. For ass2 trainees have a large amount of exposure to the rules of this task. This is particularly important for this task as during the assessment there is no feedback to let you know how you are doing, unlike for the anti, timing and stop signal task. One approach would be to allow all participants to become familiar with the assessment tasks and see the practice effect stabilise to some degree before delivering the assessment one baseline.

The ecologically valid of the training tasks could be increased by placing the targets and distracters at varying distances and angles. At present they appear a set points on a circular grid

14.2 Using the Eye tracker - Quick start guide

This write-up is not definitive. Please suggest/add any amendments that you think need to be made to this document or any tips on the use of the eye-tracker that could be added.

N.B. The eye-tracker should be turned off at the wall after use. Even if the computer is turned off the camera will still receive power if not turned off at the wall, and as a result will overheat. This can result in failure of the equipment when gathering data and will likely wear out the equipment prematurely.

The eye-tracker is currently located in the physiological lab (A09b?). To use the eye-tracker you must first book its use using the lab google calendar online booking system we are using. You will also need special card access to get into the lab, and secondly the code for the key pad lock to gain access to the key to unlock the door to the physiological lab. To arrange these things you can email myself (mcxpc1@nottingham.ac.uk) or other lab users and we will point you in the right direction.

Coding up you tasks

When coding up your tasks it is best to start with someone else's program. Programming is done with Matlab. Matlab is the programming platform. Within Matlab is it possible to use additional programs. These work ontop of Matlab using it as their base.

I identify two separate goals when programming in Matlab. Firstly, controlling when and what is displayed on the screen. The free Cogent program is very useful here. Secondly, manipulating matrices of numbers. I recommend Antonia Hamilton's tutorial " Matlab for psychologists" as a good initial introduction to this and the common commands and features of Matlab.

When it comes to developing your own programs begin with examples that bare a close similarity to what you would like to program. Learn by manipulating existing scripts and take note of the new functions of use that you come across. One of the main determinants of competency in Matlab is having a catalogue of commands at your disposal.

Within the Matlab environment we are using cogent to help with the visual display and CRS, that Cambridge Research Systems program for handling the eye-tracker. When programming have the pdf for the cogent manual handy, as well as the booklet for with the CRS commands.

At the top of your script you will have a number of housekeeping lines of code. Ensure the distance from the screen matches the parameters set in for script. Ideally the screen should be in the dead centre, and the middle of the screen should be approximately in line with the eyes. However, I have found that the reliability of the eye image is improved it the middle of the screen is slightly elevated above the level of the eyes. This encourages the participant to open the lid of their eye more fully resulting in a more consistent clear view of the pupil. If the top of the pupil is obscured but the eye lid or eye lashes the tracker will lose the eye location and within your results you will not be able to distinguish this data from an eye blink or eye closed.

Setup

When the subject is in position your first need to make sure that you are getting a clear picture from the camera. The picture should be in focus and the eye should be in the center of the image and should be well lid without shadows of the eyelids on the eye. Make sure to verify that the picture is good while the subject is looking at all four corners of the screen, not just the middle.

If the eye-tracker is going to have problems with tracking a particular individuals eyes then this will usually be seen for targets at the bottom corners of the screen. This is because when viewing targets at the bottom of the screen they will tend to allow their eye lid to drop and obscure the top most part of the pupil. When programming try avoid having stimuli at the very bottom edges of the screen.

When arranging for you participants to visit the lab ask them to refrain from wearing mascara or any other eye make-up as this can interfere with the recording. The wearing of glasses or contact lenses is not a problem. It is important the participants are wearing their glasses or lenses to see the screen clearly when gathering data.

Room luminance should be consistent across participants (in the physiological lab the light can be dimmed by holding the light switch down). I have the light turned up to maximum luminescence in order to ensure consistence. When the room is dark participant’s pupils will be more dilated, this can cause a problem if as a result your participants pupil becomes part obscured by their eye lid. The luminescence of you stimuli and screen background will also impact on the degree of pupil dilation.

Make sure participants do not need to go to the toilet before beginning. Offer them water to drink. Make it clear to them that once they sit into the head rest and are calibrated they should not move from this position until all tasks are completed. It is good to give your participants a moment to get use to sitting in the position before aligning the camera with their eye. When seating your participants make it clear to them that they should be in a comfortable position/posture which they can maintain throughout the session. People will often at first sit quite erect to begin but after a period will slouch. It is better to have them slouch from the beginning before calibration has been conducted. If you start the experiment and you notice that they have changed their position (slouching or shifted right or left) then consider recalibrating.

Calibration

Before an experiment can be run you need to do a calibration. This is an automatic procedure that will adjust the main parameters to the specific subject. It requires the subject to fixate on a point that is being moved to a number of locations all over the screen. Calibration shouldn't take more that 20-30 seconds. If the subject leaves the setup, during a break, they recommendation is that you calibrate again at the beginning of the next block. The advice is to re-calibrate quite frequently (e.g. every 10 minutes),

First adjust the high of the table. Get them to look at the direst centre of the monitor. Adjust the high of the chin rest to align their eye correctly on the vertical axis in the video screen. Readjust the table high if necessary. Then move the camera left or right to correctly align their eye on the horizontal axis having decided if you will record the left or right eye (see below). Their eye should now be in the direct centre of the camera window. There are two adjustable rings at the top of the camera. Adjust the aperture ring if needed (alters the exposure, the amount of light entering the camera). It is best to have the aperture fully open, however with some people whom you are having trouble tracking, that is the tracker is occasionally losing the pupil, I have found the a slight change in the aperture (closing it slightly) can greatly improve the quality of the recording. This is very important, take note of this point, it could really improve the quality of your data! Use the second ring to focus the camera ensuring that you are focusing on the pupil and not the eye lashes.

Sitting in the eye-tracker can be tiring on the neck muscles; therefore if you are conducting a number of tasks you should plan to give your participants a break in which they are free to sit back from the equipment. Once the break is over the advice is to recalibrate them. I have not found that this make difference if when they sit back their eye assumes the same position in the camera screen.

You want to make sure that there are no superfluous objects about that may be a source of interest or distraction for the participants. Non task relevant noise needs also to be eliminated. This includes you the experimenter ruffling though sheets or moving about in your chair.

Participants, especially children will often move their head in addition to moving their eyes. This will be extremely problematic for the quality of your data if the movements are large. All you can do is remind them not to move their head and that this is more important than going really fast. To limit the noise this introduces to your data you can consider having first a brief training session in which you monitor participant specifically for these head movements. If they are moving their heads you should train them until they cease moving their heads and then recalibrate before gathering the experimental data.

It is good to have breaks during tasks so that participants can rest their eyes. Some participants do find the tasks quite tiring on the eyes. During breaks if possible do not let the participants sit back away from the equipment. If giving participants a break, for example of 20 seconds, you need to consider whether you will require all participants to take this break. Some may be eager to get on with the task and may not feel that their eyes are tired, but considerations need to be made regarding giving a cognitive rest period to some participants and not to others. I have all participants forced to take a break of uniform length.

Monocular tracking

When using a monocular eye there are two possibilities: using the same eye for all subjects, or using the dominant eye for each subject. The dominant eye can be found by asking the subject to look through a small hole in a card. People do this with their dominant eye.

The advantage of using the same eye for all subjects is that your data will be more consistent over subjects. This is because of the distortion associated with extreme left or right gaze locations. This will be less of a problem when your experiment only involves central gaze locations.

The advantage of using the dominant eye is that the data will be less noisy. The non-dominant eye can have the tendency to make 'glissades', small eye movements to align itself with the dominant eye at the end of a saccade. These will not be present to the same extent in the dominant eye.

A simple method to determine which is the participants dominant eye is to place a small hole in a piece of card and ask the participants to read a piece of text through this hole. The participants will hold the hole in the card up to their dominant eye. The majority of people are right eye-dominant.

Asymmetries in tracking accuracy

There are typically left-right differences in (monocular) data. Eye tracking data will always be less reliable and distorted towards the edges of the screen, and the problems are more serious for the eye on the opposite side. Try to present your stimuli in the center section of the screen, if possible.

Common eye tracking problems

Pupil Center Shift

With some subject the center of the pupil shifts when the pupil changes diameter. This can actually have a quite strong effect on the eye tracking results, with some people proving almost impossible to track for this reason. There is currently no real solution for the problem, except for the advice to keep luminance levels stable during your experiment to try to keep pupil diameter from changing too much. But since diameter is not only depending on luminance, this will not always work

Ambient light

When ambient light levels are too high the raw eye picture can become a bit washed-out and the software will have trouble tracking the pupil and corneal reflection. The advice is to keep your light levels as low as possible and make sure there is no direct light from a strong source falling on the subject's face. However, I find this can dilate the pupil which leads to problems, so instead we have placed a box over the eye-tracker to reduce the light falling on the image of the participants eye.

In the MRI and MEG trackers it is also possible that the IR light source for the eye tracker isn't correctly pointed at the subject's eye. Since IR light isn't visible to the naked eye, you'll have to check the raw eye picture while trying to re-adjust the IR light source.

Glasses

Glasses are normally not a problem. Bifocal or varifocal glasses can be more problematic, but normal glasses are no obstacle for eye tracking. The only problem can be with reflections. If the orientation of the glasses is such that a clear reflection of the infra-red light source is visible eye tracking can be impossible. This can usually be solved by changing the angle of the glasses. Dirty or scratched glasses can be a problem too. Contact lenses are usually no problem at all.

The current MRI-compatible glasses use very small lenses, so it can be difficult to get to a point where the participant can see the entire screen, and the eye tracker can see the entire eye. Sometimes it is possible to get good data despite glasses, but it's probably wise to encourage your participants to wear contact lenses if they have any.

Makeup

Mascara can make eye tracking impossible, as the software will interpret the black regions in the picture as the pupil, and mascara is very black too. Mascara will always have to be removed, and it is best to ask people not to wear any mascara when they participate in an experiment involving eye tracking.

A solution might be to have makeup remover available in in the lab.

Drooping eyelids

Drooping eye lids can be a problem, as they can partly obscure the pupil. This is more common with older people. The solution is to move the camera to a lower position, if possible, so that the eye is filmed from below. I have found that raising the screen can help but this will throw the accuracy data off , by not having the eye high in line with the screen high. If that doesn't help an eyelash curler can be used.

14.3 Sample script

Example script for processing data for the identification of saccade onset time and location saccade.

```
%Raw data should have been saved while the participant completed the task.
%This raw data should first be loaded

%create a variable array in which to save the results of the processing
DataOutputs = zeros(80,6);

%Determine the size of the raw data array
R = size('raw file name here, e.g.x104Mel');

%start the main loop. The number of iteration is the size of the file (R)
%divided by 9 (because in this case there are 9 rows of variable saved for
%each trial)

for i = 1:R(1)/9
```

```
% create a variable 'H' to be used as a switch to aid the flow of the script
   H = 0;


% a number of blank variables are created
   LandingPointAccuracy = NaN;
   BestAccuracy = NaN;
   CueAccuracy = NaN;
   Response = NaN
   CorrectionTime = NaN;
   TargetDirectionTime = NaN;
   CueDirectionTime = NaN;
   BestAccuracy = NaN;
   CueAccuracy  = NaN;
   Times_Of_Early_Movement =NaN
   RT2 = 0;
   RT =0;


%any pre-existing data is cleared - this will happen for each trials as we are now in the trial loop
   clear Data

% The first row of the array Data is made to equal the recorded Times
   Data (:,1)  = x104Mel(((i-1)*9)+5,:);%Times

% The number of data points (Lengths) is calculated based on the number of Time stamps
   Length = length(Data);

% The X, Y, Fixation, and Pupil Diameter data is added to the row of the data array
   Data (:,2)  = x104Mel(((i-1)*9)+1,1:Length);%mmPositions, X
   Data (:,3)  = x104Mel(((i-1)*9)+1,Length + 1 :Length*2);%mmPositions, Y
   Data (:,4)  = x104Mel(((i-1)*9)+6,1:Length);% Fixations
   Data (:,5)  = x104Mel(((i-1)*9)+4,1:Length);% PupilDiameters

% The data is then order based on time data in row one. It is order
% from smallest to highest number. This is done to correct a technical
% error noted in the data resulting from unknown reasons. All rows are reordered based on the
reordering of row one.
   Data = sortrows(Data);

% The trial type, i.e. left or right target is loaded.
% Also loaded in the location of the target stimuli.
   Data (1,6)  = x104Mel(((i-1)*9)+7,1);%Trial type
   Data (1,7)  = x104Mel(((i-1)*9)+9,1);%Location, 1 =1 right, 2 = left

% The location of the intended target is determines
   if  Data (1,6) == 1
      trial_location = 5;
   elseif Data (1,6) == 2
      trial_location = -5;
   end

% a random period the related to a section of irrelevant data at the
% start of the trials is loaded. Random Period = (RandomPeriod/17)*13.33
   RandomPeriod = SubResults.Spreadsheet(i,3);

% A time stamp recorded during the presentation of the trial is laoded.
% It indicated the time at which the trial began
   time_pt_1 = Data (1,6);
% Other points of interest are calculated
```

```
    time_pt_2 = time_pt_1 + RandomPeriod;
    time_pt_3 = time_pt_2 + (60*17);%

%Individual variables are extracted from the Data array
    Times  = Data (:,1);
    X = Data (:,2);
    Y = Data (:,3);
    Fixations = Data (:,4);
    PupilDiameter = Data (:,5);

% The period of interest is determined
    IndexPostTargetTime1 = Times > (time_pt_1 - 1) ;
    IndexPostTargetTime2 = Times < time_pt_2 + 1;
    IndexPostTargetTime = IndexPostTargetTime1 & IndexPostTargetTime2;

% The values for the varables of interest for a given period of interest are defined.
    X = X(IndexPostTargetTime);
    Y = Y(IndexPostTargetTime);
    Times = Times(IndexPostTargetTime);
    Fixations = Fixations(IndexPostTargetTime);
    PupilDiameter = PupilDiameter(IndexPostTargetTime);

%the distance of for each gaze position (X,Y) if there is a fixation value of one (they
%are fixating) is calculated and saved to the row vector 'Distances'
    Distance = NaN(length(Times),1);
    for cc = 1:length(Times)
        if  Fixations(cc,1) == 1
            A = sqrt( (  (0*23) - X(cc,1)).^2  + (   0 -   Y(cc,1) ).^2  );
        else
            A = NaN   ;
        end
        Distance(cc,1) = A;
    end

% Within the distances points greater than 30mm and less than 150mm are identified.
    EarlyMovementIndex = Distance>30 & Distance< 150;
    EarlyMovementPoint =find(EarlyMovementIndex,1, 'first');

% Only if there are no early movement does the script process to the
% next sectionm otherwise the time of the early movement id recorded
    if isempty(EarlyMovementPoint)
        H = 1;


    else H = 0
        Response = 1 % Early Movement
        EarlyMovementPoint2 = Times(EarlyMovementPoint);
        Times_Of_Early_Movement =EarlyMovementPoint2 - time_pt_1 ;
    end

    if H == 1
%the variable of interest are redefined to include all data points, limited to the old period of interest -
that is the pre-jump period
        Times  = Data (:,1);
        X = Data (:,2);
        Y = Data (:,3);
        Fixations = Data (:,4);
        PupilDiameter = Data (:,5);

% A new period of interest is determined
        IndexPostTargetTime1 = Times > (time_pt_2 - 1) ;
```

```
        IndexPostTargetTime2 = Times < time_pt_3 + 1;
        IndexPostTargetTime = IndexPostTargetTime1 & IndexPostTargetTime2;

 % The variable of interest are redefine for this period of interest
        X = X(IndexPostTargetTime);
        Y = Y(IndexPostTargetTime);
        Times = Times(IndexPostTargetTime);
        Fixations = Fixations(IndexPostTargetTime);
        PupilDiameter = PupilDiameter(IndexPostTargetTime);

%Gaze distances greater than 30 mm and less than 90 mm from the central fixation point are recorded
        clear Distance
        Distance = NaN(length(Times),2);
        for cc = 1:length(Times)
            if  Fixations(cc,1) == 1
                A = sqrt( (  (trial_location*23) - X(cc,1)).^2  + (    0 -   Y(cc,1) ).^2  );
                B = sqrt( (  (-trial_location*23) - X(cc,1)).^2  + (    0 -   Y(cc,1) ).^2  );
            else
                A = NaN   ;
                B = NaN;
            end
            Distance(cc,1) = A;
            Distance(cc,2) = B;
        end
        LandingPointIndex = Distance(:,1)<90;
        LandingPointIndex2 = Distance(:,2)<30;
        LandingPoint =find(LandingPointIndex,1, 'first');
        LandingPoint2 = find(LandingPointIndex2,1, 'first');
        LandingPointAccuracy = Distance(LandingPoint,1);
        LandingPointAccuracy2 = Distance(LandingPoint2,1);
        CueDirectionTime = Times(LandingPoint) - time_pt_2;
        TargetDirectionTime = Times(LandingPoint2) - time_pt_2;

%There response location and time based on where there is a gaze location within the region of
interest or not is recorded
        if isempty(LandingPoint)&& isempty(LandingPoint2)
            H = 2;


            Response = 4;%No Response


        elseif isempty(CueDirectionTime)
            Response = 2 ;%Well Done
            LandingPointTime = TargetDirectionTime;
            CueAccuracy = min(Distance(:,1));
        elseif isempty(TargetDirectionTime)
            Response = 3 ;%Wrong direction
            LandingPointTime = CueDirectionTime;
            CueAccuracy = min(Distance(:,1));
        elseif TargetDirectionTime < CueDirectionTime
            Response = 2 ;%Well Done
            LandingPointTime = TargetDirectionTime;
            CueAccuracy = min(Distance(:,1));
        elseif TargetDirectionTime > CueDirectionTime
            Response = 3 ;%Wrong direction
            LandingPointTime = CueDirectionTime;
            CueAccuracy = min(Distance(:,1));

            CorrectionTime = TargetDirectionTime - CueDirectionTime;
        end
    end
```

```
    % Having identified that the gaze direction was  within
    % a range of interest during a period of interest we now
    % perform velocity analysis to identify when the saccade occurred

    %The variable are again redefined for the new period of interest
    if  H ==1
        Times  = Data (:,1);
        X = Data (:,2);
        Y = Data (:,3);
        Fixations = Data (:,4);
        PupilDiameter = Data (:,5);
        IndexPostTargetTime1 = Times > (time_pt_2 - 1) ;
        IndexPostTargetTime2 = Times < LandingPointTime + time_pt_2 + 30;
        IndexPostTargetTime = IndexPostTargetTime1 & IndexPostTargetTime2;
        X = X(IndexPostTargetTime);
        Y = Y(IndexPostTargetTime);
        Times = Times(IndexPostTargetTime);
        Fixations = Fixations(IndexPostTargetTime);
        PupilDiameter = PupilDiameter(IndexPostTargetTime);

% The distance between adjacent gaze points is determined, this row
% vector is call 'lengths'
        Lengths=sqrt((X(2:end)-X(1:end-1)).^2+(Y(2:end)-Y(1:end-1)).^2);
        Eye_velocity=zeros(size(Lengths));

        %Here the window size of 3 is set, this determines the amount of
        %smothing (noise removal).
        WindowSize = 3;

%The differences between adjacent bin of sizes of 3 (that are the average distances between points
are calculated for the length of the row vector 'lengths' to give smoothed velocity between points.
        for bb=WindowSize+1:length(Lengths)-WindowSize-1
            Eye_velocity(1,bb)=mean(Lengths(bb:bb+WindowSize-1))-mean(Lengths(bb-WindowSize:bb-
1));
        end

% the positive (acceleration) and negative (deceleration) peaks in velocity are identified
        try
            [pksOnsets,locsOnsets]=findpeaks (Eye_velocity, 'SORTSTR', 'descend');
            [pksOffsets,locsOffsets]=findpeaks (-Eye_velocity, 'SORTSTR', 'descend');
        catch
        end

% The time of the saccade us recorded
        try
            OnsetTimes=Times(locsOnsets(1,1));
            OffsetTimes=Times(locsOffsets(1,1));
            RT =OnsetTimes - time_pt_2;
        catch

        end
        try
            RT2 =   LandingPointTime;
        catch
        end
    end


% The data is then saved as an array for subsequent analysis.
    DataOutputs (i,1) = Response;
```

```
    try
        DataOutputs (i,2) = RT;
    catch
        DataOutputs (i,2) = NaN;
    end
    try
        DataOutputs (i,3) = RT2;
    catch
        DataOutputs (i,3) = NaN;
    end
    try
        DataOutputs (i,4) = RT2 - RT;
    catch
        DataOutputs (i,4) = NaN;
    end
    try
        DataOutputs (i,5) = CorrectionTime;
    catch
        DataOutputs (i,5) = NaN;
    end
    try
        DataOutputs (i,6) = TargetDirectionTime;
    catch
        DataOutputs (i,6) = NaN;
    end
    try
        DataOutputs (i,7) = CueDirectionTime;
    catch
        DataOutputs (i,7) = NaN;
    end
    try
        DataOutputs (i,8) = BestAccuracy;
    catch
        DataOutputs (i,8) = NaN;
    end
    try
        DataOutputs (i,9) = CueAccuracy;
    catch
        DataOutputs (i,9) = NaN;
    end
    try
        DataOutputs (i,10) = Times_Of_Early_Movement;
    catch
        DataOutputs (i,10) = NaN;
    end
end
```

14.4 Reading text sample

Screen one

Your Amazing Brain

You carry around a three-pound mass of wrinkly material in your head that controls every single thing you will ever do.

From enabling you to think, learn, create, and feel emotions to controlling every blink, breath, and heartbeat - this fantastic control center is your brain.

It is a structure so amazing that a famous scientist once called it "the most complex thing we have yet discovered in our universe."

Screen two

Your brain contains about 100 billion microscopic cells called neurons

Whenever you dream, laugh, think, see, or move, it’s because tiny chemical and electrical signals are racing between these neurons along billions of tiny neuron highways.

Countless messages zip around inside it every second like a supercharged pinball machine. Your neurons create and send more messages than all the phones in the entire world.

Screen three

When you learn, you change the structure of your brain.

Riding a bike seems impossible at first. But soon you master it. How?

As you practice, your brain sends "bike riding" messages along certain pathways of neurons over and over, forming new connections. In fact, the structure of your brain changes every time you learn, as well as whenever you have a new thought or memory.

Screen four

Exercise helps make you smarter.

It is well known that any exercise that makes your heart beat faster, like running or playing basketball, is great for your body and can even help improve your mood. But scientists have recently learned that for a period of time after you've exercised, your body produces a chemical that makes your brain more receptive to learning. So if you're stuck on a homework problem, go out and play a game of soccer, then try the problem again. You just might discover that you're able to solve it.

14.5 Recruitment Poster

The University of Nottingham

candal
Centre for ADHD and neurodevelopmental disorders across the lifespan

CHILDREN AND ADULTS WITH **ADHD** WANTED TO PARTICIPATE IN STUDY

A study is currently being conducted at the University of Nottingham.
We are testing a brain training game that tries to improve attention in people with ADHD.

To take part you should be - **aged between 9 and 50**
- **have ADHD (but without Tourette Syndrome)**

Participation involves a commitment to attend **10 training sessions**.
Your travel expenses will be paid and an inconvenience allowance will be given.

Contact Peter Collins - mcxpc1@nottingham.ac.uk, Tel: (0)115 74 84332

For more information - https://sites.google.com/site/adhdattentiontraining/
Here is a link with a short video of the training game - http://youtu.be/WqpvY-41TKg

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