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Identifying Cognitive Profiles in Children with Neurodevelopmental Disorders Using Online Cognitive Testing

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Abstract

Neurodevelopmental disorders (NDDs), including autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD), are characterized by diverse cognitive deficits. Early identification of cognitive deficits is fundamental to improving academic and emotional/behavioural outcomes in children. Creyos has pioneered online cognitive testing which assesses working memory, attention, reasoning and verbal abilities. We developed audiovisual instructions for the task battery and implemented them in an online sample of children ages 4-16 with ADHD ($n = 83$), ASD ($n = 37$), and typically developing children (TD) ($n = 86$), to determine whether unique cognitive profiles would emerge. Four tasks reflective of working memory, reasoning, and attentional processes correctly classified ~53-60% of each diagnostic group. The ADHD group had lower scores on attentional tasks, while the ASD group had lower scores on reasoning and more attempts across all tasks, compared to TD. Results suggest that the battery is feasible to implement in these populations.

Key Words

Neurodevelopmental disorders

Cognitive testing

Attention Deficit Hyperactivity Disorder

Autism Spectrum Disorder

Executive Functioning

Summary for Lay Audience

Commonly diagnosed Neurodevelopmental disorders (NDDs) include autism spectrum disorder (ASD), and attention deficit hyperactivity disorder (ADHD). Children with NDDs often experience a wide range of cognitive difficulties which can seriously impact their academic, emotional and behavioural outcomes at school. In this study, we partnered with Creyos, who has created online cognitive testing in adults. These ‘gamified’ tasks assess a number of cognitive abilities including working memory, attention, verbal skills, and reasoning. We developed audiovisual instructions to make these tasks more suitable to children with and without NDDs. These tasks were then used in an online sample of children with ASD, ADHD, and typically developing children. We wanted to see how each group of children performed on the tasks, to assess their relative cognitive strengths and difficulties. We found that the Creyos tasks could successfully categorize each group of children based on their task performance. The ADHD group had lower scores on attentional tasks compared to TD children. The ASD group had lower scores on reasoning compared to TD children. The Creyos task battery may eventually be used to help identify cognitive difficulties and improve outcomes in children with NDDs.

Co-Authorship Statement

This thesis contains a submitted manuscript titled "*Identifying cognitive profiles in children with neurodevelopmental disorders using online cognitive testing*" which can be found in Chapter 2. Dr. Emily Nichols, Sarah Al Saoud, and Dr. Emma Duerden are co-authors on this manuscript. Drs. Nichols and Duerden were involved in the study design. The task battery used in this study was developed by Creyos and accessed through their online platform. As first author, I completed the data analysis and wrote the manuscript independently. My co-authors provided valuable feedback and edits on the manuscript.

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Chapter 1

1.1 Introduction

Neurodevelopmental disorders (NDDs) are a group of heterogeneous conditions which are associated with significant delay in grey and white matter development in the brain. Prefrontal cortices, key structures involved in cognitive functioning, are particularly impacted by this altered trajectory of brain growth in these disorders (Bennett, & Lagopoulos, 2015; Xiao et al., 2014). Evidence suggests that NDDS are associated with dysfunction in frontal-subcortical circuits involved in executive functioning (EF) skills; which are vital for adaptive behavior and learning (e.g., working memory, planning, inhibition, attention) (Powell & Voeller, 2004; Sun & Buys, 2012). In turn, NDDs are characterized by a disturbance in the acquisition of skills in a variety of developmental domains, including motor, social, language, and cognition. Some of the most commonly diagnosed NDDs, include attention deficit hyperactivity disorder (ADHD), and autism spectrum disorder (ASD) (DSM-V, 2013). These neuropsychiatric disorders are characterized by diverse cognitive deficits that can vary within and between diagnoses. Accessible cognitive screening is needed in order for children with NDDs to receive proper intervention which addresses their specific cognitive needs.

1.1.1 NDDs and Neurocognitive Deficits

1.1.2 Autism Spectrum Disorder

ASD is broadly characterized by social/communicational deficits, and restricted/repetitive behaviors, although a wide range of symptoms may emerge from these categories. Specifically, symptom severity is assessed based on the amount of support the child requires for daily function (ranging from severely impaired to highly functional). (DSM-V, 2013). Depending on this functional severity, children with ASD may have difficulty relating to their peers, understanding other's thoughts / feelings, and communicating verbally or non-verbally (Bellini, 2004). Non-social cognitive deficits are also found in spatial reasoning, working memory, planning, and inhibition (Banker et al., 2021; Cantio et al., 2018). Research has particularly highlighted the relevance of working memory in ASD, due to its vital role in social cognition, language comprehension, and problem solving (Habib et al., 2019). Namely, significant impairments in ASD have been found in the phonological and visuospatial working memory domains, which are responsible for encoding, integrating and manipulating linguistic and visuospatial information (Baddeley, 2012; Habib et al., 2019).

1.1.3 Attention Deficit Hyperactivity Disorder

ADHD symptoms also exist on a continuum, and may include inattentiveness, and/or hyperactivity and impulsivity (DSM-V, 2013). These symptoms can cause great interference in a child's academic success, and interpersonal relationships. Specifically, hyperactive/impulsive symptoms are thought to be a result of core inhibitory deficits, resulting in attentional, working memory and affect regulation difficulties (Barkley, 1997). More recently, working memory has been proposed as the central cognitive impairment in ADHD, impacting attention regulation and organization (Kofler et al., 2018). A large meta-analysis revealed that children with ADHD had significantly worse verbal working memory when compared to typically developing (TD) individuals (Ramos et al., 2020). Further, research has indicated that children with ADHD may experience deficits in verbal function, visual-spatial skills, and processing speed (Kofler et al., 2020; Leitner et al., 2007). Overall, many subtypes can exist within each NDD depending on the child's unique set of strengths and cognitive challenges.

1.1.4 Cognitive Similarities and Differences Among ASD, ADHD

ASD and ADHD are characterized by distinct cognitive impairments as well as patterns of overlapping impairments across diagnoses. For example, ASD and ADHD are both associated with processing speed, working memory, and response inhibition impairments, irrespective of comorbid symptoms (Corbett et al., 2009; Karalunas et al., 2018). Primary deficits in ADHD, such as inattention problems and hyperactivity/ impulsivity are also observed in children with and ASD (McClain et al., 2017). As outlined above, a variety of working memory challenges (verbal, phonological, visuospatial) are frequently reported across these disorders. However, children with ASD and ADHD also demonstrate unique patterns in reaction time performance, with children with ASD demonstrating wider boundary separations (accuracy over speed trade-offs) than children with ADHD on EF measures (Karalunas et al., 2018). Learning difficulties are also highly prevalent and often attributed to deficits in EF in both groups of children, with ~44% of children with ADHD and 65–85% of children with ASD reportedly having learning difficulties (Gillberg & Coleman, 2000; Pastor & Reuben, 2008).

Due to significant heterogeneity that exists in these NDDs, some research has also suggested that within each diagnosis, subgroups according to EF skills may emerge. For example, one recent study looked at children's overall EF performance (using measures of WM, inhibition, attention, etc.) in a sample of individuals with ASD, ADHD, co-morbid ASD/ADHD and TD children. Authors found that three subgroups emerged according to EF scores: “above-average”, “average”, and “impaired” (Dajani et al., 2016). Notably, these categories did not reproduce diagnostic groups. Indeed, the "average" and "impaired" groups were comprised of a mix of diagnoses; highlighting the importance of assessing individual cognitive differences within these populations.

1.1.5 Assessment and Treatment Options

Given this wide variation of cognitive deficits in ASD and ADHD, it is imperative that these children can receive timely assessments, and effective interventions based on their specific needs. Interventions aimed at addressing cognitive deficits in children with ASD and ADHD typically involve instruction and repeated practice on specific tasks, with the goal of improving EF skills. Often, these cognitive interventions are delivered online via game-based format, and have demonstrated positive effects on attention, working memory, inhibitory skills, and may even promote the use of metacognitive strategies (i.e., monitoring one's own thinking) (Kerns et al., 2017; Loomes et al., 2008; Nash et al., 2015). Although short-term improvements on these skills have been reported in the literature, less research has been established indicating significant long-term benefits of these treatments (Robinson et al., 2014). Further, few widely accessible treatment options exist for children with these NDDs.

The scarcity of pro-cognitive treatments remains a critical gap impeding educational gains and academic achievement for children affected by these disorders. Given the ubiquitous nature of these deficits in children, an unmet need in the care for children with ASD and ADHD is identifying cognitive deficits. Cognitive testing using standardized intelligence tests remains the gold standard for assessing reasoning and general thinking abilities in children and youth (Flanagan et el., 2013). While these tests have been in use for more than a century, they are administered in person by a psychometrist or clinical psychologist. Some tests are now available online; however, they can only be administered by registered clinicians and are geared towards high functioning, verbal children (Ashworth et al., 2021; Banks & Butcher, 2020). Many children with severe ASD or ADHD have communicational and or/reading comprehension deficits, which can make it challenging to understand written instructions for these online assessments (Berglund Melendez et al., 2020).

Due to the difficulties in terms of accessing specialized clinics and online cognitive testing for children with significant developmental delays, families lack access to these tests and children's deficits may go undetected leading to significant challenges at school. Not only will these students struggle without proper academic supports and intervention, but they may be put at risk for behavioral and emotional difficulties as well. Indeed, children with NDDs have been shown to demonstrate high comorbidity with anxiety and depression (van Steensel et al., 2011). Specifically, children with more severe cognitive deficits experience worse emotional regulation, which increases their risk for internalizing and externalizing problems (Dajani et al., 2016; Tajik-Parvinchi et al., 2021). Thus, these emotional challenges may be exacerbated by untreated or unidentified cognitive deficits.

1.1.6 Early Intervention

Findings indicate that early identification of cognitive deficits may aid with early access to therapies, and improved outcomes for children with ASD and ADHD (Hirota et al., 2021; Landa & Kalb, 2012). For example, research highlights the protective role of environmental enrichment, and family-centred intervention programs for infants and young children identified as at-risk (Cioni et al., 2016; Inguaggiato et al., 2017). Early screening can help tailor these intervention programs by identifying concerns in the child's developmental domains (e.g., motor, social, cognition) (Cioni et al., 2016). Cognitive behavioral therapy (CBT) has also proved to be an effective intervention for improving adaptive behaviours in children with various NDDs, including ASD and ADHD. These therapies can address a range of goals including improved problem solving, impulse control, and verbal communication skills (Thapliyal & Kotnala, 2019). Implementing interventions early in development is necessary in order to circumvent the effects of cognitive delays on the child's behavioral, academic, and emotional outcomes. However, access to such interventions often requires early diagnosis or at-risk identification (Cloet et al., 2022).

1.1.7 Barriers to Accessing Evaluation

Before the recent COVID-19 pandemic, access to specialized cognitive evaluations were already difficult and unequal among children due to long waiting lists, personnel shortage in the public health care system, and geographic location (Reardon et al., 2017). In addition to these barriers, youth from marginalized populations experience unique challenges accessing assessment and treatment (e.g., LGBTQ+ youth, refugee/immigrant youth) (Silberholz et al., 2017). The pandemic has increased the disparity to accessing these services as well as created a backlog of children needing to be assessed during the last couple years (Farmer et al., 2020; Koterba et al., 2020). Consequently, children with ASD or ADHD may receive interventions at a later age than recommended, which may influence the degree of potential cognitive, academic or behavioral gains made later in development (Ozonoff, 2015). Thus, it is imperative that these children have access to assessment and screening services. Developing instructions for an existing online cognitive screening tool for children's cognitive abilities could palliate these barriers in accessing evaluation and treatment promptly in the context of the pandemic and beyond.

1.2 Current Study

Our industry partner, Creyos (formerly Cambridge Brain Sciences), has pioneered online cognitive testing in adults and adolescents. The adult version of the online cognitive tests includes a total of 13 subtests that target working memory, fluid reasoning, and verbal abilities that are “gamified” to maintain interest. The tests include: Spatial Span, Visuospatial Working Memory, Self-Ordered Search, Paired Associates, Spatial Planning, Spatial Rotation, Feature Match, Polygons, Deductive Reasoning, Digit Span, Verbal Reasoning, Color-Word Remapping, and Sustained Attention to Response, and last about 40 minutes. For each of these, the instructions are written and presented on the screen before each task. The construct validity of these tests has been established in adults after demonstrating strong associations between performance on these tasks and intellectual quotient (IQ) scores that were obtained through in-person clinician-administered standardized tests (Hampshire et al., 2012). Note that this tool is not intended for diagnostic purposes, but rather it is utilized to compliment standardized assessments by identifying and tracking patient’s cognitive health trends (Creyos, n.d.). This online battery of cognitive tests has been validated extensively (Hampshire et al., 2012; Owen et al., 2010). To date, approximately 10 million tasks have been completed globally, and data from 75,000 participants has established associations between performance on these tasks and IQ (Creyos, n.d.; Hampshire et al., 2012).

Additionally, the battery of tests has been administered to young children and children with cognitive difficulties (e.g., attentional) who have some reading ability

(Jackson & Wild, 2021). However, these assessments have not been validated in school-aged children. More importantly and considering the influence of reading abilities on test performance, the current battery is not adapted for younger children or children with learning difficulties who have limited reading abilities. Children with NDDs who are in most need of therapies are also the most likely to not be able to access standardized testing due to lack of resources, lack of access and lack of appropriate test measures (Cloet et al., 2022). Online cognitive testing that is easily accessible for children and families would offer an opportunity to screen for cognitive deficits but also to track progress in children over time in response to behavioural therapies to improve cognitive outcomes in these vulnerable children.

In the current work, audiovisual instructions were developed for an online battery of cognitive tests to be used as a screening tool for cognitive deficits in children with ASD, ADHD, and TD children. We aimed to gather feedback on the task's adapted instructions. We then embedded these instructions within the games and implemented them in an online sample. Cognitive performance data (i.e., final scores, number of attempts, errors, reaction times) were compared across the groups (ASD, ADHD, TD) to determine whether unique cognitive patterns would emerge.

The current instructions for the Creyos tasks are written and are accompanied by visual imagery demonstrating the tasks. In order to implement these tasks in children with limited reading abilities (i.e., preschool age) and those who have NDDs, we developed new audiovisual instructions. The audio instructions present the same information as the current written instructions, in oral format. Note that these audio recordings appear synchronously with the written instructions. The visual instructions are in video format which presents a screen capture of an interactive tutorial (i.e., playing the game with the same shapes and colours used in the task). Thus, the combined audiovisual instructions are made up of the auditory instructions overlayed onto the video demonstration. Combined audio and visual information is associated with greater recall and retention in children compared to audio or visual information alone (Beagles-Roos & Gat, 1983; Gibbons et al., 1986; Macklin, 1994). Further, audiovisual instructions can be processed similarly by children with learning difficulties and children with ASD / ADHD compared to typically developing children (Hayes et al., 2003; Manfredi et al., 2021; Mongillo et al., 2008).

1.3 Aims

1) *Gather feedback on the Creyos task instructions, and determine the feasibility of using audiovisual instructions for online cognitive screening for children with ASD and ADHD who are at high risk for cognitive difficulties, compared to typically developing children.*
    - Presently, the instructions for these tasks are presented in a written format and are thus not adapted to children who may have difficulties understanding written material, or younger individuals who have not yet developed the necessary reading skills. Additional audiovisual aids may make these instructions more comprehensible for a wider audience (younger children / children with NDDs).
2) *Determine whether the Creyos task battery can successfully discriminate cognitive abilities in children with NDDS (ASD, ADHD) and TD children, based on targeted cognitive domains (short-term memory, verbal, attention, reasoning).*

- Research suggests that there is significant heterogeneity in cognitive impairments both within and between ASD and ADHD. We want to determine whether these tasks will reveal unique cognitive patterns among children with and without these NDDs.

1.4 Hypotheses

Based on previous literature, our main predictions for the results of the study are as follows:

1) *Using adapted audiovisual instructions, the Creyos tasks will be feasible to implement with children with ASD, ADHD and TD children. This should be reflected in the number of children who can comprehend and complete the instructions as well as complete the tasks.*

- Although limited research exists on the preferred instructional modality for children with NDDs, some evidence suggests that information is best understood by children using combined audiovisual techniques. Research has highlighted the facilitative effect of images paired with verbal information on children's recall abilities (Macklin, 1994).

2) *Significant differences are expected in cognitive abilities (task performance) across groups. Tasks targeting working memory and attention/inhibition may be of particular importance in discriminating TD children from children with ASD and ADHD.*

   - Thus, we expect the Creyos task battery to successfully discriminate between these groups. However, there may also be significant overlap in cognitive patterns, given that ASD and ADHD are both associated with impairments in working memory, processing speed and response inhibition (Corbett et al., 2009; Karalunas et al., 2018).

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Chapter 2

2.1 Identifying Cognitive Profiles in Children with Neurodevelopmental Disorders using Online Cognitive Testing

Children with neurodevelopmental disorders (NDDs), including children with autism spectrum disorder (ASD) and children with attention deficit hyperactivity disorder (ADHD), often face academic challenges at school due to difficulties with executive functioning (EF) (Dajani et al., 2016) skills, which are essential for adaptive behavior and learning (e.g., working memory, planning, inhibition, attention) (Powell & Voeller, 2004; Sun & Buys, 2012). Both disorders have a high prevalence in the general child population and collectively contribute to substantive portion of global disability (Tomlinson et al., 2014). As many as 40% of children with ASD (Long et al., 2011) and 30-60% of children with ADHD have cognitive difficulties (Coghill et al., 2014; Lipszyc & Schachar, 2010). Both children with ASD and ADHD have processing speed, working memory, and response inhibition impairments, irrespective of comorbid symptoms (Corbett et al., 2009; Karalunas et al., 2018). However other evidence suggests that these children may have more distinct cognitive phenotypes (Bal et al., 2022; Rosello et al., 2023). Learning difficulties are also highly prevalent and often attributed to deficits in EF in both groups of children, with ~44% of children with ADHD and 65–85% of children with ASD reportedly having learning difficulties (Gillberg & Coleman, 2000; Pastor & Reuben, 2008).

Cognitive difficulties may influence the age at which children are diagnosed and may even exacerbate social impairments. Early identification of cognitive deficits may aid with early access to therapies, and improved outcomes for children with NDDs (Hirota et al., 2021; Landa & Kalb, 2012). Without early screening, children's deficits may go undetected, leading to significant challenges at school and be placed at risk for behavioral and emotional difficulties (van Steensel et al., 2011). Early screening can help tailor these intervention programs by identifying concerns in children's EF domains (Cioni et al., 2016). Cognitive interventions have demonstrated positive effects on attention, working memory, inhibitory skills, and may even promote the use of metacognitive strategies (i.e., monitoring one's own thinking) (Kerns et al., 2017; Loomes et al., 2008; Nash et al., 2015). However, better characterization of cognitive impairments in children with ASD and ADHD are needed to tailor future target cognitive interventions.

Online cognitive screening in adults and adolescents has advanced significantly in the last two decades. Using online methods has advanced the ease and accessibility to cognitive tests that can be used as screeners for deficits in EF. Further, cognitive difficulties in children with ASD and ASD can vary widely. Cognitive difficulties in children with ADHD can also be influenced by other factors, such as comorbidities (e.g., learning disorders, anxiety, depression) and environmental factors (e.g., home environment, school support). In turn, online cognitive screeners can aid with individual assessments and provide appropriate interventions tailored to specific cognitive needs.

The central aim for the current study was to determine whether an established online battery of tests can successfully discriminate cognitive abilities in children with NDDs (ASD, ADHD) and TD children, based on targeted cognitive domains (short-term memory, verbal abilities, attention, reasoning). This battery includes a total of 13 subtests that target working memory, attention, fluid reasoning, and verbal abilities[knowledge] that are "gamified" to maintain interest. Audiovisual instructions were developed to facilitate at-home, online testing in children with NDDs. Based on the literature (Corbett et al., 2009; Karalunas et al., 2018), we predicted that distinct cognitive patterns would emerge among the groups. ASD and ADHD groups are expected to perform worse than TD children on tasks that target attention/inhibition and working memory, which are reported as core cognitive deficits in both diagnoses. Results inform the development of accessible screening measures that can be administered to children with ASD and ADHD, with emphasis on informing appropriate school-based interventions to promote cognitive ability and academic achievement in this population.

2.1 Methods

2.1.1 Participants

Participants were English-speaking (verbal) Canadian school-aged children. Participants were recruited through the online platform, Prolific. Potential participants first completed screening questions to determine their eligibility for participation. If participants were deemed eligible to participate, they were then invited to participate in the study via a new study invitation on Prolific. Inclusion criteria were as follows: must be able to speak English, Canadian, between the ages of 4-16 years, with or without a diagnosed neurodevelopmental disorder. Exclusion criteria included diagnosed global developmental delay (GDD), and motor difficulties. The study protocol was approved by the Health Sciences Research Ethics Board. Parents provided informed consent and children provided assent.

2.1.2 Online Test Battery

The online cognitive tests are a validated battery (40 minutes), 13 in total that measure (1) working memory, (2) reasoning, (3) verbal abilities and (4) attention that are “gamified” to maintain interest. The tests include: Spatial Span (SS), Grammatical Reasoning (GR), Double Trouble (DT), Odd one Out (OOO), Monkey Ladder (ML), Rotations (R), Feature Match (FM), Digit Span (DS), Spatial Planning (SP), Paired Associates (PA), Polygons (P), Token Search (TS), and the sustained attention to a response task (SART). The tests are on-demand through the research platform provided by Creyos (http://www.creyos.com).

The Creyos platform is used to administer online cognitive tests to children, adolescents, and adults. Creyos has a database of roughly 4.5 million scores from ~400,000 users, with 75,000 of these scores being used to establish associations between task performance and IQ (Hampshire et al., 2012). The cognitive tasks have been validated in several large-scale studies examining healthy controls and patient populations. Cognitive assessments in young adults on the Creyos battery of tests were comparable to that of standardized tests to assess cognitive function such as the Wechsler Adult Intelligence Scale Revised (WAIS-R) (Levine et al., 2013), and the Montreal Cognitive Assessment (MoCA)(Brenkel et al., 2017). Descriptions of each cognitive task used in the assessment are below (Wild et al., 2018):

Spatial Span (SS). This is a spatial short-term memory tool that was based on the Corsi Block Tapping Task (Corsi, 1972). Sixteen purple blocks are presented on the screen, then a randomly selected sequence of the blocks one-by-one become green. Participants must then select the boxes that previously turned green in the correct order. The length of the longest sequence successfully remembered during the three-minute task reflects the user's final score. Test-retest reliability calculated from a population sample (N = 647) a Pearson's correlation of r = 0.62 and learning effects of 0.46 (% improvement) between session one session two, indicating high reliability.

Paired Associates (PA). This is s puzzle-based cognitive assessment of memory (Gould et al., 2005). Several boxes appear randomly distributed on the screen. One-by-one, each box opens to reveal a different icon (e.g., cube, windmill, envelope, etc.). Upon being presented with each icon sequentially, users must indicate which box the icon initially appeared in. If all icon-location pairs are identified correctly, an additional box appears in the next trial. If an identification error is made, subsequent trials will contain one less box. The task ends after three mistakes. Final scores represent the number of paired associates successfully remembered. Test-retest reliability calculated from a large sample (N = 1131) revealed a Pearson's correlation of r = 0.45 and learning effects of -0.38 (% improvement).

Digit Span (DS). An adaptation of the verbal working memory component of the Weschler Adult Intelligence Scale Revised (WAIS-R; Weschler, 1981). A sequence of digits appears on the screen. Users must reproduce the sequence in the correct order using an on-screen keyboard. The digit sequence increases in length level with each successful trial. Unsuccessful attempts cause the sequence to decrease. The task ends after three incorrect sequences. The longest digit sequence successfully reproduced reflects final scores. Test-retest reliability calculated from a population sample (N = 1022) collected on the Creyos website revealed a Pearson's correlation of r = 0.64 and learning effects of

1.33 (% improvement) between session one session two, indicating high reliability (Creyos, n.d.).

Feature Match (FM). An assessment used to measure attentional processing, based on classical feature search tasks (Treisman & Gelade, 1980). Two boxes are displayed side-by-side on the screen, each containing an assortment of shapes. Over 90 seconds, users must determine whether the contents of the two boxes are identical or different, based on each shape and relative position. Following each correct response, an additional shape is added to the next trial. Incorrect responses result in the removal of one shape. Final scores reflect correct responses, minus incorrect responses. Test-retest reliability calculated from a population sample (N = 1132) on the Creyos website revealed a Pearson's correlation of r = 0.57 and learning effects of 4.09 (% improvement) between session one session two, indicating high reliability (Creyos, n.d.).

Polygons (PO). A variation of the Interlocking Pentagons Task, used to assess visuospatial processing (Folstein et al., 1975). Two overlapping polygons appear on the left side of the screen, and a single polygon on the right. Users must indicate whether the single polygon is identical to either of the two overlapping polygons by selecting 'match' or 'mismatch.' Each correct response increases their score by the difficulty level of the trial, and vice versa occurs with each incorrect response. Difficulty increases as the difference between polygons become more subtle. Final scores reflect the number of correct identifications made in 90 seconds. Test-retest reliability calculated from a population sample (N = 905) collected on the Creyos website revealed a Pearson's correlation of r = 0.60 and learning effects of 7.91 (% improvement) between session one session two, indicating high reliability (Creyos, n.d.).

Monkey Ladder (ML). A visuospatial working memory task derived from non-human primate literature (Inoue & Matsuzawa. 2007). Numbered boxes are displayed across random locations on the screen for a limited amount of time (i.e., number of boxes x 900 milliseconds), after which the numbers disappear and only the boxes remain. Users must select the boxes in ascending numerical order. Final scores are based on the length of the longest sequence remembered. Correct responses are followed by trials with an additional digit, and incorrect responses are followed by trials that have one less digit. The assessment ends after three mistakes. Test-retest reliability calculated from a population sample (N = 804) was r = 0.57 and learning effects of 1.62 (% improvement) between session one session two.

Rotations (RT). A measure of spatial manipulation ability adapted from the Spatial Rotation Task (Silverman et al., 2000). Two grids appear on the screen, each containing a varying number of coloured squares. One of the grids may be rotated by a multiple of 90 degrees. Participants must determine whether the grids are identical when unrotated or if they differ based on the positioning of one item. Correct identifications boost the user's score by the number of squares present and adds an additional square to subsequent trials. Vice versa occurs with incorrect identifications. The task lasts 90 seconds. Test-retest reliability calculated from a population sample (N = 1122) was r = 0.70 and learning effects of 5.43 (% improvement) between session one session two.

Spatial Planning (SP). This task is adapted from the Tower of London Task (Shallice, 1982) commonly used to measure executive function. Numbered balls are positioned on a tree. Participants must relocate the balls so that they are arranged in increasing numerical order. User's have 3 minutes to solve as many puzzles as possible. Trials become progressively more complex, requiring more moves. Trials end if users make more than twice the number of moves required to solve the problem. A successfully completed puzzle increases the final score by: (2 x minimum # of moves required) minus the # of moves made. Test-retest reliability calculated from a population sample (*N* = 1150) was *r* = 0.87 and learning effects of 3.75 (% improvement) between session one session two.

Odd One Out (OOO). A deductive reasoning task based on a subset of problems from the Cattell Culture Fair Intelligence Test (Cattell, 1949). Nine patterns appear on the screen. Participants must deduce what set of rules unify the group (i.e., colour, shape, number of items) and select the pattern that does not match. They must solve as many puzzles as possible within three minutes, while trials progressively become more complex. With each correct response, the user's score increases by one, and each incorrect response decreases their score by one. Test-retest reliability calculated from a population sample (*N* = 1138) collected on the Creyos website revealed a Pearson's correlation of *r* = 0.73 and learning effects of 1.55 (% improvement) between session one session two, indicating high reliability.

Grammatical Reasoning (GR). An adaptation of Alan Baddeley's Three-Minute Grammatical Reasoning Task (Baddeley, 1967). This assessment of verbal memory ability features a brief written statement alongside two different shapes on the screen. The user must indicate whether the statement reflects the characteristics of the shapes pictured below (e.g., circle is not bigger than square) by selecting 'true' or 'false.' Each correct response increases the participant's score by one, and each incorrect response decreases their score by one. Participants have 90 seconds to complete as many trials as possible. Test-retest reliability calculated from a population sample (*N* = 1148) collected on the

Creyos website revealed a Pearson's correlation of r = 0.89 and learning effects of 2.24 (% improvement) between session one session two, indicating high reliability.

Double Trouble (DT). This task is based on the Stroop Task (Stroop, 1935) that measures cognitive inhibition. A target word ('RED' or 'BLUE') appears at the top of the screen in red-coloured or blue-coloured ink. Participants must select one of two probe words from the bottom of the screen that accurately describes the ink colour of the target word. Mappings can be congruent (i.e., the description and ink colour match for all words), incongruent (i.e., either the target word or the probe words are written in the opposite colour of what they describe), or doubly incongruent (i.e., both words are written in the opposite colour of what they describe). Scores represent the number of correct responses produced in 90 seconds. Incorrect answers deduct one point. Test-retest reliability calculated from a population sample (N = 1151) revealed a Pearson's correlation of r = 0.92 and learning effects of 4.90 (% improvement) between session one session two.

Token Search (TS). Based on an assessment commonly used to measure working memory and strategy (Collins et al., 1998). Boxes are randomly distributed around the screen. Users must search the boxes to find a green token. If the token is successfully located, another trial begins with an additional box, and a new token is hidden. Participants must remember where previous tokens were discovered, because the new tokens are never in the same location twice. If they select a box that has already been clicked or previously contained the token, a new trial begins with one less box. This task ends after three mistakes. The maximum level completed reflects the user's final score. Test-retest reliability calculated from a population sample (N = 1113) collected on the

Creyos website revealed a Pearson's correlation of $r = 0.66$ and learning effects of 4.99 (% improvement) between session one session two.

Sustained Attention to Response (SART). Designed by Robertson et al., (1997), this is a go/no go response task intended to measure sustained attention and inhibitory control. Different numbers quickly flash on the screen (250 ms / digit), followed by a circle and a cross (900 ms). The digits are displayed in one of five randomly assigned font sizes (48 point, 72 point, 94 point, 100 point, and 120 point). Users are asked to click / tap 'Go' as fast as possible after each number, except for number 3. Thus, users must respond to frequent non-targets (digits other than 3) and inhibit their response to a single infrequent target (the digit 3). The task is 4 minutes long. Reaction times (RT) for all responses are collected, and a final score is provided at the end.

2.1.3 Experimental Procedure

Before each test, a paragraph of audiovisual instructions was displayed to the participants. An enhanced set of instructions was developed for children with limited reading abilities that we based on the original instructions The instructions were created using screen captures of an interactive tutorial and voiceover stimuli of written instructions were recorded. The voice recordings were developed by one of the authors (A.H.) and were developed in a soundproof booth at the Instructional Technology Resource Centre (ITRC) at Western University. The recordings were made using a standard microphone and the files were saved as MP3 files. The files were uploaded to the Creyos platform and played at the same time the written instructions are displayed to the participants. Participants were then prompted to play an interactive tutorial to practice the tasks while receiving written feedback (e.g., “Oops! That wasn’t the right sequence.”).

To determine whether the audiovisual instructions were appropriate for online testing, field testing was conducted in a sample of children (4-11 years) with NDDs and psychiatric disorders (n = 11), as well as TD children (n = 4) and their caregivers. Participants were administered the audiovisual instructions and the tasks on the Creyos platform during in-person testing sessions. Feedback was gathered from participants on the task’s new audiovisual instructions using a standardized interview guide (See supplementary information). The interview guide with set questions in terms of the comprehension of each task were developed. For each task the participant was asked whether they understood the instructions (yes/no/maybe), whether they believe they could perform the tests (yes/no/maybe) and specific details on the instructions (open ended responses). Parents were asked whether the instructions are at the ability level of their children as well as specific details on the instructions (open ended responses). Interviews were analyzed using NVivo software to categorize responses and identify themes. Feedback was grouped according to the task’s targeted cognitive domain (short-term memory, attention, verbal abilities, and reasoning) (https://creyos.com/features/tasks).

Across the short-term memory tasks, 90% of parent responses indicated the instructions were appropriate for their child’s ability. 92% of children indicated that they understood how to play the game after watching the instructions. Across the attention tasks, 90% of parent responses indicated the instructions were appropriate for their child’s ability. 95% of responses from children indicated that they understood how to play the games after watching instructions. Across the verbal tasks, 80% of parent responses indicated the instructions were appropriate for their child's ability. 100% of responses from children indicated that they understood how to play the games after watching instructions. Across the reasoning tasks, 90% of the parent responses indicated the instructions were appropriate for their child's ability. 96% of the children indicated that they understood how to play the games after watching instructions.

All children were able to complete the 13 tasks. Note that the youngest participant (4 years) did require some parent assistance (e.g., clicking buttons on laptop, remembering rules). Over half of interview responses for all tasks (children and parents) suggested that the participants could have understood the task rules with fewer examples. Thus, the instructions could be abbreviated. Overall, the field testing indicated that audiovisual instructions that were subsequently used for the main research study were suitable for administration in these populations (NDD and TD children) of children (4-11 years).

Online cognitive testing

The main part of the study was conducted online through Prolific (https://www.prolific.com). Prolific is an online participant testing platform used to collect data from large samples of pre-screened participants. The task battery was launched online, with the new audiovisual instructions embedded before each task. The battery is self-guided, and participants watched the short instructional videos before commencing the task. After consenting to participate in the study, parents of the participants answered a short demographic questionnaire which took about 15 minutes to complete. Questions asked about the child's age, sex, and neurodevelopmental diagnosis. At the end of the demographic questionnaire there was a link to the online cognitive tests that the children completed. Prior to each task, audiovisual instructions were presented to the participants. In total, the study took about 60 min to complete.

2.1.4 Statistical Analysis

Statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS, v30, Chicago, IL). For each task, the reaction time, number of errors and correct responses, max scores, and final or average scores were recorded. Missing values in the dataset (less than 3% of the data) were addressed using the mean substitution method. Prior to analysis, all scores were transformed to z-scores and were adjusted for participant age and sex.

In order to identify which cognitive tasks were the strongest discriminators between the diagnostic (Dx) groups a single stepwise discriminant analysis (DA) and a leave-one-out cross-validation was performed. Stepwise DA is a multivariate method used to estimate group membership using continuous variables (Beggiato et al., 2016). A threshold of the probability of the F value ($p<0.05$) was used to enter the variables into the model, and a probability value ($p=0.1$) was used to remove variables from the analysis. Variables that were entered into the model included participant's final score, or average score for each of the 13 tasks. Final scores were provided in the performance output if the task measured both speed and accuracy (timed tasks, e.g., rotations), while average scores were given from tasks with no time limit (e.g., token search). Upon entering the variables into the model, the probability of group membership was fixed at 0.5. Standardized canonical function coefficients (SCFC) were given to each continuous variable in the model, which indicates the variable's relative contribution to group discrimination (larger values indicate a greater contribution). Estimated effect sizes were represented by the percentage of participants who are correctly classified into each Dx group. Significance of observed differences between Dx groups is estimated by the value of Wilk's Lambda.

2.2 Results

2.2.1 Participants

A total of 206 participants were recruited for the study, ages 4 to 16 (*M* = 7.9, *SD* = 2.7). Participants consisted of 86 TD children (44 males, 42 females), 83 children with ADHD (40 males, 42 females, 1 other / unspecified), and 37 children with ASD (27 males, 10 females). In order to maintain the focus of the research question, participants with comorbidities and other neurological or behavioral disorders were excluded (e.g., conduct disorder, OCD, ODD, sensory disorder).

Table 1 Participant Demographics

	Demographics		
Dx	N	Age	Sex (M/F/O)
TD	86	8.1 (2.9)	44/ 42
ASD	37	7.3 (2.4)	27 / 10
ADHD	83	7.9 (2.6)	40 / 42 / 1

Note. Count (n), mean age and standard deviation, and sex (male, female, other) for each participant diagnosis (Dx).

2.2.2 Stepwise DA

In order to determine which Creyos tasks were the strongest discriminators between ASD, ADHD, and TD participants, a stepwise DA was performed. With all 13 performance measures on the tasks (i.e., final score, average score) included in the analysis, the stepwise DA identified 55.3% of the original groups correctly. A leave-one-out cross-validation resulted in a comparable classification scheme, whereby 53.4% of the original groups were correctly classified. Based on the stepwise DA, overall, 4 variables that classified 53% of controls, 57 % of participants with ADHD and 60% of participants with ASD (Fig. 1).

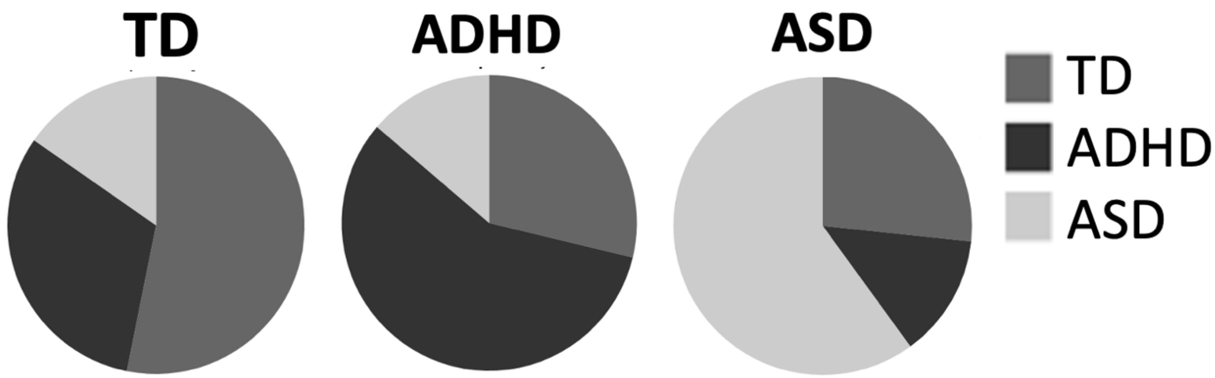

Figure 1. Predicted group membership based on stepwise discriminant analysis**.** Left: Proportion of TD (n = 59, 53%) participants correctly classified by the stepwise DA. Middle: Proportion of ADHD participants (n= 46, 57%) correctly classified. Right: Proportion of ASD participants (n= 9, 60%) correctly classified.

The two discriminant functions in the analysis were found to be statistically significant (Wilks's Λ = 0.85, χ^2 (8) = 32.79, p = .001 for discriminant function 1 through 2; Wilks's Λ = 0.93, χ^2 (3) = 14.20, p = .003 for discriminant function 2, Fig 2.). The first discriminant function explains 57% of the variance and the second discriminant function explains 43%. Canonical correlations are .30 and .26 for both discriminant functions, indicating that 30% and 26% of variances in the data were explained by the relationship between predictors (tasks) and group membership by discriminant function 1 (DF1) and discriminant function 2 (DF2) respectively.

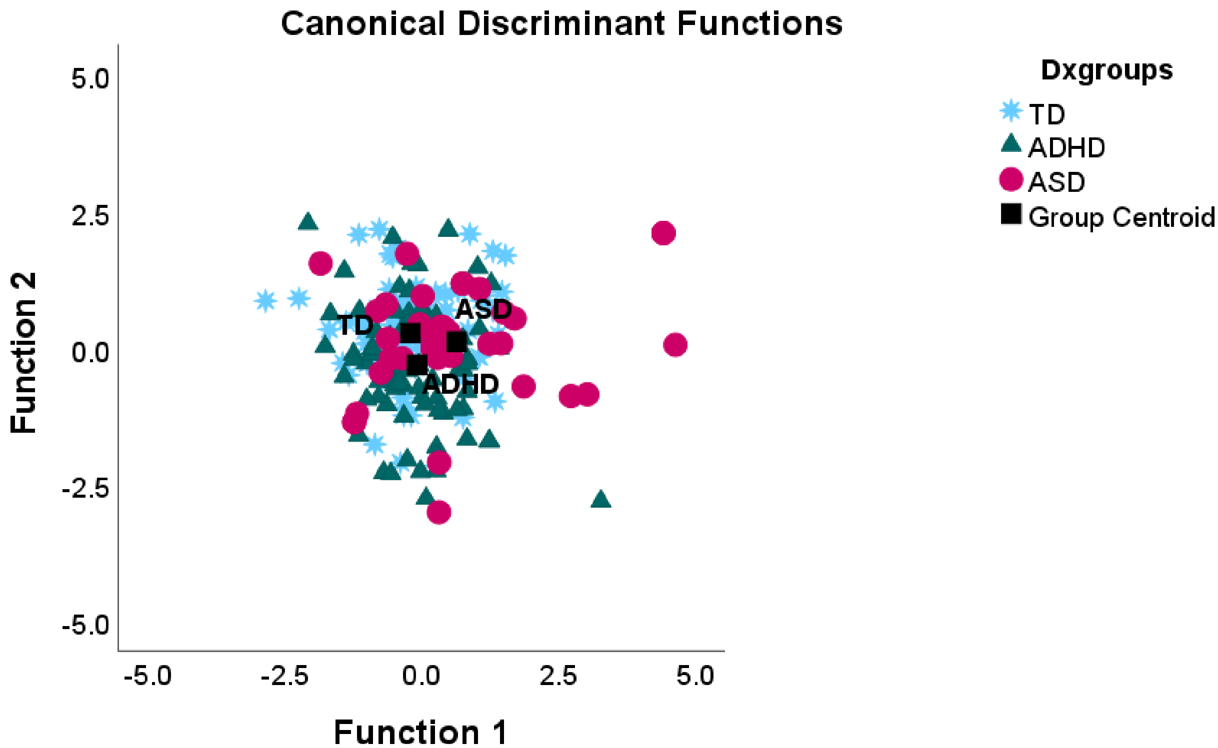

Figure 2. Plot of canonical function coefficients of the stepwise discriminant analysis for individual TD (typically developing, blue stars), ADHD (attention deficit hyperactivity disorders, green triangles) and the ASD (autism spectrum disorder, red circles) from the participants assessed on the online cognitive tests. The black squares represent group centroids.

The stepwise DA identified 4 tasks (DT, OOO, DS, SART) reflective of working memory and attentional processes. Canonical discriminant function coefficients reveal that for DF1, DS has the largest contribution to group discrimination followed by OOO, DT, and SART. In DF2, SART has the largest contribution to group discrimination followed by double trouble, digit span, and odd one out (See Table 2).

Table 2

Creyos tasks identified by Stepwise DA

Task	Task Description	Task Domain	Standardized canonical function coefficients	
			Function 1	Function 2
DT	Colour-word remapping task	Attention	.147	.590
OOO	Deductive reasoning task	Reasoning	-.678	-.197
DS	Digit sequence recall	Short-term memory	.727	-.494
SART	Go/no go response task for attention and inhibition	Attention	-.069	.744

Descriptions of the Creyos tasks identified as significant discriminators for the cognitive profiles for the 3 different diagnostic groups (TD, ADHD, ASD), with their associated cognitive domain, and discriminant function coefficients for both functions. Abbreviations: double trouble (DT), odd one out (OOO), digit span (DS), sustained attention to response task (SART).

2.2.3 Multivariate GLMs

To investigate the group differences amongst the task performance measures (i.e., average / final score, number of errors, number correct, attempts, and reaction time), four multivariate GLMs were performed for each of the four tasks identified by the stepwise DA (double trouble (DT), odd one out (OOO), digit span (DS), Sustained attention to Response task (SART)).

Results revealed a statistically significant difference in task performance based on participant diagnosis, for DT (F (10, 398) = 7.91, $p < .001$; Wilk's $\Lambda = 0.696$, partial $\eta 2 = .17$), OOO (F (10, 398) = 6.74, $p < .001$; Wilk's $\Lambda = 0.731$, partial $\eta 2 = .14$), DS, (F (10, 398) = 7.34, $p <.001$; Wilk's $\Lambda = 0.713$, partial $\eta 2 = .16$), and SART (F (10, 398) = 6.79, $p < .001$; Wilk's $\Lambda = 0.730$, partial $\eta 2 = .15$)

Table 3

Tests of Between Subjects Effects

Variable	DT	OOO	DS	SART
Final score	(F (2, 203) = 28.94; p < .001; partial η^2 = .22)	(F (2, 203) = 30.88; p < .001; partial η^2 = .23	(F (2, 203) = 29.96; p <.001; partial η^2 = .23)	(F (2, 203) = 34.76; p <.001; partial η^2 = .25)
No. attempts	(F (2, 203) = 8.37; p < .001; partial η^2 = .08)	(F (2, 203) = 8.69; p < .001; partial η^2 = .08)	(F (2, 203) = 18.34; p <.001; partial η^2 = .15)	N/A
No. correct	(F (2, 203) = 14.72; p < .001; partial η^2 = .13)	(F (2, 203) =.76; p = .47; partial η^2 = .01)	(F (2, 203) = 18.34; p <.001; partial η^2 = .15)	(F (2, 203) = 34.76; p <.001; partial η^2 = .25)
No. errors	(F (2, 203) = 14.24; p < .001; partial η^2 = .12)	(F (2, 203) = 29.66; p < .001; partial η^2 = .23)	N/A	(F (2, 203) = 34.76; p <.001; partial η^2 = .25)
Duration (ms)	(F (2, 203) = 0.67; p = .51;	(F (2, 203) =.74; p = .48;	(F (2, 203) = 15.32; p <.001; partial η^2 = .13)	(F (2, 203) = 1.87; p = .16; partial η^2 = .02)

Variable	DT	OOO	DS	SART
	partial η^2 = .01)	partial η^2 =.01)		
Ms correct	(F (2, 203) = 3.10, *p* = .05; partial η2 = .03)	(*F* (2, 203) = 5.46; *p* = .005; partial η^2 =.05)	(*F* (2, 203) = 6.13; *p* =.003; partial η^2 = .06)	(*F* (2, 203) = 10.12; *p* < .001; partial η^2 = .09)

Note. Between subject's effects for each task's multivariate GLM. Dependent variables include final scores, number of attempts, number correct, number of errors, total task duration, and milliseconds (ms) per correct item. Due to the nature of the tasks, errors and attempts were not available for DS and SART, respectively (N/A).

2.2.4 Multiple Comparisons

Double Trouble. Tukey's HSD Test for multiple comparisons revealed that the mean value of DT final score was significantly higher for controls than ADHD (p < .001, 95% C.I. = [6.92, 14.97]), and the ASD group had higher scores than the ADHD group (p < .001, 95% C.I. = [10.38, 25.83]). See Table 4. The ASD group had more attempts than controls (p < .001, 95% C.I. = [7.72, 30.86]) and the ADHD group (p = .007, 95% C.I. = [3.34, 27.00]). The ASD group had more correct responses than controls (p < .001, 95% C.I. = [5.96, 20.50] and ADHD (p < .001, 95% C.I. = [9.20, 24.07]. Lastly, the ADHD group had more errors than controls (p < .001, 95% C.I. = [4.05, 11.01].

Odd One Out. Tukey's HSD Test for multiple comparisons revealed that controls had higher OOO final scores than the ASD group (p < .001, 95% C.I. = [8.38, 16.43], and the ADHD group had higher scores than the ASD group (p <.001, 95% C.I. = [8.99, 17.22].

ASD had more errors than controls ($p < .001$, 95% C.I. = [7.76, 15.65] and ADHD ($p < .001$, 95% C.I. = [8.68, 16.75]. ASD also had more attempts than controls ($p < .001$, 95% C.I. = [6.09, 15.61] and ADHD ($p < .001$, 95% C.I. = [7.35, 17.08]). Lastly, controls had longer correct item RTs than ASD ($p = .024$, 95% C.I. = [170.24, 3687.34])

Digit Span. Tukey's HSD Test for multiple comparisons revealed that the ASD group had higher final DS scores than controls ($p = .005$, 95% C.I. = [1.34, 2.58]), the ADHD group had higher final scores than controls ($p < .001$, 95% C.I. = [0.15, 0.82], and the ASD group had higher final scores than the ADHD group ($p < .001$, 95% C.I. = [0.83, 2.11]. The ASD group had more correct responses than controls ($p < .001$, 95% C.I. = [1.77, 4.13]) and the ADHD group ($p < .001$, 95% C.I. = [1.47, 3.88]). The ASD group also had more attempts than controls ($p < .001$, 95% C.I. = [1.77, 4.13]) and the ADHD group ($p < .001$, 95% C.I. = [1.47, 3.88]. The ASD group had a longer total task duration (ms) than controls ($p < .001$, 95% C.I. = [61732.26, 162463.57]) and ADHD ($p < .001$, 95% C.I. = [32757.48, 135786.02]). Lastly, the ASD group had a longer RT for each correct response than controls ($p = .01$, 95% C.I. = [823.85, 7343.00])

SART. Tukey's HSD Test for multiple comparisons revealed that controls had significantly higher final scores and correct responses than the ADHD group ($p < .001$, 95% C.I. = [38.65, 70.51]), and the ASD group had higher final scores and correct responses than the ADHD group ($p = .002$, 95% C.I. = [13.90, 75.03]). The ADHD group had more errors than controls ($p < .001$, 95% C.I. = [38.65, 70.51]), and the ASD group ($p = .002$, 95% C.I. = [13.90, 75.03]). Lastly, controls had a longer RT(ms) for correct trials than the ADHD group ($p < .001$, 95% C.I. = [77.83, 258.05]).

Table 4

Task Final Scores

	Dx		
Task	TD	ADHD	ASD
DT	3.93(1.08)	-7.02 (1.27)	11.09 (2.94)
SART	23.24 (4.27)	-31.34 (5.03)	13.13 (11.62)
OOO	.47 (.57)	1.18 (.68)	-11.93 (1.56)
DS	-.35 (.09)	.13 (.11)	1.60 (.24)

Note. Estimated marginal means and standard errors (M (SE)) of the final scores for each task and diagnostic group (Dx)

2.3 Discussion

Children with ASD and ADHD are reported to have common cognitive difficulties impacting a broad range of executive functions. Critically, screening for cognitive difficulties, particularly in young preschool children with ASD and ADHD is essential to identify even subtle deficits, which may become more apparent when tested at school age. In turn, in the current work to address a need to identify cognitive profiles in children with ASD and ADHD, a heterogenous population of young preschool children, children and adolescents along with typically developing peers were recruited and tested on an adapted online battery of cognitive tests that assessed working memory, reasoning, verbal ability and attention. We identified distinct profiles of both children with ASD and ADHD. Children with ADHD demonstrated worse performance on tasks requiring attention compared to typically developing children. Children with ASD performed worse on reasoning tasks compared to typically developing children and were more likely to make multiple attempts, indicative of impulsivity. The identification of distinct cognitive deficits can provide the foundation for improved and accessible screening measures that can be administered longitudinally to children with NDDs.

2.3.1 Cognitive Profiles

Of the thirteen total tasks, two tasks that target attentional processes (Double Trouble, SART) discriminated the diagnostic groups. While ADHD is particularly associated with attention-regulation impairments, this has been attributed to core inhibitory or working memory deficits (Barkley, 1997; Kofler et al., 2018). Other cognitive domains that emerged as relevant discriminators from the stepwise DA include reasoning and verbal short-term memory, targeted by odd one out and digit span, respectively.

Results shed light on group differences with respect to each task's performance measures. For attentional processes (Double Trouble), typically developing children and children with ASD had higher final scores compared to children with ADHD. Double trouble is a challenging version of the Stroop task, which demands focused attention and inhibition in order to successfully navigate the incongruent and doubly incongruent trials (Wild et al., 2018). Response inhibition deficits are commonly reported in studies of EF performance in children with ADHD, compared to children without ADHD (Corbett et al., 2009; Wilcutt et al., 2005). In the current study, the ADHD group had significantly more errors than the typically developing children. The children with ASD made more attempts, but had more correct responses than the typically developing children and ADHD group. This may suggest that the ASD group was more persistent after successful and unsuccessful trials during this task, compared to the other groups. Children with ASD have been known to hyperfocus on a challenging task or activity of interest, which may have contributed to more attempts and correct responses on Double Trouble (Dupuis et al., 2022).

Typically developing children and children with ASD also performed better than the children with ADHD group on the task of sustained attention, the SART (higher scores, more correct items, and fewer errors). Typically developing children also had a longer RTs for each correct response (no-go's for targets) compared to the ADHD group. The SART is intended to be a sensitive measure of participant's vigilance to a non-engaging yet challenging task. Thus, controlled processing must be used when they encounter the rare target (number 3) in order to overcome automatic responses to the non-targets (Robertson et al., 1997). These current results are in line with previous work on sustained attention performance of ADHD children which indicates a reduced sensitivity to discriminating between targets and non-targets (Huand-Pollock et al., 2020). Such challenges may also arise due to slow processing speed (Kofler et al., 2018; Leitner et al., 2007).

In the deductive reasoning task, odd one out, ADHD and typically developing children had higher final scores compared to the children with ASD. The ASD group also had more errors and attempts than the typically developing children and ADHD group. Odd one out requires participants to keep track of various pattern features (colour, shape, number of items) and they must also be able to quickly deduce which set of rules relates all the patterns together on each trial (Wild et al., 2018). Research has suggested that individuals with ASD may show difficulty with making rapid decisions and prefer a more deliberative approach to reasoning, which is not necessarily available during a brief timed task (Brosnan et al., 2016; Luke et al., 2012). Some research suggests that spatial reasoning and planning are skills which may also be impacted in ASD (Banker et al., 2021; Cantio et al., 2018). Further, children with ASD may show more difficulty than children without ASD in maintaining multiple rules, or shifting these rules due to working memory deficits or cognitive inflexibility, which may be reflected in higher error rates (Landry & Mitchell., 2021).

Lastly, in the working memory task, digit span, the children with ASD performed better overall in terms of their final scores (more correct answers) compared to the typically developing children and the ADHD group. The children with ADHD also had higher scores compared to the typically developing children. This is contrary to what would be expected based on working memory impairments typically reported in both ASD and

ADHD populations (Habib et al., 2019; Ramos et al., 2020). Although, some research has reported no impairment on verbal working memory using digit span tasks in children with ASD, and mixed findings in ADHD (Faja & Dawson, 2014; Rosenthal et al., 2006). Results may suggest that these groups of children were relatively high-functioning as well, with little overall impairment in their verbal working-memory. As with the other tasks, the ASD group also had more attempts than controls and the ADHD group. Lastly, the ASD group had a longer total task duration (ms) than controls and ADHD, and a longer RT for each correct response than controls. Thus, it may be the case that children with ASD were using a more cautious approach to responding on this task, compared to the other groups.

Overall, results demonstrated an online battery of cognitive tests, which target attention, reasoning, and working memory could categorize over half of participants from each diagnostic group, based on performance variables. Although some unique cognitive patterns emerged, it is clear that there is also overlap in cognitive strengths and impairments across diagnostic groups (typically developing, ASD, and ADHD). Indeed, significant heterogeneity in overall EF (based on attention, inhibition, and working memory performance) has been reported within NDDs and typically developing children, revealing subgroups according to impairment levels (Dajani et al 2016). However, results show that the ADHD children performed significantly worse than children without ADHD on the attention tasks. Although similar deficits are reported in ASD, performance measures revealed the greatest attentional / inhibitory impairment in the ADHD group. This is an important finding in the context of dissociating cognitive patterns among children with and without ADHD.

2.3.2 Limitations

A few notable limitations of the current study should be mentioned. First, this study had a relatively small sample size, particularly with respect to ASD participants. Thus, it is difficult to interpret some of the unexpected findings in this group. In the future, larger sample sizes with greater statistical power may reveal more distinct cognitive patterns among children with NDDs compared to typically developing children and may permit more concrete conclusions when comparing ADHD and ASD groups. Further, participants were not assessed for symptom severity or IQ, which may have impacted cognitive performance differences among the groups.

A second main limitation of the study is the lack of in-person cognitive assessments. Although the use of the online tasks have been validated in adults, they have not been validated extensively in school-age children. Further, there are some inherent limitations to online assessment, including a loss of researcher control. For example, it is unclear whether participants completed the tasks independently with no outside influence, or assistance from caregivers. Younger children may have been particularly likely to seek assistance; however, based on the field testing we believe that the participants were able to complete the tasks without assistance from their caregivers. Indeed, higher scores have been reported on online cognitive assessments when compared to their in-person counterpart (Ashworth et al., 2021). Since an aspect of this study was feasibility in relation to the use of the audiovisual instructions, conclusions are limited until the task battery has been validated in these populations of children. An additional consideration for online cognitive screening, is that the participants may have come from backgrounds with higher socioeconomic statuses in general as only families with access to devices and the internet would be eligible to participate.

2.3.3 Conclusions

Children with NDDs can experience diverse cognitive difficulties, which may affect multiple cognitive domains (e.g., attention, working memory, verbal abilities, and reasoning). Left unidentified, these deficits can seriously impact children's academic, and emotional/behavioural outcomes (Dajani et al., 2016; Gray et al., 2017). Readily accessible online screeners for cognitive functioning, may be a feasible option for early identification of these cognitive difficulties. The online battery of tests identified unique cognitive profiles in children with ADHD, ASD and TD children, and revealed cognitive patterns across diagnoses. Future work should examine task performance in a larger sample, in relation to standardized cognitive assessment measures. Overlapping EF impairments underscore the importance of cognitive screening for individuals regardless of NDD diagnosis. Future work examining whether children with an ASD or ADHD diagnosis have distinct subgroups with varying cognitive profiles should be examined in larger and more heterogenous populations.

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Chapter 3

3 Extended Discussion

In this study, audiovisual instructions were developed for an online task battery. Our goal was to make these tasks more accessible to children (TD and NDDs) and to determine whether task performance would reveal unique cognitive patterns among the groups. Field testing was conducted in a small sample of children with and without diagnosed NDDs, and parents. Interviews conducted in this sample revealed and overall positive response to the adapted instructions and the use of the different tasks within these populations. The battery and new instructions were then implemented in an online sample of children aged 4-16 years, with and without diagnosed NDDs (ASD, ADHD, and TD). Data was analyzed using a stepwise discriminant analysis, in order to evaluate the discriminating ability of the cognitive tasks in identifying cognitive deficits. Stepwise DA revealed four tasks out of the thirteen that were most effective at discriminating the groups: double trouble, odd one out, digit span, and SART. Performance variables from these cognitive tasks successfully categorized approximately 53-60% of participants from each diagnostic group. Results of this study inform the development of online accessible cognitive screening methods for children. Early detection of cognitive deficits is imperative for children with ASD and ADHD in order to improve school outcomes (Dajani et al., 2016; Gray et al., 2017).

3.1 Study Outcomes

As expected, the online cognitive tasks with audiovisual instructions were feasible to implement in children both with and without NDDs. Without the audiovisual instructions, the tasks would have likely been more challenging for children of all ages and abilities to understand, due to the level of verbal comprehension required of the previous written instructions (Berglund Melendez et al., 2020). Most parents indicated that the tasks were appropriate for their child's abilities, and most children felt confident in their understanding of the task rules, following the instructional videos. Further, all children were able to complete all tasks in the battery. In the online sample, tasks could successfully discriminate between the groups. Performance differences in attention and reasoning domains aligned with current research, though unexpected results were found for verbal working memory. Attentional tasks emerged as perhaps the most important in discriminating children with ADHD from the TD and ASD groups. Study outcomes provide an important first step in obtaining feasibility metrics that will provide the foundation for further validating online cognitive screening tasks in children with and without NDDs.

3.2 Implications

By building upon this existing online cognitive battery for adults, we hope this study can aid in developing a novel screener for cognitive impairments and strengths in children. An accessible online cognitive screener can be used to identify at-risk children with NDDs. Results of this study could be used to better understand some of the key cognitive patterns associated with these common NDDs. Further, findings are relevant in the context of supporting students with diverse needs in education. Our results echo previous work which highlights attention and inhibition impairments often found in children with ADHD. This cognitive domain is highly relevant in children's overall success at school, as unidentified attention difficulties may be misinterpreted or manifest as behavioural issues in the classroom (Molfese et al., 2010). ADHD is one of the most commonly diagnosed NDDs in Canada, with an estimated prevalence of 5-8% in children (Centre for ADHD awareness Canada, n.d.; Espinet et al., 2022). As well, children with ADHD are more likely to have poor academic achievement and performance outcomes than those without ADHD, which has been linked to classroom inattention (Gray et al., 2017).

Reaction time variables also revealed important cognitive performance patterns. That is, the group who attained the highest scores for a given task typically also had the longest RTs (total or for correct answers). Long RTs may be misconstrued as cognitive deficiency if examined in isolation (i.e., they are taking longer to answer because they are struggling). However, results seem to highlight that accuracy corresponds with more cautious responses, while more errors correspond with quicker responses (Feldman & Huang-Pollock, 2021). Note that the ASD group consistently had more attempts than both typically developing children and the ADHD group on all tasks, which may point to perseveration in ASD (Landry & Mitchell., 2021). That is, individuals with ASD have been shown to make repetitive errors or get ‘stuck’ in consistently applying the same cognitive strategy, which may result in more attempts. Unexpectedly, the ASD group outperformed the ADHD group on three of the tasks, and the typically developing children on two of the tasks. It is possible that the ASD sample was relatively high-functioning, though this remains unclear.

As noted, it can be challenging to distinguish unique cognitive impairment patterns in ASD and ADHD, given the significant overlap and heterogeneity that exists among and within diagnoses (Corbett et al., 2009; Dajani et al., 2016; Karalunas et al., 2018). However, the present results suggest that the Creyos task battery may be a feasible method to screening EF skills (working memory, attention, reasoning) which are fundamental to children's success in and outside of the classroom (Gray et al., 2017; Molfese et al., 2010). This knowledge would be of great interest to families, educators, and psychologists looking to gain a deeper insight into accessible online cognitive testing options for children with NDDs. Identifying subgroups according to EF skills may help create a clearer picture of cognitive deficits within NDDs.

3.3 Future work

Online screening offers unique potential to overcome barriers to accessing in-person cognitive testing, so long as these online assessments are clear and comprehensible to younger populations with various reading abilities. The cognitive tasks developed by Creyos have been extensively validated in adult populations, but not yet school-aged children. Successfully adapting these instructions for children with NDDs would extend the potential use of this widely used platform, to younger individuals with diverse needs. Future work should explore the use of these tasks in larger populations, which may also allow for co-morbid group comparisons (i.e., children with ASD and ADHD). Participants in this sample were not screened for internalizing symptoms however, children with ASD and ADHD do show high-comorbidity with anxiety and depression and more severe cognitive deficits are associated with emotional regulation issues (Dajani et al., 2016; Tajik-Parvinchi et al., 2021; van Steensel et al., 2011). Thus, it may be worthwhile to explore these relationships using the Creyos tasks, to better understand the implications of cognitive impairments in NDDs beyond academic outcomes. Next steps will require validating the use of these cognitive tasks in larger samples of children with NDDs, by comparing results to standardized cognitive assessment data, such as the WISC-V (Wechsler, 2014).

3.4 Final conclusions

Results of this study highlight the heterogeneity of cognitive impairments that exists among children with ASD, ADHD, and TD children. An online cognitive screener may prove to be a helpful resource for psychologists, families, and educators as a first step to identifying cognitive difficulties in children, regardless of diagnostic status. Accessing screening as early as possible is imperative for children with NDDs to develop this profile of their strengths and needs, and to access early therapies.

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4.1 Appendix A

Focus group Interview Guide

- Questions will be asked following each Creyos game

<u>Child</u>

1) Did you understand how to play the game? Follow up: What helped you understand?
2) Was there anything confusing about the written instructions/the instructions I read to you? Was there anything confusing about the pictures before the games?
3) What did you like most about the game instructions? What did you dislike?
4) How ready do you feel to play the games after watching the instructions? Can you show me using these faces? (sad = not at all ready, happy = super ready)

<u>Parents</u>

1) Do you feel that the instructions were appropriate for your child's ability? Why/why not?
2) Do you think the instructions were engaging? Why/why not?
3) Do you feel that the instructions appropriately explain the game rules? Why/why not?
4) Do you feel the visual instructions were attractive (colours, shapes used)? How easy was it to monitor the visual instructions presented on the screen along with the written instructions?

5) On a scale from 1 to 10, how confident where you that your child could complete the games after viewing the instructions?

4.2 Appendix B

Ethics Approval

Date: 20 October 2022

To: Dr Emma Duerden

Project ID: 121203

Study Title: Accessible Instructions for an Online Screener of Cognitive Impairments in Children with and without Neurodevelopmental Disorders

Short Title: CBS Prolific

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: November 4 2022

Date Approval Issued: 20/Oct/2022 18:36

REB Approval Expiry Date: 20/Oct/2023

Dear Dr Emma Duerden

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
CBS_Prolific_Study_V1 Aug 24:2022	Online Survey	24/Aug/2022	1
CBS Prolific sample games_V1 Aug 24, 2022	Other Data Collection Instruments	24/Aug/2022	1
CBS Prolific Protocol V1 Aug 24.2022	Protocol	24/Aug/2022	1
Screener advertisment V1 Aug 24, 2022	Recruitment Materials	24/Aug/2022	1
Study advertisment V1 Aug 24, 2022	Recruitment Materials	24/Aug/2022	1
CBS_Prolific_Screening V2 Oct 4_2022	Online Survey	04/Oct/2022	2
CBS Prolific Assent_V2 Oct 4, 2022	Implied Consent/Assent	04/Oct/2022	2
CBS Prolific LOI_V2 Oct 4 2022	Implied Consent/Assent	04/Oct/2022	2

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Kelly Patterson , Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Western
Research

Date: 29 July 2022

To: Dr Emma Duerden

Project ID: 120070

Study Title: Developing Accessible Instructions for an Online Screener of Cognitive Impairments in Children with Neurodevelopmental Disorders

Short Title: CBS Interviews

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: September 9 2022

Date Approval Issued: 29/Jul/2022 14:01

REB Approval Expiry Date: 29/Jul/2023

Dear Dr Emma Duerden

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Focus Group interview guide_V1 May 21, 2022	Interview Guide	21/May/2022	1
CBS instructions script_V1 May 21, 2022	Other Data Collection Instruments	21/May/2022	1
Int_Demographics V2_Jul 15_2022	Online Survey	15/Jul/2022	2
CBS Int sample games_V1 May 24, 2022	Other Data Collection Instruments	24/May/2022	1
Int Protocol_V2 Jul 15, 2022	Protocol	15/Jul/2022	2
Int ads_V2 Jul 15, 2022. docx	Recruitment Materials	15/Jul/2022	2
Int POND Script_V1 May 21, 2022	Oral Script	21/May/2022	1
Int Assent_V1 May 21, 2022	Written Consent/Assent	21/May/2022	1
Int LOI_V2 Jul 15, 2022	Written Consent/Assent	15/Jul/2022	2

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
Using Qualtrics for Research Surveys - MySurveys - Western University-2	Technology Review document	21/May/2022	1

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered

Page 1 of 2

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Please do not hesitate to contact us if you have any questions.

Sincerely,

Kelly Patterson , Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

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Related Work Experience	Research Internship Mitacs Accelerate 2022-2023
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Publications:

Hennessy, A., Seguin, D., Correa, S., Wang, J., Martinez-Trujillo, J. C., Nicolson, R., & Duerden, E. G. (2022). Anxiety in children and youth with autism spectrum disorder and the association with amygdala subnuclei structure. *Autism*. https://doi.org/10.1177/13623613221127512

Conference Presentations:

Hennessy, A., Robinson, S., & Roberts, W.A. Assessing Metacognition in Rats. Presented at the Western USRI Showcase, 2021. [Poster].