Beyond the Dichotomy: Cognitive Proficiency and Executive Functioning Profiles in an ADHD Sample

by

Amber Nicole Schaefer

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Graduate Supervisory Committee:

Cristalís Capielo Rosario, Chair
Nancy Truong
Christopher Nicholls
Michael Lavoie

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ABSTRACT

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by difficulties in aspects of executive functioning such as inattention, hyperactivity, and impulsivity (American Psychiatric Association [APA], 2022). These challenges may impact learning and information retrieval, leading to variations in academic, vocational, and social skill development (APA, 2022). Precise assessment of these skills is crucial for understanding the diverse cognitive, behavioral, and emotional challenges associated with an ADHD diagnosis. Despite a global prevalence rate between 5-10%, no standardized assessment method has been established (Neprily et al., 2023). The development of digital tools like the NIH Toolbox Cognition Battery (NTCB) and Test of Variables of Attention (T.O.V.A.) offer enhanced accessibility and efficacy in early detection (Greenberg et al., 2007; Weintraub et al., 2013).

The study evaluates select NTCB measures of executive functioning, assessing their convergent and discriminant validity alongside established neuropsychological tests. It also investigates whether the T.O.V.A. and NTCB can identify unique cognitive profiles in an ADHD sample, further evaluating sex- and age-based profile differences. Correlation analyses using *SPSS (Version 28)* revealed strong convergent and discriminant validity of the NTCB Flanker, Dimensional Change Card Sort, and Pattern Comparison tests, with variable discriminant validity on the List Sorting test. Latent profile analysis (LPA) was used to identify distinct profiles using NTCB and T.O.V.A. tests within a sample of 213 participants between the ages of 5 and 26 years diagnosed with ADHD. Analyses were performed using *MPlus8* statistical software, with missing data being accounted for by using full information likelihood estimation (FIML). Model selections were based on the number of fit indices and criteria (Nylund et al., 2013). By adjusting unique combinations of subtests and scores from both measures, 2 to 3 distinct profiles emerged within the data, underscoring the heterogeneity and complexity of this clinical population. The data did not support sex-based performance differences; however, older cohorts demonstrated stronger NTCB working memory and processing speed performances.

The results highlight the versatility of the NTCB and T.O.V.A. in identifying unique neurocognitive profiles. Future research should explore their efficacy in diagnosing ADHD within diverse medical and psychiatric cohorts, aligning with emerging neuronal circuit theories.

In fond remembrance of my beloved parents, Michael and Karen Schaefer, whose profound influence shaped the person I am today.

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CHAPTER 1

INTRODUCTION

Overview

Attention-Deficit Hyperactivity Disorder (ADHD) constitutes a complex neurodevelopmental condition characterized by developmental deficits in neural processes, giving rise to functional impairments across diverse personal, social, academic, or occupational domains, as defined in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision (DSM-5-TR; APA, 2022). In accordance with the DSM-5-TR guidelines, precise criteria have been expounded to facilitate the diagnosis of ADHD, necessitating the coexistence of an array of symptoms of inattention and/or hyperactivity with impulsivity. For children 16 years and under, a minimum threshold of six symptoms is mandated, whereas for individuals aged 17 years and older, a minimum of five symptoms is deemed requisite. The diagnostic framework also mandates that the onset of symptoms occurs before 12 years of age, and significant functional impairments should be evident in at least two settings (e.g., home, school, work). Further, to ensure accurate diagnosis, rigorous exclusion of alternative psychiatric disorders as more plausible explanations for the observed symptomatology is emphasized (APA, 2022). Within this diagnostic context, ADHD is subtyped into three distinct presentations: predominantly inattentive, predominantly hyperactive-impulsive, or a combined presentation of the two subtypes (APA, 2022). The differential diagnostic process places substantial regard on the developmental stage of the individual, thus acknowledging the inherent multifariousness of ADHD across the lifespan, encompassing diverse brain-behavior manifestations (APA, 2022).

Empirical evidence gleaned from worldwide scientific investigations underscores the prevalence differences of ADHD subtypes (Gomez et al., 1999; Sharma & Couture, 2014; Simon et al., 2009; Skounti et al., 2007). Among the triad of classifications, the predominantly inattentive type (ADHD-I) emerges as having the highest frequency of ADHD presentations across the lifespan (Sharma & Couture, 2014; Simon et al., 2009; Skounti et al., 2007). The combined type (ADHD-C) is the second most prevalent subtype, with the hyperactive-impulsive type (ADHD-H) having the lowest lifetime prevalence rates (Skounti et al., 2007). In the context of ADHD subtypes, there exist various biological sex-based symptom distinctions. While males are more likely to be diagnosed with any ADHD, females are more likely to present with the inattentive features and be diagnosed with ADHD-I (Bauermeister et al., 2007; Gomez et al., 1999). These findings on prevalence and sex-based distribution shed light on the underlying biological etiology of the ancillary symptoms associated with the disorder.

Despite substantial strides in elucidating the intricate neurobiological substrates and cerebral-behavioral interdependencies pertinent to ADHD, the diagnostic criteria regulating this intricate condition have remained relatively unchanged since the introduction of the fourth edition of the DSM (APA, 2000). Apart from including additional illustrations of symptom manifestation in individuals aged 17+ years and a reduction in the number of required symptoms for late adolescent and adult populations, the foundational framework of ADHD's diagnostic criteria has endured minimal transformation (APA, 2022). This has triggered a critical reassessment of the adequacy of the current diagnostic criteria by the scientific community in capturing the diverse cognitive and behavioral profiles exhibited by neurodivergent individuals with ADHD.

While definitive neurological imaging tests for precise ADHD diagnosis remain elusive, recent empirical evidence has shed light on the existence of distinct behaviors and executive control challenges that appear to arise from specific neural substrates (Barkley, 2009; Lange et al., 2010; Martinez-Badia & Martinez-Raga, 2015). Such revelations underscore the need for a more nuanced and refined classification system that aptly acknowledges the intricate interplay between neural circuitry and behavioral manifestations in ADHD. Amidst this continuous scientific inquiry, both researchers and clinicians strive to enhance diagnostic acuity and deepen the field's comprehension of ADHD, thereby fostering nuanced and individualized interventions to bolster the well-being of those diagnosed.

The persistent stability of the diagnostic criteria for ADHD, juxtaposed with the expanding knowledge of its biological underpinnings, has engendered a seemingly paradoxical duality in the field. On one hand, scientific investigations have increasingly illuminated the intricate neural substrates and genetic heritability associated with ADHD. Neuroimaging studies, employing sophisticated artificial intelligence models, have spotlighted alterations in cortical thickness and the shape of key brain regions such as the inferior frontal cortex, bilateral sensorimotor cortex, left temporal lobe, and insula in individuals with ADHD (Barkley, 2009; Lange et al., 2010; Martinez-Badia & Martinez-Raga, 2015; Rafalovich, 2001). However, the definitive evidence confirming ADHD as a neurodevelopmental disorder as opposed to an acquired one has remained elusive, partly due to the inconclusive findings from neuroimaging and hereditary studies such as the Genome-Wide Association Study (GWAS). For instance, some twin studies suggest a heritability estimate of approximately 74%, whereas GWAS presents a more modest heritability estimate of 22% (Koutsoklenis & Honkasilta, 2023; Joseph, 2014).

This complex web of evidence and its inconclusive nature challenge the straightforward classification of ADHD as solely a familial-genetic neuropsychiatric disorder, necessitating cautious interpretation of findings and further investigation (APA, 2022; Batstra et al., 2014; Schleim, 2022). Furthermore, unlike established neurological disorders such as epilepsy or Parkinson's disease, ADHD lacks definitive imaging modalities that can offer exact diagnostic accuracy (APA, 2022; Koutsoklenis & Honkasilta, 2023). This paucity of definitive imaging modalities leaves clinicians with an undue reliance on subjective symptom reports, potentially leading to inaccurate diagnoses secondary to over-reporting of symptoms and/or overlooking atypical presentations (Bodenburg et al., 2022). Additionally, the current diagnostic classification system incompletely apprehends the intricate and diverse interrelationship between brain-based symptom manifestations and their corresponding underlying neuronal pathways. Consequently, a more nuanced approach is necessary to comprehensively understand the diversity evident in these distinct symptom presentations.

In light of these challenges, the exploration of additional neuropsychological facets becomes increasingly crucial in refining the diagnostic landscape of ADHD. The conventional core symptoms of ADHD, including inattention, hyperactivity, and impulsivity, are essential components of the diagnostic criteria. However, researchers have increasingly emphasized the relevance of cognitive proficiency as an integral aspect of the disorder (Devena & Watkins, 2012; Jacobson et al., 2011; Kibby et al., 2019). Cognitive proficiency, comprising working memory and processing speed, is vital for the efficient application of intellectual abilities, facilitating problem-solving and adaptive behaviors (Wechsler, 2014). Individuals with intact cognitive proficiency can efficiently process information, freeing up cognitive space for higher-order thinking and learning. In contrast, deficits in cognitive proficiency can hamper learning processes and impede academic and professional achievements (Weiss et al., 2019).

Objective evaluation of executive functions, including cognitive proficiency, can provide novel insights into the distinct cognitive profiles present within different subtypes of ADHD. The incorporation of cognitive proficiency measures in ADHD evaluations extends beyond the conventional attentional and executive dysfunction facets, offering a deeper comprehension of the intricate cognitive and behavioral complexities inherent in this disorder. By delving into the domain of cognitive proficiency, researchers and clinicians strive to distinguish ADHD from other conditions exhibiting overlapping symptomatology and explore cognitive nuances among individuals diagnosed with ADHD (Capdevila-Brophy et al., 2014; Elia et al., 2009; Karalunas et al., 2019; Lee et al., 2014; Rostami et al., 2020).

Although objective assessments of executive function skills provide comprehensive insights into an individual’s unique strengths and weaknesses, access to these evaluations is not equitable. Traditional neuropsychological evaluations are resource-intensive processes that historically have been inaccessible to underserved and marginalized communities. These assessments often involve extensive time commitments, requiring individuals to dedicate significant periods for testing sessions, consultations, and follow-up appointments. Additionally, the specialized expertise of neuropsychologists, who conduct and interpret these evaluations, contributes to the overall cost and scarcity of services. Moreover, the demand for traditional neuropsychological evaluations often leads to extended waitlists, further exacerbating the accessibility issue. Individuals from underserved communities may face financial constraints, limiting their ability to afford these services, and geographic barriers may hinder access to specialized neuropsychological facilities.

Statement of the Problem

The problem with the current diagnostic assessment of ADHD is two-fold: 1) the static nature of diagnostic criteria contrasts with the evolving literature on neural circuits associated with executive functions across the lifespan, and 2) neuropsychological evaluations remain inaccessible to economically disadvantaged individuals, further perpetuating inequities and health disparities among historically marginalized communities.

Idle Evolution of ADHD Diagnostic Classification

As mentioned earlier, the evolving literature and applied science of ADHD assessment and diagnosis present a paradoxical duality. Despite remarkable progress in unraveling the intricate biological and genetic underpinnings of the disorder, the diagnostic criteria have remained relatively static, relying on the established subtypes (Predominantly Inattentive, Predominantly Hyperactive-Impulsive, Combined Presentation) as the primary means of classification. However, this rigidity may inadvertently obscure the considerable heterogeneity of symptom presentations among individuals with ADHD, potentially overlooking subtle nuances in the clinical profile of affected individuals and hindering personalized treatment approaches. As a consequence, certain individuals may remain undiagnosed or misdiagnosed, as their unique symptomatology may fall outside the confines of the traditional diagnostic categories.

To overcome this limitation, there is an urgent call for a more discerning approach that goes beyond the conventional focus on basic attention and behavior regulation (i.e., hyperactivity and impulsivity). By expanding the assessment toolkit to include a nuanced understanding of various cognitive dimensions, researchers and clinicians can gain crucial insights into the multifaceted nature of ADHD. This approach facilitates the development of tailored interventions that address the individualized needs of affected individuals. A refined and comprehensive diagnostic strategy has the potential to optimize therapeutic approaches, enhancing treatment outcomes for those diagnosed.

Limited Accessibility of Assessments in Marginalized Communities

Historically, the cost and resource-intensive nature of traditional neuropsychological evaluations for ADHD has perpetuated delays in accurate diagnosis and appropriate treatment, particularly for marginalized and underserved poor communities. The reliance on pencil and paper tasks and lengthy assessment procedures has contributed to barriers in access, creating disparities in healthcare delivery. These challenges are especially pronounced for racial and ethnic cultural groups that have been overlooked and marginalized by the field of neuropsychology. For instance, communities of color, such as Black, Latinx, and immigrant populations, have faced systemic neglect and cultural bias in the design and implementation of neuropsychological assessments (Fujii, 2023; Rabin et al., 2020). The traditional assessment methods, often rooted in Eurocentric norms and values, may not adequately account for cultural differences, leading to misinterpretation of symptoms and underrepresentation of these communities in research and clinical settings (Fujii, 2023; Rabin et al., 2020). This lack of cultural sensitivity has resulted in inaccurate diagnoses and delayed interventions, exacerbating the disparities in ADHD diagnosis and treatment for individuals from diverse racial and ethnic backgrounds.

The reluctance of the scientific community and practicing neuropsychologists to address the accessibility issue in neuropsychological assessments can be perceived as an act of hostility and aggression towards communities of color. The failure to rectify these disparities perpetuates a systemic imbalance that disproportionately affects underserved communities and reinforces the broader issue of white supremacy within the field. By perpetuating barriers to access and ignoring the needs of marginalized communities, the field of neuropsychology risks perpetuating the inequitable power structures that perpetuate racial and social disparities in healthcare.

Study Purpose

The integration of digital assessment measures represents a paradigm shift, offering unprecedented possibilities for early detection of ADHD beyond the confines of the neuropsychologist's office (Parsons et al., 2018). This transformative approach entails the development of concise, objective assessments, amenable to administration by suitably trained healthcare professionals across various disciplines, such as medical assistants and nurses within pediatricians' offices. By embedding such measures within routine medical visits, a unique opportunity arises to formally evaluate an individual's attention and executive functioning skills, surpassing over-reliance on subjective reporting methods.

In light of these promising prospects, this study seeks to determine the comparability of specific selected digital measures with empirically validated assessments for ADHD diagnosis in a clinical setting. The primary objectives involve exploring the applicability of executive functioning measures from the National Institutes of Health (NIH) Toolbox Cognition Battery (NTCB) in capturing the diverse heterogeneity and subtle cognitive intricacies inherent in individuals with ADHD. This will be accomplished by comparing the convergent validity of the executive function measures of the NTCB with other validated neurocognitive assessments within an ADHD sample. Furthermore, it endeavors to unveil distinctive cognitive profiles that could serve as diagnostic hallmarks of ADHD, contributing to a more nuanced and comprehensive comprehension of this condition. This will be accomplished by examining latent profiles based on participants' performances on select measures from the NTCB and the T.O.V.A.

Potential Contributions

Advancing Assessment Equity and Accessibility

The field of neuropsychology has conventionally relied heavily upon, and at times solely, on traditional pencil and paper tasks for evaluations. However, as previously stated, these methods suffer from substantial drawbacks in our technology-driven era, being time-consuming and increasingly lacking in ecological validity with younger demographics. This not only renders them cost-intensive but also creates barriers to access for economically disadvantaged and underserved communities. A transformative shift has emerged with the advent of digital and computerized neuropsychological assessment measures, such as the NTCB and T.O.V.A., given their versatility and expediency, as well as the potential for regularly updated statistical norms. Researchers and clinicians alike have embraced its capacity to capture unique facets of patients' neurocognitive profiles while operating within an efficient and cost-effective framework. The flexibility of the NTCB and T.O.V.A. extends to the administration procedures, allowing for less restrictive requirements, thereby fostering diagnostic clarity, and enabling their utilization in various outpatient settings, transcending the traditional confines of the neuropsychologist's office. With their broad applicability, these digital measures open new vistas for early detection and evaluation of ADHD symptoms, facilitating timely intervention and support for individuals grappling with the disorder. In this rapidly evolving landscape of neuropsychological evaluation, the embrace of advanced digital tools like the NTCB and T.O.V.A. represents a profound step forward in enhancing the precision and accessibility of ADHD assessments.

Research and Development

As a remedial endeavor to the stagnant diagnostic criteria, this study aspires to enrich existing knowledge by delving into additional facets of executive functioning beyond an inattentive and hyperactive-impulsive profile. These cognitive constructs hold cardinal significance in an individual's ability to adeptly employ their intellectual faculties, thereby exerting a profound influence on problem-solving abilities and adaptive behaviors (Logue, 2015). By embarking on an exploration of how both primitive (e.g., basic attention) and higher-order executive functions (e.g., cognitive flexibility) manifest within individuals diagnosed with ADHD, this research endeavors to yield fresh insights into the idiosyncratic cognitive profiles characteristic of this disorder.

In the pursuit of diagnostic efficiency, the present study incorporates four brief executive function assessments from the NTCB, totaling 17 minutes, along with the

T.O.V.A., which takes 22 minutes. This yields a combined administration time of 39 minutes, significantly faster than traditional neuropsychological assessments that demand considerably more time. Mindful of the difficulties entailed in recruiting participants for research endeavors, the inclusion of these concise assessments not only economizes time but also furnishes invaluable information on the executive function abilities of the study participants. By assimilating these measures as indicators for latent profile analysis, the study seeks to scrutinize their potential applicability within clinical research settings, thereby propelling the elucidation of cognitive subtleties and nuances manifested in individuals with ADHD.

Relevance for Clinical Practice

The present study brings forth manifold insights with profound implications for both clinicians and patients, engendering the possibility of more precise and tailored interventions to bolster the well-being of those with symptom profiles of ADHD. By integrating a nuanced understanding of executive functioning, encompassing cognitive proficiency aspects, clinicians can tailor interventions to address specific cognitive strengths and weaknesses exhibited by individual clients. For instance, patients with intact working memory and reduced processing speed could substantially benefit from personalized recommendations, including leveraging modern technologies such as lecture recordings and talk-to-text systems, along with receiving repetitive instructions from educators to ameliorate their information processing challenges and foster academic and professional achievements. Alternatively, clients with intact processing speed but poor working memory may benefit from strategies like using lists, repeating information for accurate tracking, and employing step-by-step approaches to ensure tasks are executed in the appropriate sequence. In essence, the field's increased understanding of the neural underpinnings of ADHD obsoletes the 'one size fits all' approach to treatment.

Moreover, the current study incorporates brief digital tools designed to measure aspects of attention, working memory, processing speed, and set switching to advance the field's understanding of this intricate disorder. While inattention and hyperactivity/impulsivity have long been recognized as core facets of ADHD diagnosis, cognitive proficiency has remained underrepresented, despite extant literature highlighting its relevance in the context of ADHD (Devena & Watkins, 2012; Jacobson et al., 2011; Kibby et al., 2019). Consequently, this investigation enriches the existing knowledge by meticulously examining the variability of several executive functions within ADHD profiles throughout stages of neurodevelopment. This novel perspective unlocks avenues for identifying diverse cognitive patterns and challenges within the ADHD population, laying the foundation for more informed and tailored interventions.

Notably, the adoption of computerized assessments such as the NTCB and T.O.V.A. herald a paradigm shift in neuropsychological evaluation, endowing practitioners with the capability of continuous performance monitoring over time. This unprecedented feature not only expedites the assessment process for ADHD but also facilitates the ongoing evaluation of treatment efficacy with remarkable ease and precision. These transformative advancements in neuropsychological evaluation augur a new era in ADHD care, promising streamlined and comprehensive interventions that resonate profoundly with the needs and realities of clients, ultimately fostering improved outcomes and well-being.

Frequently Updated Statistical Norms

Relevant to both clinicians and researchers, the continuous data collection that occurs with increased use of the NIH Toolbox facilitates frequent updates of norms and versions, in contrast to conventional neuropsychological tests which tend to rely on older normative data. The NTCB can access and update normative data from subscribers, ensuring more current and relevant population demographics. As evidenced by the recent update of NTCB norms in April 2023 (Weintraub et al., 2013), this approach allows for timelier and more reflective data.

CHAPTER 2

LITERATURE REVIEW

This chapter delves into the intricate historical trajectory and evolutionary dynamics of ADHD, contextualizing it as a hybrid diagnosis encompassing both neurodevelopmental and psychiatric dimensions. It investigates the intricate interplay between contemporary diagnostic criteria and the underlying biological substrates that give rise to diverse symptom presentations, aiming to unravel the complexities inherent in this condition. Moreover, the chapter expounds upon the pivotal role of neuropsychological assessment in comprehensively characterizing the cognitive intricacies associated with ADHD. In accordance with the field's bid to advance the diagnostic process for earlier identification and treatment, this chapter also explores the burgeoning utilization of digital assessments. These advanced technologies hold immense promise in fostering early detection and facilitating precision in capturing the diverse symptomatology prevalent within this disorder. Finally, the chapter concludes with a detailed discussion about two cutting-edge computerized neuropsychological tests, poised to unveil critical insights into various dimensions of attention and executive functioning. By leveraging these sophisticated tools, clinicians and researchers can attain a more sophisticated and nuanced understanding of ADHD, ultimately empowering them to devise tailored interventions to optimize the lives of individuals navigating the challenges associated with this complex neurodevelopmental condition.

Evolving Understanding of ADHD

The contemporary understanding of ADHD is derived from scientific investigations and professional deliberations for over a century. Researchers have traced its origins as far back as 1798, revealing the enduring fascination with this complex neurodevelopmental condition within both the scientific community and amongst lay audiences (Barkley, 2009; Lange et al., 2010; Martinez-Badia & Martinez-Raga, 2015; Rafalovich, 2001). However, it was not until 1902 that Sir George Still, a prominent pediatrician at that time, delivered the first clinical portrayal of ADHD during his lectures at the Royal Society of Medicine (Barkley, 2009). His influential insights were subsequently published in the academic journal *Lancet*, characterizing ADHD as an "abnormal defect of moral control in children" (Still, 1902, p.1008). In the succeeding decades, the scientific community has evolved beyond viewing ADHD as a character flaw, embracing a more nuanced understanding of its biological etiology and genetic underpinnings that contribute to this neurodevelopmental disorder.

Along this journey, the nomenclature associated with this diagnosis has transformed, with former designations including fidgety Phil, Hyperkinetic Reaction of Childhood, and Attention Deficit Disorder (ADD) with or without hyperactivity (APA, 1980; APA, 1987; APA, 1994; APA, 2000; Barkley, 2009). Nevertheless, ADHD continues to be a subject of study, uniting both clinicians and researchers to enhance society's understanding of its etiological foundations and improve interventions for those with this diagnosis.

Despite significant progress in understanding its genetic underpinnings, the DSM-5-TR authors candidly acknowledge that definitive evidence confirming ADHD as a neurodevelopmental disorder remains elusive (APA, 2022; Koutsoklenis & Honkasilta, 2023). Neuroimaging studies have not yielded consistent differences between individuals with ADHD and controls, precluding the use of neuroimaging as a diagnostic tool (APA, 2022; Koutsoklenis & Honkasilta, 2023). Furthermore, while heritability estimates from twin studies are reported to be around 74%, Genome-Wide Association Studies (GWAS) present a heritability estimate of 22%, with limited replicated findings (Koutsoklenis & Honkasilta, 2023; Joseph, 2014). These complexities challenge the unequivocal classification of ADHD as solely a familial-genetic neurological disorder, warranting cautious interpretation and further investigation (APA, 2022; Batstra et al., 2014; Schleim, 2022). Moreover, in contrast to well-established neurological disorders like epilepsy or Parkinson's disease, ADHD lacks definitive imaging modalities that can offer exact diagnostic accuracy (APA, 2022; Koutsoklenis & Honkasilta, 2023).

It is likely for these reasons that the current diagnostic classification system incompletely apprehends the intricate and diverse interrelationship between brain-based symptom manifestations and their corresponding underlying neuronal pathways, thereby fostering an undue reliance on subjective report, which is susceptible to inaccuracies and may lead to an excessive diagnosis of the disorder in the absence of adequate validity testing (Bodenburg et al., 2022). This raises questions about why Symptom Validity Tests (SVTs) and Performance Validity Tests (PVTs) would be employed without, at the very least, some objective evaluation of executive functioning skills. If SVTs and PVTs can detect instances of exaggerated symptom reporting and malingering test behaviors (Bodenburg et al., 2022; Hirsch et al., 2022; White et al., 2022), assuming the patient is adequately attending to the validity measure upon testing, it becomes justifiable to conclude that a brief assessment of such skills is essential. Given the highly sought-after nature and misuse of stimulant medications by individuals without a genuine medical need (Sadek, 2022), it becomes imperative for ADHD assessors to adopt meticulous evaluation procedures that combine objective and subjective measures. It is imperative to underscore that meticulous evaluation does not necessarily entail protracted and resource-intensive assessments. Efficient and concise screening through the administration of digital assessments and SVTs/PVTs, alongside subjective symptom reporting, presents a viable option for achieving more accurate assessments of executive function skills. Considering the intricate nature of the brain-behavior relationship and the inherent limitations of relying solely on subjective symptom reports, a more nuanced approach is necessary to comprehensively understand the diversity evident in these distinct symptom presentations.

Despite the paucity of definitive neuroimaging studies for precise ADHD diagnosis, endeavors aimed at enhancing the current understanding of the concomitant symptoms and traits associated with ADHD have yielded substantial progress in illuminating the underlying neurobiological substrates of this multifaceted disorder. Despite this, the diagnostic criteria, established in the year 2000, have endured with minimal modification over the past two decades (APA, 2000; APA, 2022). Such stability, while ensuring continuity, has sparked debate among scholars and practitioners, questioning the sufficiency of the current criteria in accurately representing the diverse cognitive and behavioral profiles inherent to the neurodivergent individuals with ADHD. This discussion underscores the pursuit of a more comprehensive and refined classification system that can capture the intricate array of manifestations exhibited by this clinical population.

Central to this ongoing inquiry is the exploration of various neuropsychological facets that extend beyond the traditional core symptoms (i.e., attention, hyperactivity, impulsivity). Researchers are now delving into domains not previously considered such as: cognitive tempo (Fredrick & Becker, 2023a; Fredrick & Becker, 2023b; Mayes et al., 2023), emotional reactivity (Liu et al., 2022; Jaisle et al., 2023), cognitive proficiency (Lenhard & Daseking, 2022), intrinsic motivation (Serrano et al., 2023), and temperament (Joseph et al., 2023; Karalunas et al., 2019). This examination seeks to broaden our diagnostic perspective by embracing a more comprehensive understanding of the cognitive and emotional complexities underpinning ADHD (Capdevila-Brophy et al., 2014; Elia et al., 2009; Karalunas et al., 2019; Lee et al., 2014; Rostami et al., 2020).

The aspiration to develop a more nuanced classification system aligns with the endeavor to distinguish ADHD from other conditions that may exhibit overlapping symptomatology. By incorporating these additional neuropsychological dimensions, researchers and clinicians aim to forge a diagnostic framework that is more discriminative and refined, enabling a precise characterization of ADHD presentations, and differentiating them from other clinical entities (Capdevila-Brophy et al., 2014; Elia et al., 2009; Karalunas et al., 2019; Lee et al., 2014; Rostami et al., 2020). This diversity of cognitive and emotional traits accentuates the need for a comprehensive diagnostic approach that goes beyond a unidimensional focus on core 'superficial' and more obvious symptoms. By embracing this multidimensional perspective, researchers seek to expand our understanding of ADHD's intricate neural underpinnings and refine our diagnostic capacity to aptly capture the unique presentations witnessed within this diverse clinical population.

The persistent preservation of relatively unchanged diagnostic criteria for ADHD, despite significant scientific progress in elucidating the intricate neuronal substrates and brain-behavior relationships associated with the disorder, has catalyzed a critical reassessment of their adequacy in comprehensively capturing the diverse cognitive and behavioral profiles displayed by neurodivergent individuals with ADHD. While a definitive neurological imaging test for precise ADHD diagnosis remains elusive, emerging empirical evidence has illuminated the existence of distinct behaviors and executive control challenges that seem to arise from specific neural substrates. Such revelations beckon the consideration of a more nuanced and refined classification system that acknowledges the intricate interplay between neural circuitry and behavioral manifestations in ADHD. Amidst this perpetual investigation, both researchers and clinicians strive to augment diagnostic acuity and deepen the field's comprehension of ADHD, thereby enabling nuanced and individualized interventions to bolster the well-being of those traversing the neurodivergent terrain.

Advancements in Neuroimaging

The question of whether ADHD can be observed through imaging studies has been a subject of extensive investigation and debate within the scientific community (Wu et al., 2022). Despite substantial progress in understanding the neurobiological underpinnings of ADHD, definitive evidence confirming the disorder through neuroimaging remains sparse and inconsistent. Recently, sophisticated artificial intelligence models applied to brain anatomy assessment have illuminated alterations in cortical thickness and the morphology of specific brain regions, such as the inferior frontal cortex, bilateral sensorimotor cortex, left temporal lobe, and insula (Firouzabadi et al., 2022). Despite these advancements, neuroimaging studies have not consistently revealed distinctive differences between individuals with ADHD and those without, which hinders the use of neuroimaging as a definitive diagnostic tool for ADHD. Moreover, it appears that the disorder's multifactorial nature and the involvement of various neural circuits contribute to the challenges of capturing ADHD through traditional imaging methods.

In line with this variable evidence about neuroimaging, the authors of the DSM-5-TR have candidly acknowledged that conclusive evidence substantiating ADHD as a neurodevelopmental disorder has not yet surfaced (APA, 2022). Precisely, the authors have explicitly stated that no discernible biological marker exists to definitively diagnose ADHD, and even comprehensive meta-analyses of various neuroimaging studies have yielded no substantial distinctions between individuals with ADHD and those without the condition (APA, 2022). Consequently, the DSM-5-TR categorically asserts that no form of neuroimaging can currently be employed as a reliable diagnostic tool for ADHD (APA, 2022).

The intricacy and elusive nature of ADHD's underlying neurobiological mechanisms are evident in the DSM-5-TR's cautious acknowledgment. Despite well-documented behavioral manifestations, encompassing inattention, hyperactivity, and impulsivity, the precise neural substrates that underpin these symptoms continue to challenge researchers. This quandary necessitates continuous and rigorous investigation, urging the pursuit of comprehensive research endeavors that delve into the multifaceted nature of the disorder. Unraveling the intricacies of ADHD's neural underpinnings is paramount to foster advancements in the field, with the ultimate goal of identifying reliable biomarkers or neuroimaging techniques that can augment the accuracy and objectivity of ADHD diagnosis. Only through such endeavors can the field further evolve and enhance our understanding of this complex neurodevelopmental condition.

To date, research on ADHD has relied on behavioral assessments and subjective reports from patients and caregivers to arrive at clinical diagnoses. Although these methods are valuable and widely used, they inherently bear limitations due to their subjective nature. The paucity of definitive neurobiological markers or unequivocal imaging findings presents distinct diagnostic complexities and may engender misdiagnoses, given the obscurity surrounding the frequency and intensity of symptoms. Nevertheless, it is vital to acknowledge the significant strides made in the field of ADHD research. Neuroimaging studies have provided valuable insights into brain regions and networks that might be implicated in the disorder's etiology. Additionally, genetic and epigenetic studies have shed light on potential genetic risk factors and environmental influences on the development of ADHD (Palladino et al., 2019; Yadav et al., 2021). Still, the quest for precise neurobiological correlates of ADHD persists, and the DSM-5-TR's prudent stance on this matter reflects a commendable commitment to scientific rigor and the pursuit of an accurate and evidence-based diagnostic framework.

Impact of ADHD on Executive Functions

Executive functions encompass an array of intricate cognitive, behavioral, and emotional regulatory processes pivotal for goal-directed behaviors, problem-solving, and self-regulation. Individuals afflicted by ADHD often grapple with challenges in one or more of these functions. This can manifest as difficulties in maintaining composure while seated in work or educational settings, impulsively blurting out responses, and exhibiting excessive verbal output (APA, 2022; Swanson, 2003). Furthermore, they may encounter reduced attentional focus, compromised planning abilities, scheduling mishaps, spurts of hyperactivity, or impulsive moments. Although these difficulties can be experienced by individuals without ADHD, the distinguishing factor lies in the gravity and pervasiveness of these symptoms, hampering the functionality of those with ADHD in proportion to their intellectual capabilities (Brown, 2017). Consequently, their cognitive potential may not fully manifest, resulting in suboptimal outcomes (Brown, 2017). This section provides a comprehensive enumeration delineating distinct aspects of executive functions and their possible manifestations in individuals coping with ADHD.

Cognitive proficiency, encompassing processing speed and working memory, is a fundamental aspect of executive functioning crucial for optimal cognitive functioning and problem-solving (Wechsler, 2014; Weiss et al., 2019). It enables seamless execution of cognitive tasks and efficient allocation of mental resources for complex operations, enhancing higher-order thinking and problem-solving (Wechsler, 2014; Weiss et al., 2019). Deficits in cognitive proficiency can impact learning and cognitive performance, making it essential to examine its role in ADHD and implications for interventions (Feldman & Huang-Pollock, 2021). Although not directly specified in the accepted subtypes of ADHD, reduced cognitive proficiency can affect social interactions and home functioning (de Boo & Prins, 2007). For instance, challenges in working memory may hinder social reciprocity and interaction with peers (de Boo & Prins, 2007). Understanding cognitive proficiency can improve ADHD assessment and treatment, as it may contribute to behaviors and tendencies often attributed solely to attentional fluctuations (de Boo & Prins, 2007; Brown, 2017). While not explicitly included in the

DSM-5-TR diagnostic criteria, cognitive proficiency's role in ADHD warrants consideration for comprehensive evaluation and management of the disorder.

Cognitive Regulations

Selective Attention. The cognitive process involving the capacity to attend to a specific stimulus or task while disregarding irrelevant or distracting information, enabling individuals to concentrate on pertinent details and filter out extraneous stimuli in their environment (Cowan, 2008). For instance, during a scenario where an individual reads a book in a bustling coffee shop, selective attention aids in directing focus towards the text while disregarding background conversations and ambient noise. However, in the context of ADHD, selective attention can be adversely affected, resulting in challenges to sustain attention on relevant stimuli while concurrently disregarding irrelevant distractions. As a manifestation of this impairment, individuals with ADHD may encounter difficulties in maintaining focus during a classroom lecture, as they become susceptible to external stimuli such as noises or movements, potentially causing them to overlook crucial information provided by the teacher.

Sustained Attention. The capacity to maintain focus and concentration on a specific task or stimulus for an extended duration without succumbing to fatigue or losing interest (Sarter et al., 2001; Fortenbaugh et al., 2017). An illustration of sustained attention is when a student stays attentively engaged during a lengthy academic lecture, or when an individual persists in focusing on repetitive work tasks without experiencing boredom. ADHD, a neurodevelopmental condition, can significantly impinge upon sustained attention, causing challenges in sustaining focus over prolonged periods. For instance, a child with ADHD might encounter difficulties in completing an extended reading assignment or staying attentive during protracted classroom discussions. Frequently, their attention may wander, readily diverting to external stimuli like ambient noises or movements in the environment. Consequently, their ability to maintain attention on the assigned task becomes compromised, subsequently influencing their learning outcomes and academic performance. Unlike their peers without ADHD, who often manifest an extended capacity for sustained attention, individuals with ADHD may necessitate additional support and strategies to ameliorate their sustained attention abilities.

Divided Attention. Colloquially known as multitasking, denotes the cognitive capacity to simultaneously process and manage multiple tasks or stimuli in a coherent manner (Spelke et al., 1976). An illustrative example of divided attention entails a person adeptly listening to a lecture while concurrently taking comprehensive notes or a driver deftly attending to the road while skillfully adjusting the car's air conditioning system. Notably, individuals grappling with ADHD may confront formidable challenges in wielding divided attention effectively, grappling to seamlessly juggle diverse tasks or stimuli concurrently. For instance, a student afflicted by ADHD might grapple to harmonize attentive listening to the teacher's instructions with the simultaneous endeavor of taking legible and coherent notes, culminating in the generation of fragmented and disorderly records. Similarly, an individual wrestling with ADHD may find it arduous to concentrate on navigating the road while also navigating and mitigating other disruptive distractions within the vehicle's milieu, thereby engendering a potential compromise in driving safety. These intricacies in divided attention constitute palpable impediments to daily functioning and can impart substantial repercussions upon academic and occupational performance in those contending with ADHD.

Focused Attention. The cognitive capacity to sustain undivided focus on a singular task or stimulus, characterized by minimal distractibility (Cohen, 2014; Van der Meere & Sergean, 1988). This heightened concentration allows individuals to deeply engage in a specific activity or process information with precision and depth. For instance, when engrossed in a captivating presentation, one exhibits focused attention while intently listening to the speaker. Conversely, individuals with ADHD may manifest a heightened level of distractibility across various contexts, even when attention is required for brief intervals. This may result in challenges with tracking and sustaining short conversations, leading to potential misunderstandings or overlooking pertinent information. Similarly, they may encounter difficulties in locating objects while searching for them, as their attentional focus is prone to being disrupted by external stimuli. These experiences highlight the impact of ADHD on maintaining sustained and undivided attention, affecting daily functioning and task completion.

Working Memory. Working memory is a vital cognitive system responsible for temporarily holding and manipulating information for various cognitive tasks (Adams et al., 2018). It involves the temporary storage and manipulation of incoming information while concurrently processing other stimuli, enabling individuals to perform complex cognitive functions such as problem-solving, reasoning, and comprehension. Individuals with ADHD often face challenges in working memory, affecting their ability to remember and follow multi-step instructions, complete tasks efficiently, and recall and organize information from previous lessons. These deficits in working memory can also manifest during conversations, leading to forgotten key points and difficulties staying on topic. Consequently, academic performance, communication skills, and daily activities requiring the temporary retention and manipulation of information may be impacted.

Cognitive Flexibility. The cognitive ability to fluidly shift attention and focus among disparate tasks or activities (Steinhauser, M., & Hübner, 2007). This cognitive faculty, also known as task-switching and alternating attention, demands adaptability and malleability in navigating varying tasks, thoughts, or strategies. In the realm of everyday existence, cognitive flexibility empowers individuals to seamlessly transition between activities or routines, embrace diverse perspectives, and acclimate to alterations in their environment. It necessitates mental suppleness and dexterity in smoothly navigating from one task to another. For instance, in professional settings, cognitive flexibility allows one to effortlessly switch between different assignments or projects while maintaining productivity throughout each transition. Conversely, individuals contending with ADHD may encounter challenges in the domain of cognitive flexibility, evincing rigid cognitive patterns and struggling to adapt to novel circumstances or tasks.

Behavioral Regulations

Inhibition (Inhibitory Control). The ability to suppress impulsive responses and resist distractions or temptations (Adams et al., 2008). On a daily basis, inhibition allows individuals to control their impulses, stay focused on tasks despite distractions, and avoid risky behaviors. For individuals with ADHD, inhibition challenges can manifest as impulsive behaviors, difficulty staying focused, and making hasty decisions without considering consequences.

Planning and Organization. These skills refer to the ability to create and execute step-by-step strategies to achieve goals efficiently (Langberg et al., 2011). In daily life, this executive function is utilized for planning daily schedules, organizing materials for tasks, and prioritizing activities. In individuals with ADHD, planning and organization difficulties can lead to challenges in time management, completing tasks, and staying on track.

Initiation. The ability to start a task or activity independently and with appropriate effort (Netzer Turgeman & Pollak, 2023). In daily life, initiation is essential for beginning homework, chores, or work tasks without procrastination. Individuals with ADHD may encounter initiation difficulties, frequently struggling to start projects or tasks without external prompting.

Shifting. The capacity to transition fluidly and adaptively between different situations, activities, or facets of a problem, contingent upon contextual demands (Halleland et al., 2012). Vital dimensions of shifting encompass adeptness in handling transitions, tolerating alterations, engaging in flexible problem-solving, alternately allocating attention to various tasks, and seamlessly redirecting focus from one endeavor or subject to another. Mild impairments in shifting may hinder problem-solving efficiency, engendering a proclivity to become fixated or engrossed in a particular topic or quandary. Conversely, more pronounced challenges can manifest in perseverative behaviors and pronounced resistance to change.

Emotional Regulations

Emotional Control. The ability to effectively manage and express emotions appropriately within the given context (Mauss et al., 2007). This executive function enables individuals to remain calm in stressful situations, express emotions appropriately, and control emotional reactions. Impaired emotional regulation is frequently exhibited as emotional lability, characterized by abrupt outbursts or emotional explosiveness. Individuals with ADHD are at an increased risk of experiencing challenges in this domain and displaying disproportionately intense emotional responses to seemingly trivial events. They may easily burst into tears or experience uncontrollable fits of laughter with minimal provocation, or who manifest temper tantrums of a frequency or intensity that surpasses developmental norms for their age group.

Traditional Assessment Methods

Despite increased understanding of the disorder and the recognition of secondary gain in obtaining a diagnosis due to the misuse of stimulant medications, there is no widely accepted assessment process to diagnose this disorder (Johnson & Suhr, 2021). In fact, the current ADHD diagnostic standard primarily relies on historical interviews and subjective symptom reports from the client or caregivers, lacking the requirement for objective measures (APA, 2022). The use of qualifiers like “often” for symptom frequency introduces subjectivity and lacks statistical norms, potentially leading to over- or under-pathologizing due to limited public knowledge and the tendency to inaccurately report symptoms (Emser et al., 2018; Saulnier & Klaiman, 2018).

While self-reports and caregiver input furnish valuable narratives of daily functioning of the afflicted individual, the precise nature of executive dysfunction may elude clarity when solely relying on subjective accounts. Therefore, appropriate diagnosis demands accurate, objective assessment of executive functioning dysregulations, which extend beyond hyperactivity and impulsivity, emphasizing the need for broader measures

(Berlin, 2003; Emser et al., 2018; Saulnier & Klaiman, 2018). To address these limitations, a combined approach of objective and subjective assessments is recommended to accurately determine ADHD diagnosis suitability.

Clinical Utility of Objective Assessment

Objective cognitive testing facilitates both inter- and intra-individual comparisons of cognitive capacities within an age-matched cohort, elucidating any statistically significant deviations (normative strengths or weaknesses) relative to peers. This pivotal assessment aspect gauges the extent to which self-reported deficits align with developmental peers. Moreover, employing performance-based measures enables the assessment of executive function in the context of broader cognitive functioning, mitigating the risk of excessive pathologizing and potential misalignment with global developmental abilities. Isolating executive functioning evaluation from intellectual, developmental, and adaptive domains ensures a precise distinction between global developmental delays and reduced executive control. Thoroughly comparing objective performances across diverse cognitive tests reveals distinctive relative weaknesses, signifying specific deficits significantly divergent from the overall cognitive profile, effectively pinpointing areas of notable difficulty or suboptimal performance.

Furthermore, in accordance with the DSM-5-TR diagnostic criteria, achieving an accurate differential diagnosis mandates thorough exclusion of alternative neurodevelopmental or psychiatric presentations, including Intellectual Developmental Disorder, Autism Spectrum Disorder, Major Depressive Disorder, Generalized Anxiety Disorder, and personality disorders, among others, as these conditions may manifest overlapping symptoms that can be misattributed to ADHD (APA, 2022). Although the possibility of satisfying diagnostic criteria for multiple psychiatric disorders exists, there is an increased potential for erroneous interpretation of self-reported executive dysfunction. Careful evaluation of executive functioning within the context of global cognitive abilities is paramount, given the substantial risk posed by insufficient comprehension of an individual's cognitive abilities. Without this essential knowledge, precise determination of whether observed executive dysfunction surpasses typical expectations based on overall cognitive capacities becomes arduous and imprecise.

To achieve adequate comparison, broad-based objective neurocognitive assessments provide comprehensive evaluation of cognitive capacity, covering domains like verbal, non-verbal, fluid reasoning, visual-spatial, quantitative reasoning, planning, attention, working memory, processing speed, learning, memory, and academic achievement (Flanagan & Alfonso, 2017; Naglieri & Otero; 2017; Reynolds & Kamphaus, 2009). The choice of assessment depends on factors like age, presenting concerns, prior assessment exposure, and the evaluation purpose. For the purposes of assessing and diagnosing ADHD, many of these domains do not need to be assessed, thereby facilitating a briefer assessment process. That said, the problem is not the abundance of neurocognitive tests that can assess several domains of function. Instead, it is the resource and time commitment that disproportionately impacts the accessibility to these assessments. Ascertaining access to these traditional measures requires time and financial resources that are not available to all populations, thereby delaying assessment and diagnosis.

As previously mentioned, one way around this has been to diagnose in the absence of any objective cognitive testing. While on the surface this appears to be a reasonable solution, it introduces risk for inaccurate assessment of symptoms due to the propensity of inaccurate reporting of symptoms. Further, without objective data, subtle nuances of the disorder that are not always as noticeable by patients and caregivers can be overlooked such as cognitive processing speed, working memory, and cognitive flexibility. This has been evidenced in recent literature capturing various profiles that underscore the heterogeneity of this disorder (Mayes & Calhoun, 2006; Moura et al., 2019; van Hulst et al., 2015). This is why a more thorough assessment of specific executive functions is important, as these skills impact a person's ability to apply their intelligence in daily life on a consistent basis. That said, traditional pencil and paper neuropsychological assessments can be costly and resource-consuming, limiting accessibility to many populations and leading to delays in diagnosis and treatment.

Qualifications for Administration and Interpretation of Neurocognitive Tests

The administration, scoring, and interpretation of neurocognitive tests demand specialized training and, in some instances, advanced educational credentials. This ensures that only adequately trained professionals are entrusted with the assessment and diagnosis of psychiatric disorders such as ADHD. The *Standards for Educational and Psychological Testing* elucidates the criteria for competent assessors (American Educational Research Association [AERA] et al., 2014). This comprehensive framework delineates various levels of licensure designating professionals (i.e., "test users") responsible for the entire process of appropriate test administration, scoring, and interpretation. "Test users" refer to individuals tasked with the comprehensive management of tests, including their selection, administration, scoring, and interpretation, as well as the dissemination of outcomes. In accordance with Standards (AERA et al., 2014), a qualified evaluator must gather a comprehensive history and understanding of the individual's presenting concerns to curate a tailored test battery. This process necessitates training and experience with a diverse range of assessment instruments.

Level A. Level A assessments encompass tests and tools that can be competently administered, scored, and interpreted by responsible non-clinicians such as teachers and paraprofessionals/aides (AERA et al., 2014). Among the Level A tests are trade and vocational proficiency assessments and most interest inventories (AERA et al., 2014). Utilizing Level A tests typically mandates completion of advanced-level coursework, either at the undergraduate or graduate level, in testing from an accredited college or university, or equivalent training under the guidance of a qualified supervisor or consultant (AERA et al., 2014).

Level B. Level B comprises tests requiring specific training and, in some instances, certification, to be qualified to administer, score, and interpret the data (AERA et al., 2014). These assessments are more intricate than Level A tests, necessitating an understanding of psychometric principles, traits measured, and the relevant discipline (e.g., education, clinical, counseling). Level B encompasses most individual or group achievement/interest tests, screening inventories, and personnel tests (AERA et al., 2014). Users need advanced coursework (senior undergraduate/graduate level) in testing from accredited institutions or equivalent supervised training. Adequate psychometric training, reliability, validity, test construction, and supervised administration, scoring, and interpretation are prerequisites. Some tests may demand a master's in psychology, education, or equivalent, with membership in professional organizations requiring relevant assessment training and experience per *Standards* (AERA et al., 2014).

Level C. Level C requires advanced training and experience in administering, scoring, and interpreting tests (AERA et al., 2014). These assessments encompass aptitude, language, personality, or clinical diagnostic evaluations for individuals or groups. Utilization of Level C tests necessitates graduate-level training in relevant fields like school, clinical, or counseling psychology. A minimum of a master's or doctoral (i.e., Ph.D., Psy.D., Ed.D.) degree in education, psychology, or related disciplines is mandated for teaching or decision-making purposes, along with licensure or registration as a psychologist or certification by relevant associations or agencies (AERA et al., 2014). While there is no set number of courses that are required for the administration of these measures, completion of two university courses in tests and measurement, covering psychological measurement principles and assessment at the graduate level, is often required by licensing boards (AERA et al., 2014). Academic and supervised clinical experience, including training in test theory, administration, scoring, interpretation, and psychometric principles, are also often required (AERA et al., 2014). In specific cases, individuals with an MA or BA degree (e.g., psychometrist, graduate student of applied or related science) may administer Level C tests under the close supervision of a licensed professional. Qualified faculty members and professional staff can use Level C tests for research purposes, while graduate students need faculty countersignature (AERA et al., 2014).

Technology-Enhanced Assessment

An alternative approach to this predicament involves the creation of abbreviated assessments that exhibit comparable validity and reliability in evaluating cognitive functions. The essential goal is to design measures that are more accessible and feasible in diverse healthcare settings, such as during annual wellness visits with primary care physicians, enabling early detection of symptoms, mitigating suffering, and preventing adverse consequences resulting from delayed treatment. Favorably, the integration of digital assessment measures has emerged as a transformative approach, offering promising prospects for more comprehensive and accessible diagnostic processes (Parsey & Schmitter-Edgecombe, 2013). By harnessing the power of these digital measures, clinicians and researchers can now delve into the depths of cognitive intricacies, seeking to unlock a more nuanced understanding of ADHD and its myriad manifestations, ultimately paving the way for personalized interventions and improved diagnostic precision.

Advancements in neuropsychological assessments have led to the integration of digital administration options, such as Pearson Q-Global and Q-Interactive, including the adoption of iPad-based administration for Wechsler tests. This technological integration optimizes efficiency by curtailing the time needed for assessment and scoring, ultimately enhancing accessibility for individuals seeking evaluation. Through electronic delivery of subtests, the cumbersome tasks associated with traditional paper-and-pencil methods, like stimulus booklets and manual response recording, are rendered obsolete. Furthermore, instantaneous real-time scoring enables immediate access to results, facilitating swift analysis and interpretation. By embracing these digital advancements, the field not only bolsters efficiency but also expands the reach of neuropsychological testing, thereby providing more timely and accessible evaluation services to a broader population. However, conventional neuropsychological assessments, whether in digital or traditional format, necessitate substantial time and resources, primarily limited to the confines of a neuropsychologist's office. In this context, the efficacy of fast-paced digital assessment tools becomes evident. These tools can be deployed across various settings and yield instant results, facilitating the accurate confirmation or exclusion of an ADHD diagnosis.

NIH Toolbox Cognition Battery

The NIH Toolbox Cognition Battery (NTCB) is a comprehensive array of neuropsychological assessments crafted by the National Institutes of Health, targeting multifarious cognitive domains of individuals between the ages of 3 years, 0 months and 85 years, 11 months (Weintraub et al., 2013). This battery comprises a diversity of tasks and measures that scrutinize pivotal aspects of cognitive functioning, encompassing attentional faculties, working memory capacity, processing speed, executive functions, episodic memory, and linguistic proficiency. The resulting comprehensive report provides standard scores ($\bar{X}$ = 100, *SD* = 15) for administered measures, as well as composite scores of crystalized and fluid intelligences. By capturing a wide spectrum of cognitive abilities, the NTCB confers the capability to assess cognitive strengths and vulnerabilities in individuals, thereby facilitating the discernment of cognitive impairments, tracking longitudinal cognitive trajectories, and informing clinical decision-making and intervention strategies for individuals grappling with neurological and neurodevelopmental conditions (Akshoomoof et al., 2014; Denboer et al., 2014; Weintraub et al., 2013).

Test Development. Development of the NIH Toolbox emerged from a robust methodological investigation in two phases. The first phase consisted of a thorough literature review and gathering input from domain-area experts. The second consisted of pilot testing and applicability testing in diverse settings in the second phase (Khilari &

Narayan, 2014). The development process entailed the incorporation of additional constructs based on criteria like inter-rater reliability, responsiveness to real change, stability over time, and linguistic equivalence in Spanish, with a vision to encompass lifespan coverage of the construct. The NIH Toolbox aims to facilitate longitudinal assessment of neurological and behavioral functions using validated, quantified, objective, and computerized tools (Gershon et al., 2013; Khilari & Narayan, 2014). While the focus of this study is on the Cognitive Battery (CB) of the NIH Toolbox, it also assesses various other domains of neuropsychological functioning including motor, sensation, and emotion (Gershon et al., 2013; Khilari & Narayan, 2014).

Item Response Theory. Unlike more traditional neuropsychological assessment tools, the NTCB employs Item Response Theory (IRT; Richardson, 1936) for scoring, a method that predicts statistical and psychometric properties of a test and the probability of an examinee's response to an item (Khilari & Narayan, 2014). The IRT approach enables predicting individual behaviors in the real world and represents how an individual's ability or skill influences their response to each item (Khilari & Narayan, 2014). Most constructs, except for motor and sensory evaluation, are bolstered by IRT-based evaluation. Norms for the constructs were established based on population and age, with provisions for future modifications without compromising the validity of prior data. This computer-based assessment covers a wide range of abilities, minimizing floor and ceiling effects, and providing precise records of response accuracy and speed with heightened sensitivity (Gershon et al., 2013; Khilari & Narayan, 2014).

Qualification Level Requirements. The NTCB tests are categorized as C-Level assessments, akin to the Weschler scales, which necessitate a high level of expertise in test interpretation (Weintraub et al, 2013). Accordingly, access to C-Level tests should be granted solely to test users holding state licensure or certification in fields relevant to the assessment's purpose or possessing a doctorate degree in psychology, education, or closely related disciplines, complemented by formal training in the ethical administration, scoring, and interpretation of clinical evaluations pertaining to the intended application of the assessment. In accordance with this protocol, any users engaging with C-Level assessments must be under the supervision of one or more qualified individuals holding C-Level qualifications, which must have been obtained in advance through the prescribed process. Only upon careful review and approval of the applicant's license(s) and credential(s) will users receive an exclusive code for unlocking the NTCB Application.

Despite the comparable qualification level to other cognitive assessments, the advantage of the NTCB lies in its user-friendly nature, streamlined administration process, and required testing items, enabling confident and standardized delivery by diverse healthcare and educational professionals without necessitating a qualifying masters- or doctoral-level degree, provided they receive appropriate supervision. The digital delivery of instructions further mitigates the potential for administration errors that may compromise standardization practices. Additionally, the brevity of the NTCB renders it conducive to administration in various settings, including physicians' offices and school guidance offices, which are more frequented by individuals compared to neuropsychology practices with long waitlists.

Test of Variables of Attention

The Test of Variables of Attention (T.O.V.A.; Leark et al., 2007) is a computerized continuous performance test (CPT) used to assess key components of attention and inhibitory control in individuals aged 4 years, 0 months through 80+ years. offered in separate visual and auditory versions (Leark et al., 2007). This CPT has proved for validity and reliability in the assessment of sustained attention and inhibitory control (Forbes, 1998). The visual version involves verbal instructions, a 2-minute practice, and a 20-minute assessment. Examinees respond to visual targets by clicking a remote button with their dominant thumb. The resulting comprehensive report provides quarterly and total Standard Scores ($\bar{X}$ = 100, SD = 15) for response time, response time variability, commission errors, and omission errors, contributing to an overall ADHD attention comparison score (ranging between ≤ -10 to ≥ +10). It is utilized by qualified healthcare professionals for evaluating attention deficits, including ADHD, in both children and adults. The T.O.V.A. measures response time variability, response time, commissions, and omissions, which are compared to a large normative sample and a sample of individuals with diagnosed ADHD. The test does not require left/right discrimination or sequencing and offers visual or auditory stimuli response recording through a precise microswitch (±1 ms). The results are presented in an accessible report.

Qualification Level Requirements. The T.O.V.A. developers do not specify a specific qualification level for the administration and interpretation of the data. Instead, they maintain that "the T.O.V.A. test scores should be interpreted in context of a subject's history, neuropsychological test profile as well as neurobehavioral characteristics" (Leark et al., 2020, p.19). This represents a crucial differentiation, emphasizing the necessity for the tool's diagnostic use exclusively by qualified individuals.

CHAPTER 3

METHODS

This chapter discusses the study aims and objectives, as well as the research questions and hypotheses. It also delves into the intricacies of the data collection methods, selection of instruments used for the assessment of study variables, participant inclusion criteria, and the analytical approaches to test the formulated hypotheses.

Aims and Objectives

This study aims to investigate the comparability between specific selected digital metrics and empirically validated assessments for the diagnostic classification of ADHD within a clinical context. The overarching objective is to assess whether the implementation of briefer and more efficient digital assessments can enhance the accessibility of neuropsychological evaluations for traditionally underserved communities. This will be accomplished by comparing the convergent validity of the executive function measures of the NTCB with other validated neurocognitive assessments within an ADHD sample. Furthermore, it endeavors to unveil distinctive cognitive profiles utilizing the NTCB and T.O.V.A. that could serve as diagnostic hallmarks of ADHD, contributing to a more nuanced and comprehensive comprehension of this condition. Building upon existing literature regarding sex- and age-based differences in executive function profiles within ADHD samples, analyses were conducted to evaluate variations in performance outcomes across the measures. Given that the T.O.V.A. is a well-established and empirically validated CPT for the use of diagnosing ADHD, the convergent and discriminant validity are not tested for the purposes of this study.

Institutional Review Board

This study was approved by Arizona State University's Institutional Review Board (STUDY00018161).

Data Collection

From July 1, 2021, to April 30, 2022, I worked as a practicum student at a psychology private practice and developed a de-identified dataset. During this period, I actively participated in the data collection process, administering assessments to the participants. Subsequently, I compiled the data required for the study by meticulously reviewing each individual client file and creating the codebook. For the purposes of this study, the data were analyzed after I was no longer a practicum student and did not have access to patient files. Therefore, the IRB determined that the data included in this study were considered archival and de-identified.

Inclusion Criteria

The inclusion criteria for this study encompassed individuals with ADHD falling within the age range of 5 to 26 years, who had undergone a neuropsychological evaluation at an outpatient psychology private practice located in Scottsdale, Arizona. The selection of this age range emanated from meticulous consideration of scientific evidence elucidating the progressive maturation of the human brain and the age range of assessments employed in the study. While certain facets of attention and executive functioning commence their development in the early stages of childhood (around 3 to 4 years old), other intricacies of these cognitive processes manifest later, typically at 9 years of age or beyond. Additionally, it is firmly established that the process of brain development persists until approximately 25 years of age, as substantiated by the World

Health Organization (2021). To ensure homogeneity in the sample and guarantee that all participants had completed their 25th year, an upper age cutoff of 26 years was deemed appropriate.

In terms of test measures, the selected executive function subtests from the NTCB have varying starting ages for when they can be administered. While the Flanker and Dimensional Change Card Sort can be administered to children as young as 3 years, List Sorting and Pattern Comparison are for children ages 7 years and older. It is for this reason that certain analyses necessitated the exclusion of participants below this age threshold so as to not introduce potential statistical error in estimating performance on a test that otherwise is deemed too advanced for their developmental age. This meticulous selection and application of test measures underscore the study's rigor and commitment to drawing meaningful conclusions while accounting for the developmental nuances of attention and executive functioning across the chosen age span.

Informed Consent

Given that all data utilized in this study is derived from archival sources, explicit prior consent had already been secured, authorizing the future utilization of participants' de-identified data for research pursuits. In the context of this esteemed outpatient psychology practice, consent is procured via an online intake process, wherein prospective clients are presented with the imperative task of confirming or declining consent to permit the utilization of their or their child's deidentified data from the assessment battery for research objectives. It is noteworthy that opting to decline consent bears no adverse repercussions upon the client or participant. Solely those clients or participants who willingly granted their consent were deemed eligible for inclusion in this study, further accentuating the ethical commitment to upholding the principles of informed consent and respecting participants' autonomy.

Research Questions and Hypotheses

Comparing performances within a sample of individuals diagnosed with ADHD across neural developmental stages, this study aims to investigate the following questions:

- **Question 1:** Does a relationship exist between the participants' performances on the executive functioning tests from the NTCB and other corresponding empirically validated neuropsychological tests?
    - **Hypothesis:** Participants' performances across measures of executive functioning from the NTCB will demonstrate a significant positive relationship with performances on corresponding measures from other empirically validated tests assessing similar skills.
- **Question 2:** Does a relationship exist between the participants' performances on the executive functioning tests from the NTCB and unrelated measures from other empirically validated neuropsychological tests?
    - **Hypothesis:** Participants' performances across measures of executive functioning from the NTCB will exhibit a minimal or negligible correlation with measures of unrelated cognitive functions, indicating strong discriminant validity in distinguishing executive functions from these distinct constructs.

- **Question 3:** How many latent profiles will emerge using mean scores from the NTCB Flanker ("FL"), List Sorting ("LS"), Dimensional Change Card Sort ("DCCS"), and Pattern Comparison ("PC") subtests?
    - **Hypothesis:** Based on cognition features assessed by each of these measures as they relate to the diagnostic current classification system, at least five (5) distinct profiles are predicted to emerge with the aforementioned NTCB indicators:
        - ***Inattentive:*** Profiles will reflect statistically significant difficulty ($SS \leq 85$) with working memory ($\bar{x}_{LS}$), with age-appropriate to above ($SS > 85$) attention & inhibitory control ($\bar{x}_{FL}$), cognitive flexibility ($\bar{x}_{DCCS}$), and processing speed ($\bar{x}_{PC}$).
        - ***Inefficient Processor:*** Profiles will reflect statistically significant difficulty ($SS \leq 85$) with working memory ($\bar{x}_{LS}$) and processing speed ($\bar{x}_{PC}$), with age-appropriate to above ($SS > 85$) inhibitory control ($\bar{x}_{FL}$), and cognitive flexibility ($\bar{x}_{DCCS}$).
        - ***Inattentive & Impulsive:*** Profiles will reflect statistically significant difficulty ($SS \leq 85$) with working memory ($\bar{x}_{LS}$) and inhibitory control ($\bar{x}_{FL}$), with age-appropriate to above ($SS > 85$) processing speed ($\bar{x}_{PC}$), and cognitive flexibility ($\bar{x}_{DCCS}$).
        - ***Impulsive & Inflexible:*** Profiles will reflect statistically significant difficulty ($SS \leq 85$) with inhibitory control ($\bar{x}_{FL}$) and cognitive flexibility ($\bar{x}_{DCCS}$), with age-appropriate to above ($SS > 85$) working memory ($\bar{x}_{LS}$), and processing speed ($\bar{x}_{PC}$).

- ■ ***Inefficient, Impulsive, & Inflexible:*** Profiles will reflect statistically significant difficulty (SS ≤ 85) across all domains of working memory ($\bar{x}_{LS}$), inhibitory control ($\bar{x}_{FL}$), cognitive flexibility ($\bar{x}_{DCCS}$), and processing speed ($\bar{x}_{PC}$).

- **Question 4:** How many latent profiles will emerge using mean scores from the NTCB List Sorting ("LS"), NTCB Pattern Comparison ("PC"), T.O.V.A. Commission Errors ("TovaCE"), and T.O.V.A. Omission Errors ("TovaOE")?
  - **Hypothesis:** Based on cognition features assessed by each of these measures as they relate to the diagnostic current classification system, at least three (3) distinct profiles are predicted to emerge with the aforementioned NTCB indicators:
    - ■ ***Inattentive:*** Profiles will reflect statistically significant difficulty (SS ≤ 85) with working memory ($\bar{x}_{LS}$), with age-appropriate to above (SS > 85) processing speed ($\bar{x}_{PC}$), sustained attention ($\bar{x}_{TovaOE}$), and inhibitory control ($\bar{x}_{PC}$).
    - ■ ***Waning Vigilance:*** Profiles will reflect statistically significant difficulty (SS ≤ 85) with sustained attention ($\bar{x}_{TovaOE}$), with age-appropriate to above (SS > 85) working memory ($\bar{x}_{LS}$), processing speed ($\bar{x}_{PC}$), and inhibitory control ($\bar{x}_{TovaCE}$).
    - ■ ***Inefficient, Distractible, & Impulsive:*** Profiles will reflect statistically significant (SS ≤ 85) difficulties across all domains of working memory ($\bar{x}_{LS}$), processing speed ($\bar{x}_{PC}$), inhibitory control ($\bar{x}_{TovaCE}$), and sustained attention ($\bar{x}_{TovaOE}$)

- **Question 5:** Will there be performance differences based on sex?
    - **Hypothesis:** In accordance with the current literature, males are predicted to demonstrate significantly lower performance on measures of inhibitory control (Flanker, T.O.V.A. Commission Errors) compared to females. No differences between male and female performance are predicted for measures of sustained attention, working memory, cognitive flexibility, or processing speed.
- **Question 6:** Will there be performance differences based on age?
    - **Hypothesis:** In accordance with the literature on neurodevelopment, younger participants are predicted to have significantly lower scores on measures assessing higher-order executive functions (cognitive flexibility, sustained attention, working memory). Age is not predicted to impact performance on measures of processing speed.

Analytical Plan

To accomplish the study aims and answer the aforementioned research questions, several types of analyses were selected. First, bivariate correlations were chosen to assess the strength of the relationship between the executive functioning measures from the NTCB and other empirically validated neuropsychological tests measuring the same corresponding functions. Second, a sophisticated statistical approach known as Latent Profile Analysis (LPA) was selected to discern distinct profiles among a sample cohort of individuals diagnosed with ADHD. Finally, ANOVA and t-tests were selected to analyze age- and sex-based performance differences within this sample. This section will delve into greater detail about the analytical process and why these methods were chosen.

Information about the individual measures is detailed in the following subsection entitled "Measures".

Step One: Assessing Convergent and Discriminant Validity of the NTCB

Convergent Validity. Convergent validity, as posited by Campbell and Fiske (1959), concerns the extent of the positive association observed between a measurement or assessment tool and other theoretically linked measures. In the field of neuropsychology, its primary role lies in establishing the alignment between a particular test or instrument and established assessments that target akin cognitive domains. By attesting to convergent validity, both researchers and neuropsychologists can verify the congruence of their chosen evaluation with the intended cognitive construct within their specific sample, thereby enhancing the precision and significance of their findings. It is worth noting that even if a previous study demonstrated good convergent validity between similar measures, this may not necessarily translate to a different population, necessitating an evaluation of convergent validity for the present study to ensure its applicability to the specific context at hand. Convergent validity analyses were assessed using IBM SPSS Statistics (Version 27). This statistical software was also used to report on the frequencies of participant demographics

Discriminant Validity. In contrast, discriminant validity, a concept advanced by Campbell and Fiske (1959), centers on the extent to which a measurement or assessment tool demonstrates a lack of association with unrelated measures. In the realm of neuropsychology, this serves to ensure that a specific test or instrument accurately discriminates between its intended cognitive domain and other unrelated constructs. By confirming discriminant validity, both researchers and neuropsychologists can establish the distinctiveness of their chosen evaluation within their unique sample, thereby reinforcing the precision and robustness of their results. It's important to highlight that even if prior research demonstrated strong discriminant validity between similar measures, this may not necessarily hold true for different populations. Thus, an assessment of discriminant validity was undertaken in this study to ensure its appropriateness for the specific investigative context. Discriminant validity analyses were conducted using IBM SPSS Statistics (Version 27), with the software also utilized to present participant demographic frequencies.

Step Two: Latent Profile Analyses

Latent Profile Analysis (LPA) is an innovative clustering method that categorizes individuals within a diverse population into more homogeneous subgroups based on their values on continuous indicators (Lazarsfeld & Henry, 1968). This person-centered approach reveals distinct response patterns, termed latent profiles, representing unique combinations of observed continuous indicators. LPA assumes an unobserved categorical variable that divides the population into mutually exclusive and exhaustive latent classes. By identifying these meaningful subgroups, LPA provides valuable insights for developing prevention and treatment strategies. In the present study, two separate latent profile analyses were conducted using indicator variables from the NTCB and T.O.V.A. to capture nuanced cognitive profiles within an ADHD sample. Analytical procedures utilized MPlus8, a renowned statistical software for latent variable modeling. To address missing data, full information likelihood estimation (FIML) was employed for truncated age-appropriate subsamples, ensuring accurate results without superimposing scores for measures not applicable to specific age demographics. Model selections were carefully made by evaluating various fit indices and criteria (Nylund et al., 2013).

LPA 1. This analysis will include four executive functioning measures from the NTCB: the Flanker Inhibitory Control and Attention Test, List Sorting Working Memory Test, Dimensional Change Card Sort Test, and Pattern Comparison Processing Speed Test. The aim is to evaluate the NTCB's capacity to independently capture nuanced profiles within an ADHD sample.

LPA 2. This analysis will integrate the List Sorting Working Memory Test and Pattern Comparison Processing Speed from the NTCB, along with two subscores extracted from the T.O.V.A.: Total commission errors and total omission errors. The objective is to evaluate the collective performance of these cognitive proficiency measures from the NTCB and T.O.V.A. in identifying distinctive patterns within an ADHD sample.

Step 3: Assessing for Age- and Sex-Based Differences

As outlined in Chapter 2, the diagnosis of ADHD by subtype and the manifestation of symptoms vary depending on age and sex, influenced by factors such as brain development and biology. Consequently, the examination of differences across these measures was integrated as the concluding step in this comprehensive study. The following two tests were identified as the most suitable tools for assessing these differences within the sample of this study.

Independent Samples T-Test. A *t*-test is a statistical test used to assess whether there is a significant difference between the means of two independent groups (Boneau, 1960). This is particularly useful for assessing sex-based mean score differences across the various measures of executive functions. Since participants were categorized as either male or female, an independent samples t-test was chosen as the optimal analysis to evaluate statistical differences in performances across subtests.

One-Way Analysis of Variance (ANOVA). An ANOVA is designed for research questions aiming to assess if there are significant differences in the means of a continuous dependent variable (Cardinal & Aitken, 2013). According to the NIH guidelines on brain development by chronological age (NIH, 2022), the current study encompasses three independent groups: Childhood (5-12 years), Adolescence (13-17 years), and Young Adults (18-26 years). Given that there were three categorical predictor variables (age group) and one continuous variable (performance score), a one-way ANOVA was deemed the best analysis to answer this question.

Digital Assessment Measures

NIH Toolbox Cognition Battery

The following total standard scores ($\bar{X}$ = 100, *SD* = 15) will be derived from the NTCB for the purposes of this study:

Flanker Inhibitory Control and Attention Test. This test assesses the cognitive function of inhibitory control in individuals ages 4 years and older. This test evaluates an individual's ability to focus on a central target while disregarding distracting surrounding stimuli. During the test, a series of arrows are presented on a computer or tablet screen, with one central arrow flanked by distracting arrows on either side. The participant is required to indicate the direction of the central arrow by pressing a corresponding button while inhibiting responses to the distracting arrows. The speed and accuracy of the participant's responses are measured, thus shedding light on their inhibitory control capabilities. This test has been demonstrated to show high convergent validity with other measures of working memory and executive functioning (Weintraub et al., 2013).

List Sorting Working Memory Test. This measure was designed to assess working memory in individuals ages 7 years and older. subtest assesses both auditory and visual working memory. During the early trials, participants are presented with sequences of either animals or foods, which they must state in size order as they appear on the screen (smallest to largest). As the test progresses, individuals are confronted with set-switching demands which require them to accurately reproduce the presented items in the correct order, separating the images by category (e.g., "First say the foods, then the animals."). This task has been demonstrated to show high convergent validity with other measures of working memory and executive functioning (Tulsky et al., 2013).

Dimensional Change Card Sort Test. This cognitive test assesses the capacity to shift attention between different dimensions (cognitive flexibility) in individuals ages 4 years and older. During the task, the participant is presented with a series of cards featuring shapes that vary in color and shape. Initially, they are asked to sort the cards based on one dimension, such as color. Once a successful sorting criterion is established, the rules are abruptly changed, and the participant must adapt their sorting strategy to a new dimension, such as shape. The test measures the participant's ability to shift their cognitive set swiftly and accurately, demonstrating their cognitive flexibility and capacity to adjust their attentional focus in response to changing task demands (Weintraub et al., 2013).

Pattern Comparison Processing Speed Test. This measure was designed to assess processing speed in individuals ages 7 years and older. Pattern Comparison involves a participant being presented with two images and needing to decide whether they are identical by indicating "yes" or "no". Both speed and accuracy are assessed within this measure to produce an age-adjusted standard score of processing speed. This task has demonstrated strong convergent and discriminant validity (Carlozzi et al., 2015).

Test of Variables of Attention

The following standard scores ($\bar{X} = 100$, $SD = 15$) will be derived from this measure for the purposes of this study:

Commission Errors Total. Measures impulsivity and disinhibition. This score materializes when the subject inappropriately responds to a non-target stimulus, exemplified by inadvertently pressing the button when it should be withheld. In the context of the T.O.V.A., these commission errors manifest more prevalently during the latter half, characterized by heightened response demands. Given their potential to influence other variables, excessive commission errors hold significance as a gauge of test validity. Notably, a surfeit of commission errors may correspondingly reduce omission errors, expedite response times, and augment variability.

Omission Errors Total. Measures focus and vigilance. This score manifests when the subject fails to respond to a target stimulus, exemplified by the omission of pressing the button upon the presentation or playback of a target. These lapses in responsiveness may stem from inattention, distractibility, or hyperactivity, the latter manifesting as instances when the subject looks away from the computer interface.

Validity Measures

Derived from previously established neuropsychological tests, the following measures were selected to assess either convergent or discriminant validity of the NTCB executive functioning subtests within this sample. Subtests labeled with an "*" indicate measures for convergent validity, while "^" denotes measures for discriminant validity.

Wechsler Scales of Intelligence

***Digit Span Backwards**.** The Wechsler Digit Span Backward test is a measure of working memory and attention, providing results as scaled scores ($\bar{X} = 10$, $SD = 3$). In this test, the examiner presents a sequence of digits orally at a rate of about one per second, and the examinee is required to repeat the digits in reverse order. The test starts with a short sequence and progressively increases in length until the examinee is no longer able to correctly recall the sequence. The specific Wechsler intelligence scale from which this test is derived depends on the age of the participant. For the purposes of this study, participants aged 6 years, 0 months through 15 years, 11 months were administered the Digit Span subtest from the Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V; Wechsler, 2014) was administered, though this version can be administered up through 16 years, 11 months of age. Participants 16 years, 0 months and older were administered the Digit Span subtest from the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV; Wechsler, 2008).

***Spatial Span Backwards**.** The Wechsler Spatial Span Backward test assesses visual-spatial working memory and attention, providing results as scaled scores ($\bar{X} = 10$, $SD = 3$). The examiner shows the examinee a sequence of blocks in a particular spatial order, and the examinee is then asked to recreate the sequence in reverse order by tapping the blocks in the correct sequence. The test gradually increases in difficulty as the sequence lengthens, measuring the examinee's ability to manipulate and retain visual-spatial information. For the purposes of this study, participants aged 6 years, 0 months through 15 years, 11 months were administered the Spatial Span subtest from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003), even though this version can be administered up through 16 years, 11 months of age. The reason for the older version is because this subtest was dropped in the most recent edition of the WISC. Participants 16 years, 0 months and older were administered the Digit Span subtest from the Wechsler Memory Scale, Third Edition (WMS-III; Wechsler, 1997). The reason for the older version is because this subtest was dropped in the fourth edition of the WMS.

Reynolds Intellectual Assessment Scales, Second Edition

The Reynolds Intellectual Assessment Scales, Second Edition (RIAS-2; Reynolds & Kamphaus, 2003) is a comprehensive intelligence test assessing cognitive capacities in individuals aged 3 years, 0 months to 94 years, 11 months. The RIAS-2 measures verbal and non-verbal intelligence, working memory, and processing speed. Its normative data were derived from a sample of 2,154 individuals from 32 states, representing diverse 2012 U.S. Census data pertaining to age, gender, geographic region, ethnicity, and years of education.

***Composite Memory Index**.** The RIAS-2 Composite Memory Index assesses an individual's auditory and visual working memory abilities and is reported as a standard score ($\bar{X} = 100$, $SD = 15$). Despite the name, the composite and subtests are actually reflective of short-term (working) memory, rather than long-term recall or recognition memory over time. It combines performance on two subtests: Verbal Memory and Nonverbal Memory. These subtests are both reported in *T*-scores ($\bar{X} = 50$, $SD = 10$).

- **Verbal Memory***- The subtest is tailored to the individual's age, comprising a series of sentences or age-appropriate stories read aloud during the evaluation. Subsequently, the examinee is tasked with accurately recalling these sentences or stories immediately after the examiner has finished reading them.
- **Nonverbal Memory***- This subtest entails the presentation of pictures depicting diverse objects or abstract designs, each displayed for a duration of 5 seconds. Following this, the examinee is presented with a page featuring six similar objects or figures and is required to identify which object or figure was presented earlier.

***Speeded Processing Index**.** The RIAS-2 Speeded Processing Index assesses an individual's capacity for expeditious visual information processing and swift response to visual stimuli. This index concentrates on gauging the aptitude for rapid visual scanning, adept visual-motor coordination, and prompt cognitive decision-making. It elucidates an individual's efficiency in processing visual data within temporal constraints, affording intricate insights into their cognitive processing velocity and acumen in integrating visual and motor functions. Scores are reported as a standard score ($\bar{X} = 100$, $SD = 15$). It combines performance on two subtests: Speeded Naming and Speeded Picture Search. These subtests are both reported in *T*-scores ($\bar{X} = 50$, $SD = 10$).

- **Speeded Naming***- This task is designed to assess an individual's rapid retrieval of information and processing speed. In this task, the examinee is presented with an array of items (e.g., tree, car, cat) on a page and is required to name them as quickly as possible within a limited timeframe.

The objective of the test is to evaluate an individual's ability to efficiently access and verbalize information from memory in a timely manner.

- **Speeded Picture Search*-** This is a cognitive assessment designed to measure an individual's processing speed and visual scanning abilities. In this task, the examinee is presented with a page containing a set of pictures arranged in a grid format. Among the pictures, there is a specific target picture that the examinee needs to quickly identify and circle within a limited timeframe. The primary goal of the task is to evaluate an individual's efficiency in visually searching for and identifying a specific target item within an array of distractor items.

***Verbal Intelligence Index*^.** The Verbal Intelligence Composite derived from the RIAS-2 assesses an individual's cognitive abilities pertaining to language-based reasoning, verbal memory, and verbal expression. Collectively, this assesses an individual's aptitude for comprehending, manipulating, and recalling linguistic information. (Reynolds & Kamphaus, 2003. Results are reported as standard scores ($\bar{X}$ = 100, *SD* = 15).

***Nonverbal Intelligence Index*^.** The Nonverbal Intelligence Composite derived from the RIAS-2 evaluates a participant's nonverbal and perceptual reasoning abilities, excluding linguistic and verbal components (Reynolds & Kamphaus, 2003. Results are reported as standard scores ($\bar{X}$ = 100, *SD* = 15).

Cognitive Assessment System, Second Edition

The Cognitive Assessment System, Second Edition (CAS-2; Naglieri et al., 2012) is grounded in the cognitive framework known as the PASS Model of neurocognitive functioning: Planning, Attention, Simultaneous, and Successive Processing (Naglieri & Otero, 2011). Geared towards children and adolescents spanning from 5 years, 0 months to 18 years, 11 months, the CAS-2 embodies four PASS Composites, each encompassing two primary subtests, supplemented by an auxiliary subtest within the Extended Battery configuration.

***Planning Composite**.** The CAS-2 Planning Composite Score offers an evaluation of an examinee's executive functions, encompassing their adeptness in strategic thinking, plan development and execution, as well as their speed of information processing. Scores are reported as a standard score ($\bar{X} = 100$, $SD = 15$). It combines performance on two subtests: Planned Codes and Planned Connections. These subtests are both reported in scaled scores ($\bar{X} = 10$, $SD = 3$).

- **Planned Codes***- This subtest assesses an examinee's ability to comprehend, strategize, and execute sequences of coded symbols. This evaluation appraises their aptitude to formulate organized plans for manipulating symbols based on explicit instructions, revealing their capacity for structured information processing and strategic implementation. The subtest entails the child using a key to decipher and encode symbols, thus reflecting their cognitive precision and ability to adhere to systematic procedures. Each trial duration is 60 seconds, and there are 4 trials in total.
- **Planned Connections*-** This subtest evaluates an examinee's cognitive flexibility, visual scanning speed, and processing speed. In the early trials, the examinee is required to connect consecutively numbered boxes in

ascending order, assessing their visual motor skills and processing speed (children between 5-7 years only complete these trials). Later trials extend this task for examinee's 8-18 years old by instructing the examinee to alternate between connecting numbered and lettered boxes in ascending order, evaluating their cognitive flexibility and set-shifting abilities. The time taken to complete each part is recorded and analyzed as an indicator of cognitive processing speed and task-switching efficiency.

Attention Composite*. The CAS-2 Attention Composite Score is a comprehensive measure designed to assess an individual's processing speed, visual scanning, attention to detail, and inhibitory control. This score takes into account an individual's performance on specific subtests within the CAS-2 battery that are indicative of verbal and nonverbal speed of information processing. Scores are reported as a standard score ($\bar{X} = 100$, $SD = 15$). It combines performance on two subtests: Expressive Attention and Number Detection. These subtests are both reported in scaled scores ($\bar{X} = 10$, $SD = 3$).

- **Expressive Attention*-** Depending on the examinee's age, the subtest presents either pictures of animals of varying sizes that are incongruent with their actual size (ages 5-7) or color words printed in incongruent ink (ages 8-18). Examinees state the animal size while inhibiting page content (e.g., "big" for a small-printed elephant) or name ink color while inhibiting word reading (e.g., "red" in blue). This assesses interference suppression, cognitive flexibility, selective attention, and inhibitory control.

- **Number Detection*-** This subtest presents an examinee with a booklet that has a series of rows with various numbers across the page. This task requires the examinee's prompt scanning and discernment of the target number (e.g., "4") amid distractor numbers. The assessment quantifies an individual's visual scanning speed and visual processing efficiency, furnishing valuable insights into their capacity for swift visual information processing and target identification in the presence of distracting stimuli. Results are reported as scaled scores ($\bar{X}$ = 10, *SD* = 3).

***Successive Composite**.** The CAS-2 Successive Score Composite encompasses an evaluation of an individual's aptitude for sequential processing, working memory, and auditory-verbal assimilation. Scores are reported as a standard score ($\bar{X}$ = 100, *SD* = 15). It combines performance on two subtests: Word Series and Sentence Repetition/Questions. These subtests are both reported in scaled scores ($\bar{X}$ = 10, *SD* = 3).

- **Word Series*-** This subtest assesses an individual's working memory of word sequences. It involves the examiner reading a series of words, followed by the examinee's recall of the words in the exact order they were presented.
- **Sentence Repetition/Questions*-** This subtest evaluates auditory processing and working memory. Examinees are asked to repeat nonsensical sentences and answer questions about the nonsensical sentences.

***Working Memory Composite**.** The CAS-2 Working Memory Composite Score is a supplementary index score that assesses an individual's capacity to hold both verbal and visual spatial information in their head for a brief amount of time in order to correctly respond to a series of tasks. Scores are reported as a standard score ($\bar{X}$ = 100, *SD* = 15). It combines performance on two subtests: Verbal-Spatial Relations and Sentence Repetition/Questions. These subtests are both reported in scaled scores ($\bar{X}$ = 10, *SD* = 3).

***Executive Function without Working Memory Composite**.** The CAS-2 Executive Function without Working Memory Composite evaluates cognitive skills related to planning, cognitive flexibility, and inhibitory control, encompassing the ability to organize and strategize while excluding working memory tasks. Scores are reported as a standard score ($\bar{X}$ = 100, *SD* = 15). It combines performance on two subtests: Planned Connections and Expressive Attention. These subtests are both reported in scaled scores ($\bar{X}$ = 10, *SD* = 3).

***Matrices*^.** This subtest evaluates nonverbal reasoning and problem-solving abilities by assessing an individual's capacity for abstract reasoning and identifying patterns within visual stimuli (Naglieri et al., 2012). Examinees are presented with a series of incomplete visual patterns and are required to select the correct piece to complete each pattern from a set of options. Scores are reported as a scaled score ($\bar{X}$ = 10, *SD* = 3).

CHAPTER 4

RESULTS

Within this chapter, I present the results of the analyses employed to answer the research questions and test the hypotheses outlined in Chapter 3. Tables are presented in tabular form in Appendix B.

Participant Demographics

The participants in the study were 213 children, adolescents, and young adults with ADHD (male = 123, 57.7%; female = 90, 42.3%) ranging in age from 5-26 years (*M*= 12.21, *SD* = 4.26). In accordance with the age cohort nomenclature used by the NIH (2022), 52.1% of the current sample are "children" (*n* = 111), 38.5% are "adolescents" (*n* = 82), and 9.4% are "young adults" (*n* = 20). Based on the current diagnostic classification system, 75.6% had the Combined Presentation (*n* = 161), 22.5% with the Predominantly Inattentive Presentation (*n* = 48), and 1.9% with the Hyperactive-Impulsive Presentation (*n* = 4). Of the 213 participants, 82.2% (*n* = 175) identified as White, 2.8% as Black (n = 6), 4.7% as Asian (*n* = 10), and 10.3% as "other" (*n* = 22). Regarding ethnicity, 91.5% identified as non-Hispanic/Latinx (*n* = 195), with only 8.5% (*n* = 18) as Hispanic/Latinx. Number of years of education ranged between 0 to 16 years (*M*= 6.62, *SD* = 4.11). Comorbid neurodevelopmental diagnoses included 18.8% with one more Specific Learning Disability (*n* = 40) and 8% with Autism Spectrum Disorder (*n* = 17).

Convergent and Discriminant Validity

Flanker Inhibitory Control and Attention Test

Performance on the Flanker exhibited significant positive correlations with the CAS-2 Attention Composite Index ($r = 0.329$, $p < 0.01$), as well as with performances on the CAS-2 Expressive Attention subtest ($r = 0.265$, $p < 0.01$) and the CAS-2 Number Detection subtests ($r = 0.295$, $p < 0.01$).

Performance on the Flanker did not demonstrate a significant relationship with CAS-2 Matrices ($r = 0.175$, $p = .084$). It also did not reflect a significant relationship with the RIAS-2 Verbal Intelligence Index ($r = 0.061$, $p = .679$) or RIAS-2 Nonverbal Intelligence Index ($r = 0.239$, $p = .102$).

List Sorting Working Memory Test

Performance on List Sorting exhibited significant positive correlations with performances on Wechsler Digit Span Backwards ($r = 0.270$, $p < 0.01$) and Wechsler Spatial Span Backwards ($r = 0.332$, $p < 0.01$). Similarly, a significant positive correlation was shown between performances on List Sorting and the RIAS-2 Verbal Memory subtest ($r = 0.349$, $p = 0.027$). Overall score on the RIAS-2 Composite Memory Index was also shown to have a significant positive correlation with List Sorting ($r = 0.363$, $p < 0.01$). However, performance on List Sorting was not statistically significant with performance on the RIAS-2 Nonverbal Memory subtest ($r = 0.179$, $p = 0.269$). A significant positive correlation was found between performance on List Sorting and the CAS-2 Working Memory Composite ($r = 0.426$, $p < 0.01$).

Performance on List Sorting demonstrated a significant positive relationship with CAS-2 Matrices ($r = 0.373$, $p < .01$) and the RIAS-2 Verbal Intelligence Index ($r = 0.378$,

$p < .01$). However, it did not demonstrate a significant relationship with the RIAS-2 Nonverbal Intelligence Index ($r = 0.101$, $p = .534$).

Dimensional Change Card Sort Test

Performance on Dimensional Change Card Sort showed significant positive correlations with the CAS-2 Planning Composite ($r = 0.240$, $p < 0.01$) and the CAS-2 Executive Functioning without Working Memory Composite ($r = 0.235$, $p < 0.01$). Significant positive correlations were also found between performances on the Dimensional Change Card Sort and the following subtests: CAS-2 Planned Codes ($r = 0.222$ $p < 0.01$), CAS-2 Planned Connections ($r = 0.195$, $p < 0.01$), and CAS-2 Expressive Attention ($r = 0.228$, $p < 0.01$).

Performance on the Dimensional Change Card Sort did not demonstrate a significant relationship with CAS-2 Matrices ($r = -0.019$, $p = .854$). It also did not reflect a significant relationship with the RIAS-2 Verbal Intelligence Index ($r = 0.206$, $p = .155$) or RIAS-2 Nonverbal Intelligence Index ($r = 0.155$, $p = .289$).

Pattern Comparison Processing Speed Test

Performance on Pattern Comparison demonstrated significant positive correlations with the CAS-2 Attention Composite ($r = 0.376$, $p < 0.01$) and RIAS-2 Speeded Processing Index ($r = 0.352$, $p < 0.05$). Significant positive correlations were also found between performances on Pattern Comparison and the following subtests: CAS-2 Expressive Attention ($r = 0.325$, $p < 0.01$), CAS-2 Number Detection ($r = 0.307$, $p < 0.01$), and RIAS-2 Speeded Picture Search ($r = 0.346$, $p < 0.05$). However, performance on Pattern Comparison was not statistically significant with performance on the RIAS-2 Speeded Naming subtest.

Performance on the Pattern Comparison did not demonstrate a significant relationship with CAS-2 Matrices ($r = -0.117$, $p = .282$). It also did not reflect a significant relationship with the RIAS-2 Verbal Intelligence Index ($r = 0.113$, $p = .475$) or RIAS-2 Nonverbal Intelligence Index ($r = 0.144$, $p = .365$).

Latent Profile Analysis 1

Indicator Variables

The following tests from the NIH Toolbox Cognition Battery were included as indicators: Flanker Test, List Sorting, Dimensional Change Card Sort, and Pattern Comparison.

Model Selection

Models with two to five profile solutions were compared. Among the different LPA models considered, the 2-profile LPA model stands out as the most robust choice. This inference is principally substantiated through the outcomes of the Vong-Lo-Mendell-Rubin likelihood ratio test, in which the 2-profile model yields a statistically significant result ($p < 0.001$). In contrast, when comparing the 3-profile model against the 2-profile model, the former was not warranted because there was not a significant difference between the two model solutions ($p = 0.139$).

In addition to the statistical significance of the Vong-Lo-Mendell-Rubin test, the 2-model model also showcases strong entropy (0.829), akin to that observed in the 3-profile (0.888) and 4-profile (0.888) models. The 2-profile model also demonstrates strong fit indices, as evidenced by the AIC (6261.479), BIC (6303.622), and aBIC (6262.444). These are comparable to those found in the 3-profile model, which only demonstrates marginally lower scores for the AIC (6244.702), BIC (6303.054), and aBIC

(6246.038). What accentuates the strength of the 2-class model, despite the slightly higher values of these indices, is the fact that both the 3-class and 4-class models have at least one class representing less than 5% of the total sample size. This indicates potential instability and limited practical significance for these classes. Thus, the 2-profile model is the strongest fit based on the current data.

Latent Profiles

Objectively Impulsive & Inflexible. This latent profile comprised 76.2% of the sample size (n = 144). It was characterized by statistically significant difficulty (SS $\leq$ 85) with inhibitory control ($\bar{x}_{FL}$ = 83.5) and cognitive flexibility ($\bar{x}_{DCCS}$ = 84.95). This latent profile also demonstrated age-appropriate working memory ($\bar{x}_{LS}$ = 98.09), and processing speed ($\bar{x}_{PC}$ = 89.10).

Relatively Impulsive. This latent profile comprised 23.8% of the sample size (n = 45). It was characterized by a relative weakness (SS $\geq$ 15 difference between mean scores) in inhibitory control ($\bar{x}_{FL}$ = 99.18). This stands in stark contrast to their advanced cognitive flexibility ($\bar{x}_{DCCS}$ = 114.46) and processing speed ($\bar{x}_{PC}$ = 112.65). Overall working memory was age appropriate ($\bar{x}_{LS}$ = 108.20).

Latent Profile Analysis 2

Indicator Variables

The following performance scores were included as indicators: NTCB List Sorting, NTCB Pattern Comparison, T.O.V.A. Commission Errors Total, and T.O.V.A. Omission Errors Total.

Model Selection

Models with two to four profile solutions were compared. Among the different LPA models considered, the 3-profile LPA model stands out as the most robust choice. This inference is principally substantiated through the outcomes of the Vong-Lo-Mendell-Rubin likelihood ratio test, in which the 3-profile model yields a statistically significant result ($p < 0.001$). However, when the 3-profile solution was compared to the 4-profile solution, the comparison was not significant ($p = 0.0173$). Therefore, I retained the 3-profile model.

While the 2-profile model also demonstrated a significant Vong-Lo-Mendell-Rubin likelihood ratio ($p < 0.001$), the 3-profile model demonstrated stronger entropy (0.913) compared to the 2-profile (0.912). Additionally, the 3-profile model also demonstrates better fit indices, as evidenced by the AIC (6321.526), BIC (6379.878), and aBIC (6322.862). The 2-profile model was found to demonstrate higher scores for the AIC (6377.131), BIC (6419.274), and aBIC (6378.096). Conceptually, the 3-profile model also adds increased nuance to the understanding of the various executive functioning profiles within the sample. Thus, the 3-profile model is deemed as the strongest fit based on the current data.

Latent Profiles

Fading Inhibition with Impaired Vigilance. This latent profile comprised 44.9% of the sample size ($n = 85$). It was characterized by statistically significant difficulty (SS ≤ 85) with inhibitory control ($\bar{x}_{\text{TovaCE}} = 74.05$) and impaired (SS ≤ 70) sustained attention ($\bar{x}_{\text{TovaOE}} = 40.92$). This latent profile also demonstrated age-appropriate working memory ($\bar{x}_{\text{LS}} = 96.23$), and processing speed ($\bar{x}_{\text{PC}} = 92.06$).

Fading Inhibition & Control. This latent profile comprised 16.4% of the sample size (n = 31). It was characterized by statistically significant difficulty (SS $\leq$ 85) with inhibitory control ($\bar{x}_{\text{TovaCE}}$ = 79.33) and sustained attention ($\bar{x}_{\text{TovaOE}}$ = 73.76). This latent profile also demonstrated age-appropriate working memory ($\bar{x}_{\text{LS}}$ = 102.67), and processing speed ($\bar{x}_{\text{PC}}$ = 97.38).

Intact Profile. This latent profile comprised 38.6% of the sample size (n = 73). It was characterized by age-appropriate functioning across all domains: inhibitory control ($\bar{x}_{\text{TovaCE}}$ = 104.51), sustained attention ($\bar{x}_{\text{TovaOE}}$ = 97.32), working memory ($\bar{x}_{\text{LS}}$ = 97.63), and processing speed ($\bar{x}_{\text{PC}}$ = 99.38).

Age- and Sex-Based Performance Differences

Distribution Assumptions

Prior to assessing for demographic performance differences, tests of normality and homogeneity of variance (homoscedasticity) needed to be evaluated. Sex-based distributions for the NTCB and T.O.V.A. scores had mixed results based on the Kolmogorov-Smirnov and Shapiro-Wilk tests (Table 19); however, Levene's test was not significant. Additionally, histogram and box-and-whisker plots revealed similar patterns of performance between the males and females (Figures 1-12), thereby demonstrating similar distributions despite not meeting normality of assumptions. Further, variable performance across skills is expected amongst individuals diagnosed with ADHD; therefore, some degree of abnormality in distributions would not be beyond the realm of possibility with this population. Additionally, the T.O.V.A. has a floor of a standard score (SS = 40), which appeared to have impacted the distribution of commission and omission errors across both males and females. It is for this reason that the following tests were determined appropriate to assess the following demographic differences.

Concerning the assumptions for the ANOVA, the varied sample sizes across the three age groups (refer to Table 5) might introduce potential bias. Nevertheless, prioritizing adherence to brain development cutoff ages was deemed more important than uniform sample sizes. Given certain assumption violations, the results should be interpreted with some degree of caution, as a larger sample size of young adults might influence the data. Further details on this limitation can be found in the dedicated section in Chapter 5.

Flanker Inhibitory Control and Attention Test

Sex: There was no significant effect of sex on Flanker performance, $t(207) = 1.27$, $p = .206$, although males had slightly higher standard scores ($M = 89.61$, $SD = 14.16$) than females ($M = 87.18$, $SD = 13.02$).

Age: Compared to their age-matched cohorts, children earned the highest standard scores ($M = 89.48$, $SD = 13.57$), followed by adolescents ($M = 88.13$, $SD = 13.74$), and with young adults earning the lowest scores ($M = 85.55$, $SD = 15.48$) in Flanker performance. However, these differences were not significant ($F(2, 206) = 0.76$ $p = .469$).

List Sorting Working Memory Test

Sex: Although males attained a slightly higher standard scores ($M = 101.06$, $SD = 15.15$) than females ($M = 100.04$, $SD = 15.02$) on the List Sorting performance, this difference was not significant $t(186) = 0.46$, $p = .644$.

Age: Results indicated a significant difference in List Sorting performance among the three age groups ($F(2, 185) = 5.26$ $p = .006$). Compared to their age-matched cohorts, young adults earned the highest standard scores ($M = 104.75$, $SD = 15.56$), followed by adolescents ($M = 103.58$, $SD = 15.22$), and with children earning the lowest scores ($M = 96.86$, $SD = 14.05$).

Dimensional Change Card Sort Test

Sex: There was no significant effect for sex on Dimensional Change Card Sort performance, $t(207) = 1.01$, $p = .315$, although males attained a slightly higher standard scores ($M = 93.83$, $SD = 16.64$) than females ($M = 91.53$, $SD = 15.83$).

Age: There was no significant difference in Dimensional Change Card Sort performance among the three age groups ($F(2, 206) = 0.28$ $p = 760$). Compared to their age-matched cohorts, all age groups had relatively equal scores: adolescents ($M = 93.89$, $SD = 16.98$), young adults ($M = 92.32$, $SD = 16.52$), children ($M = 92.15$, $SD = 15.85$).

Pattern Comparison Processing Speed Test

Sex: There was no significant effect for sex on Pattern Comparison performance, $t(186) = -1.40$, $p = .162$, even though females attained a slightly higher standard scores ($M = 97.74$, $SD = 25.29$) than males ($M = 92.75$, $SD = 23.34$).

Age: Results indicated a significant difference in Pattern Comparison performance among the three age groups ($F(2, 185) = 10.38$ $p < .001$). Compared to their age-matched cohorts, young adults earned the highest standard scores ($M = 106.25$, $SD = 19.85$), followed by adolescents ($M = 100.95$, $SD = 21.86$), and with children earning the lowest scores ($M = 86.84$, $SD = 25.04$).

T.O.V.A. Commission Errors

Sex: There was no significant effect for sex on T.O.V.A. Commission Errors, $t(183) = 0.98$, $p = .922$, with males attaining commensurate standard scores ($M = 83.49$, $SD = 20.74$) compared to females ($M = 83.19$, $SD = 19.90$).

Age: Compared to their age-matched cohorts, young adults earned the highest standard scores ($M = 92.56$, $SD = 17.14$), followed by children ($M = 84.11$, $SD = 20.24$), and with adolescents earning the lowest scores ($M = 80.36$, $SD = 20.56$) in T.O.V.A. However, this difference was not significant ($F(2, 182) = 2.81$ $p = .063$).

T.O.V.A. Omission Errors

Sex: There was no significant effect for sex on T.O.V.A. Omission Errors, $t(183) = 1.38$, $p = .168$, although males attained higher standard scores ($M = 72.22$, $SD = 26.93$) than females ($M = 66.64$, $SD = 27.71$).

Age: Compared to their age-matched cohorts, young adults earned the highest standard scores ($M = 71.72$, $SD = 30.61$), followed by adolescents ($M = 69.63$, $SD = 28.41$), and with children earning the lowest scores ($M = 69.33$, $SD = 26.00$) in the T.O.V.A. Omission Errors. However, this was not a significant difference ($F(2, 182) = 0.06$ $p = .944$).

CHAPTER 5

DISCUSSION

In this chapter, I present a thorough overview of the results, delving into how effectively the NIH Toolbox Cognition Battery measures various executive functions and how digital assessment can enhance our understanding of supplementary executive function symptoms in ADHD. I also discuss the study's limitations, explore the potential implications of the findings for research and practical purposes, and propose directions for future research endeavors.

NIH Toolbox Assessment Validity

Flanker Inhibitory Control and Attention Test

The current findings reveal that the Flanker Inhibitory Control and Attention Test emerges as a robust indicator of inhibitory control, substantiated by its noteworthy positive associations with the CAS-2 Attention Composite Index, the CAS-2 Expressive Attention subtest, and the CAS-2 Number Detection subtests. These relationships underscore that the Flanker Inhibitory Control and Attention Test is adequate to evaluate attentional processes and the mechanisms underlying inhibitory control. Importantly, my inquiry into the distinctiveness of the Flanker test points its independence from abstract reasoning, as it exhibits no substantial connections with the CAS-2 Matrices. Additionally, its limited correlations with the RIAS-2 Verbal Intelligence Index and RIAS-2 Nonverbal Intelligence Index further accentuate its independence from broader measures of cognitive aptitude. Together, this provides evidence for the Flanker Inhibitory Control and Attention Test's utility in discerning and evaluating inhibitory control processes with specificity.

List Sorting Working Memory Test

The hypothesis that the List Sorting Working Memory Test would demonstrate significant and positive relationships exclusively with other measures of working memory and not measures of discriminant validity finds partial validation in the current results. Within this study, List Sorting emerged as a robust evaluator of both auditory and visual working memory, displaying a notable preference for auditory working memory. This conclusion is supported by its substantial correlation with the CAS-2 Matrices, indicating an inherent linkage to abstract reasoning. Furthermore, its notable connection to the RIAS-2 Verbal Intelligence Index accentuates its correlation with verbal cognitive proficiencies. Notably, its modest relationship with the RIAS-2 Nonverbal Intelligence Index highlights its divergence from specific nonverbal cognitive dimensions.

The multifaceted essence of the List Sorting Working Memory Test finds expression in its distinct associations. The significant correlation with the CAS-2 Matrices suggests cognitive intertwinement beyond the realms of mere working memory, expanding into broader cognitive territories. Similarly, the robust correlation with the RIAS-2 Verbal Intelligence Index underscores its involvement in verbal cognitive domains. Remarkably, the test's stronger association with the CAS-2 Matrices alludes to its potential in evaluating overarching cognitive aptitude. This intricate interplay of connections underscores the nuanced role of the test, encompassing both working memory and higher-order cognitive dimensions.

Within the context of multitasking scrutiny, the List Sorting Working Memory Test retains its utility, albeit transcending pure working memory assessment. The test's distinctiveness shines through its exclusive focus on organizing items based on size order, thereby incorporating elements of visual-spatial ability and verbal reasoning. This unique emphasis contributes to its distinctive discriminant validity patterns. While it stands apart from nonverbal intelligence realms, its extensive relational landscape attests to its capacity to capture not just working memory but also broader dimensions of higher-order executive control.

Dimensional Change Card Sort Test

The hypothesis that the Dimensional Change Card Sorting Test would demonstrate significant and positive relationships exclusively with other measures of cognitive flexibility and not measures of discriminant validity was entirely supported based on the current results. The Dimensional Change Card Sort Test demonstrates its utility as an effective measure of cognitive flexibility through meaningful correlations with various cognitive domains. The current results highlight its capacity to assess cognitive adaptability and flexible thinking within the realm of executive functioning with ADHD populations. This was supported by its moderately strong associations with the CAS-2 Planning Composite and the CAS-2 Executive Functioning without Working Memory Composite emphasize its role in evaluating strategic planning and cognitive flexibility. Additionally, its links with CAS-2 Planned Codes, CAS-2 Planned Connections, and CAS-2 Expressive Attention underscore its ability to assess processes related to planning, forming connections, and directing attention.

The distinctive pattern of correlations observed with the Dimensional Change Card Sort Test, in conjunction with its limited associations with abstract reasoning and intelligence indexes, underscores its specialized role in capturing cognitive flexibility. The test's emphasis on assessing an individual's ability to adapt cognitive strategies to changing circumstances underscores its relevance in exploring the dynamic interplay of cognitive control and adaptability. In this capacity, it presents a promising avenue for investigating the multifaceted dimensions of executive functioning and understanding the role of cognitive flexibility in various aspects of cognitive performance and adaptive behaviors.

Pattern Comparison Processing Speed Test

The hypothesis asserting that the Pattern Comparison Processing Speed Test would solely exhibit substantial and positive associations with measures of cognitive flexibility, while not correlating with measures of discriminant validity, finds complete support in the current findings. Notably, its robust associations with the CAS-2 Attention Composite, CAS-2 Expressive Attention, CAS-2 Number Detection, and RIAS-2 Speeded Picture Search attest to its proficiency in capturing the velocity of cognitive operations and the efficiency of attentional mechanisms. These linkages, together with its distinctive patterns of relationships, underscore Pattern Comparison's distinct role as a specialized gauge of information processing speed, encapsulating the rapid manipulation of cognitive stimuli with precision.

Importantly, the current findings differentiate Pattern Comparison from broader cognitive indices, as reflected in its limited affiliations with broader intelligence measures of visual-spatial reasoning, as well as verbal and nonverbal intelligence. Its pronounced connections with factors centered on rapid information processing emphasize the test's distinct capacity to probe swift processing speed. This intricate matrix of relationships positions Pattern Comparison as a valid tool for delving into the nuances of information processing speed within this ADHD sample.

Nuanced Neurocognitive Profiles

LPA 1

The initial latent profile analysis, utilizing four NTCB subtests, has revealed important insights into the varied executive function profiles. By identifying distinct patterns, the study provides a more refined understanding of how these cognitive processes manifest in this ADHD sample. Among the profiles identified, the *Objectively Impulsive and Inflexible* (LPA 1) latent profile emerges as a prominent representation, encompassing the majority of the sample at 76.2%. Noteworthy is the substantial difficulty observed in inhibitory control and cognitive flexibility within this profile. These challenges are evident in scores falling below the designated threshold for both measures. Nevertheless, it's important to emphasize that even in the face of these significant challenges, individuals within this particular profile demonstrated age-appropriate levels of working memory and processing speed. This indicates a complex interaction between different aspects of executive function, rather than a uniform pattern of "executive dysfunction."

The second latent profile identified in the first LPA analysis, termed *Relatively Impulsive*, shows a distinct cognitive profile that constitutes 23.8% of the sample. A striking feature of this profile is the relative weakness displayed in inhibitory control, which starkly contrasts with the notable strengths observed in cognitive flexibility and processing speed. This counterintuitive pattern highlights the complexity of executive function presentations and underscores the importance of considering a broader context when interpreting individual profiles. Despite the identified weakness in inhibitory control, individuals within this profile exhibit advanced cognitive flexibility and processing speed. The intriguing observation of age-appropriate working memory within this profile adds another layer of complexity, reinforcing the notion that executive function operates within a constellation of interconnected cognitive abilities. Collectively, these profiles underscore the variability and interdependence of executive function domains, underscoring the significance of a holistic perspective in both research and practical applications.

Interestingly, the findings of this study underscore the significance of considering relative weaknesses within the context of individual executive function profiles. The identification of the *Relatively Impulsive* profile, which showcases a distinctive strength in cognitive flexibility despite a weakness in inhibitory control, highlights the importance of viewing executive function as a multifaceted construct. This approach accounts for the complexities of executive function presentations and emphasizes the need to assess both strengths and weaknesses comprehensively. This consideration was not initially a primary focus when embarking on this study, yet its recognition enriches our understanding of the diverse nature of executive functioning in the population under investigation. By illuminating distinct patterns of strengths and weaknesses, this study contributes to a more nuanced perspective on executive function profiles and their implications for interventions and targeted support strategies.

LPA 2

In the second LPA, three distinct latent profiles were identified: *Fading Inhibition with Impaired Vigilance*, *Fading Inhibition & Control*, and *Intact Profile*. Each profile provides a unique perspective on the interplay between inhibitory control, sustained attention, working memory, and processing speed.

The *Fading Inhibition with Impaired Vigilance* profile, representing nearly half of the sample (44.9%), exhibited noteworthy deficits in inhibitory control and sustained attention. Participants in this group displayed compromised inhibitory control, as evidenced by a statistically significant performance below the cutoff score, indicative of inhibitory control difficulties. Additionally, their sustained attention was impaired, with a significant proportion of omissions in the sustained attention task. Remarkably, despite these deficits, their working memory and processing speed were consistent with age-appropriate levels, suggesting a selective vulnerability in inhibitory control and sustained attention.

The *Fading Inhibition and Control* profile, comprising a smaller percentage of the sample (16.4%), also demonstrated challenges in inhibitory control and sustained attention. Similar to the first profile, individuals in this group exhibited difficulties in inhibitory control and sustained attention tasks. However, their working memory and processing speed were again on par with age-appropriate levels, further contributing to the unique cognitive profile exhibited by this group.

In contrast, the *Intact Profile* encompassed a significant portion of the sample (38.6%) and portrayed a markedly different cognitive picture. Individuals in this group demonstrated intact functioning across all cognitive domains assessed. Their inhibitory control, sustained attention, working memory, and processing speed were all within the expected range for their age. This profile serves as a reference point for typical cognitive functioning and provides a valuable context for understanding the variations observed in the other profiles. However, it is crucial to emphasize that participants grouped within this profile still carry an ADHD diagnosis, highlighting the possibility that these indicators may not fully capture the nature of dysfunction experienced by these individuals.

These findings from this second LPA further underscores the importance of considering multiple cognitive domains when assessing cognitive functioning. The identified profiles emphasize the dissociation between inhibitory control, sustained attention, though it was less sensitive to capturing the nuances in cognitive proficiency (working memory and processing speed) from the NTCB with the addition of the T.O.V.A. scores. This was evidenced by intact cognitive proficiency across all three profiles, despite previously demonstrating more nuance in the first LPA. Nevertheless, the presence of distinct profiles within the sample highlights the complexity of cognitive functioning and suggests potential avenues for further research.

Demographic Differences in Performance Profiles

Sex-Based Differences

Contrary to the hypothesis that males would exhibit lower scores in inhibitory control measures, the data did not support this assumption. No statistically significant differences were observed between male and female performance across NTCB and T.O.V.A. This contrasts with existing literature suggesting that males tend to display higher levels of hyperactivity and impulsivity. Interestingly, the study reveals not only a lack of significant differences in performance but also a noteworthy trend wherein males outperformed females across all measures, except for processing speed. These findings challenge prevailing notions, emphasizing the importance of a nuanced understanding of ADHD. Despite a higher prevalence of ADHD diagnoses in males, our results suggest that, within an ADHD sample, males and females exhibit comparable difficulties across various domains. This underscores the necessity for a refined comprehension of the disorder beyond generalized prevalence rates, highlighting that gender differences in ADHD symptomatology may be more nuanced and complex than previously thought.

Age-Based Differences

The hypothesis regarding age-based differences in executive functioning received partial support from the data, revealing significantly stronger working memory abilities in older cohorts. However, the data did not align with the expectation of significantly stronger cognitive flexibility or sustained attention in these age groups. Contrary to the hypothesis that processing speed would remain consistent across age cohorts, children exhibited statistically lower performance on the NTCB Pattern Comparison test. It's crucial to note that none of the measures in this study isolate a single skill, and additional aspects of cognitive functioning may have influenced performance, particularly impulsivity, given the absence of self-corrections in this test. Therefore, caution must be exercised against making generalized assumptions about an individual's abilities in any specific domain based on a single test. This underscores the necessity for a comprehensive systems approach when contemplating an ADHD diagnosis.

Clinical Implications

The current findings highlight the need for a more nuanced approach to evaluating, diagnosing, and treating ADHD. This section highlights the clinical implications derived from this study by combining the results with current resources available for treatment.

Treatment and Recommendations for Inattention

Aligned with existing scholarly works, this study reaffirms that inattention, encompassing both brief and sustained forms, stands as the most frequently impaired skill for those diagnosed with ADHD. Beyond this affirmation, this research also advances the current understanding by not only evaluating brief attention but also discerning it from sustained attention (vigilance). This highlights the imperative for evidence-based interventions designed to address attentional fluctuations through the cultivation of cognitive strategies for sustaining focus.

Behavioral interventions, including cognitive-behavioral therapy and organizational skills training, aim to improve both brief and sustained attention. Beyond conventional therapeutic settings, it's essential to consider the broader impact of diminished attention, especially on social skills development. Alternative approaches such as speech therapy may be appropriate to enhance cognitive skills that facilitate sustained attention in social settings, aiding a child in slowing down to interpret social cues and respond appropriately. Speech language pathologists can lead social skills groups, both in outpatient and school-based settings, to support the improvement of attentional skills, thereby fostering the development of social skills (Arefin et al., 2022).

Academic accommodations, such as extended time on tasks, offer valuable support within educational settings. Additionally, pharmacological interventions, particularly stimulant medications like methylphenidate and amphetamines, exhibit efficacy in ameliorating attention and mitigating inattentive symptoms. These interventions are can help confront the precise cognitive challenges linked with attentional fluctuations commonly associated with ADHD, ultimately fostering enhancements in focus, organization, and overall cognitive functioning. However, for those individuals who present with challenges in cognitive flexibility and impulsivity, medication alone may not be the most effective form of treatment.

Treatment and Recommendations for Cognitive Rigidity

A less-discussed symptom of ADHD involves cognitive rigidity, characterized by inflexible thinking, which can negatively impact problem-solving approaches. This rigidity may manifest as difficulties in set-switching, otherwise known as the ability to transition between tasks seamlessly. This study utilized the NTCB Dimensional Change Card Sort test to assess this skill, revealing a profile indicative of cognitive rigidity marked by diminished performance in task-switching. Noteworthy is that this skill was not reduced in isolation in the current dataset, as participants with this symptom also demonstrated reduced impulse control.

This underscores a subtle aspect frequently disregarded in the current diagnostic framework, notably exemplified by the “hyperactive-impulsive” category, which tends to overshadow the dimension of cognitive rigidity. While impulsive behaviors may superficially seem merely impetuous, they could also signify challenges in cognitive flexibility, hindering effective task-switching. Behaviors like speaking without forethought or taking actions without permission may serve as external manifestations of an internal struggle involving difficulty in shifting one’s focus to a new task, consequently heightening frustration and implicating other neuronal systems. Moreover, cognitive flexibility, an advanced executive functioning skill, might escape detection in early childhood but becomes more conspicuous in adolescence with heightened academic demands and a busier schedule. As per existing diagnostic criteria, the absence of these symptoms before age 12 could regrettably disqualify individuals from diagnosis, potentially depriving them of essential treatments and accommodations crucial for their future success.

Therefore, addressing cognitive rigidity in individuals with ADHD requires a multifaceted approach encompassing both behavioral interventions and pharmacological strategies. Cognitive-behavioral therapy (CBT) has shown efficacy in reshaping cognitive patterns, fostering flexibility, and promoting adaptive thinking in individuals with ADHD (Sprich at al., 2016). Targeted cognitive training programs, designed to enhance cognitive flexibility and problem-solving skills, can also contribute to mitigating cognitive rigidity.

Additionally, educational accommodations, such as individualized learning plans and environmental modifications, create supportive settings for individuals with ADHD to navigate tasks with greater flexibility (Harrison et al., 2020). Pharmacological interventions, particularly stimulant medications like methylphenidate and amphetamines, have shown efficacy in improving cognitive flexibility by modulating neurotransmitter activity (Van der Oord et al., 2008). A tailored treatment plan, integrating a combination of these interventions based on individual needs and preferences, holds promise in alleviating cognitive rigidity and enhancing overall cognitive functioning in individuals with ADHD. Regular monitoring and adjustments to the treatment plan, guided by ongoing assessments, ensure a dynamic and responsive approach to address cognitive rigidity within the context of ADHD.

Treatment and Recommendations for Impulse Control

The current findings continue to demonstrate that impulsivity is one of the core presentations observed in ADHD. For the hyperactive-impulsive presentation of ADHD, evidence-based interventions focus on managing impulsivity, hyperactivity, and associated behavioral challenges. Behavioral therapies, such as Parent Management Training (PMT; Ghanizadeh & Shahrivar, 2005) and Supporting Teens' Autonomy Daily (STAND; Sibley, 2017), are crucial components. These interventions aim to reinforce positive behaviors, teach self-regulation skills, and establish consistent routines. School-based interventions, such as environmental modifications and individualized educational plans, can create supportive learning environments. Overall, evidence-based interventions for the impulsive presentation of ADHD prioritize behavioral strategies and, when deemed appropriate, pharmacological interventions to address specific symptoms and improve overall functioning.

Scientific Implications

As previously stated, the collective administration of the NTCB executive function subtests and the T.O.V.A. is approximately 39 minutes. In contrast, traditional comprehensive neuropsychological evaluations typically involve a one-hour intake or clinical interview, a protracted testing session that may span several hours, and an additional hour-long feedback appointment. Moreover, the time between the initial interview and the feedback session can extend for weeks or even months, which can be burdensome for individuals dealing with undiagnosed and untreated ADHD. The prolonged evaluation process can lead to deleterious consequences across scholastic, occupational, and personal domains, hindering their overall functioning and well-being.

Despite the intrinsic value of comprehensive evaluations in certain cases, the use of objective data from the digitized assessment tools such as the NTCB and T.O.V.A. can increase access to early detection and diagnosis of ADHD. These measures provide valuable insights into specific aspects of executive functioning, including attention, inhibitory control, cognitive flexibility, working memory, and processing speed. Their brief yet comprehensive nature enables a focused evaluation of these specific cognitive domains, offering valuable information that complements the data obtained from traditional intelligence scales such as the Wechsler Intelligence Scales (WISC), and other cognitive assessments like the Reynolds Intellectual Assessment Scales (RIAS-2), and the Cognitive Assessment System (CAS-2).

While the Wechsler intelligence scales and other comprehensive cognitive assessments are valuable for providing a broad overview of an individual's cognitive abilities, they also require more time and, therefore, more financial resources. The NTCB effectively evaluates a range of executive functions, including cognitive flexibility, working memory, and processing speed, with a high degree of accuracy and conciseness. Its robust correlation with similar measures in the Wechsler intelligence scales, RIAS-2, and CAS-2 underscores its reliability. This allows for a comprehensive evaluation of the specific executive function domains that are often affected in individuals with ADHD.

Beyond just brief assessment, integrating the NTCB and T.O.V.A. data with other cognitive assessments, such as the Wechsler intelligence scales, RIAS-2, and CAS-2, can offer a multi-dimensional understanding of an individual's cognitive profile. This combination of assessments provides a robust and comprehensive evaluation that can inform diagnosis, intervention planning, and treatment monitoring. By leveraging the benefits of the NTCB and T.O.V.A. in combination with traditional cognitive assessments, clinicians can obtain a more nuanced and in-depth understanding of an individual's cognitive strengths and weaknesses, ultimately leading to more effective and tailored interventions for individuals with ADHD and other cognitive challenges.

Social Justice Implications

With robust validation observed in this study, the NTCB and T.O.V.A. tests emerge as promising tools for expeditious and effective executive functioning assessment. The incorporation of concise and economically viable digital measures in ADHD evaluation signifies a significant advancement, especially in promoting equity among historically marginalized groups. As previously stated, traditional neuropsychological assessments are often resource-intensive and contribute to disparities in access to care, especially for underserved communities. By embracing digital measures that are both concise and economically viable, barriers to early detection, diagnosis, and treatment of ADHD are substantially reduced. These digital tools enable a more widespread and accessible approach to assessments, facilitating early intervention and support. This proactive stance is crucial in addressing ADHD in historically marginalized groups, where timely detection can pave the way for tailored interventions and mitigate the risk of long-term academic and socio-emotional challenges. The increased accessibility of digital assessments aligns with a commitment to dismantling systemic disparities, ensuring that individuals from diverse backgrounds have equitable access to diagnostic resources, ultimately fostering a more inclusive and just healthcare landscape.

Study Limitations

The study's participant sample is characterized by a notable limitation due to its lack of diversity, primarily centered around racial and ethnic representation. Among the 213 participants, an overwhelming 82.2% identified as White, accentuating the underrepresentation of individuals from other racial backgrounds. This lack of representation is further highlighted by the marginal percentages of Black, Asian, and "other" racial identifications, which underscore the limited inclusion of diverse racial groups within the study cohort.

A parallel trend is observed concerning ethnicity, with 91.5% of participants identifying as non-Hispanic/Latinx and a mere 8.5% identifying as Hispanic/Latinx. This paucity of ethnic diversity raises pertinent concerns regarding the broader cultural implications and generalizability of the study's findings. The lack of representation from various racial and ethnic backgrounds may impede a comprehensive understanding of how executive function and ADHD are experienced and manifested within different cultural contexts. Moreover, the predominantly homogeneous sample may lead to a skewed interpretation of the relationships between executive function profiles and ADHD-related traits, potentially missing nuances that could be present within more diverse populations.

In the realm of ADHD research, recognizing the influence of cultural factors on its presentation and assessment is pivotal. The limited diversity within the sample restricts the scope of insights that can be drawn and applied to individuals from various cultural backgrounds. As a result, caution is warranted when extrapolating the study's conclusions to broader populations, particularly those with different sociocultural contexts. To foster a more comprehensive and nuanced understanding of executive function and ADHD, future research endeavors should prioritize the inclusion of diverse participants, allowing for a richer exploration of the interplay between executive function profiles, ADHD, and cultural influences.

Data collected from a private pay psychology practice introduces inherent bias, favoring economically privileged participants able to afford ADHD evaluations. This skews the sample and limits the study's generalizability to economically diverse populations, potentially overlooking ADHD experiences of those with limited resources. Future research should adopt more inclusive sampling strategies for a comprehensive understanding of ADHD across socioeconomic contexts.

Future Directions

Future investigations hold the potential to expand the scope and impact of this study by further extending the evaluation of NIH Toolbox validity across a spectrum of treatment settings and diverse medical cohorts. The introduction of Version 3 of the Toolbox presents an opportune moment to delve even deeper into the intricacies of executive functioning, particularly within the context of ADHD. This is particularly true given the recent broadening of the age range for which cognitive proficiency measures, List Sorting and Pattern Comparison, thus enabling a more comprehensive understanding of both objective and relative cognitive vulnerabilities at an earlier stage of development.

Deliberate attention is essential when assessing historically marginalized communities, including racial and ethnic minorities, English-language learners, immigrants, and economically disadvantaged groups. This is crucial, given that existing norms, mirroring the demographics of the current study, predominantly involve a white and English-speaking sample. While disparities in actual abilities based on race are not expected, it is crucial to examine the validity and reliability of these measures in assessing skills within underrepresented groups. Telehealth measures may offer advantages for specific demographics, but individuals with limited prior exposure may face distorted results. Overinterpretation of such results without consideration to potential mitigating sociocultural and political factors could cause undue harm to clients and patients seeking an ADHD evaluation. Therefore, thoughtful consideration is required to ensure the fairness and effectiveness of assessment tools across diverse populations. For instance, the novelty associated with using a tablet or computer for assessment could heighten attention to the task, potentially masking the genuine extent of the individual's struggles with the evaluated skills. Conversely, discomfort with digital devices might adversely affect one's score, potentially leading to overdiagnosis. Additionally, further research is imperative for vision and hearing-impaired communities, as digital assessment tools may impact their ability to accurately perceive and engage with the assessment tasks.

Moreover, to strengthen diagnostic accuracy and to mitigate the potential biases arising from self-reporting measures, the incorporation of performance-based assessments like the T.O.V.A. and other CPT measures remains a promising strategy. These objective assessments provide a distinct advantage by tapping into cognitive functions directly, thus circumventing the pitfalls of over-reporting symptoms for secondary gain. By integrating such tools, researchers can better decipher the underlying cognitive patterns, leading to a more precise differentiation between genuine deficits and the influence of external factors. This expanded approach would undoubtedly contribute significantly to a more nuanced and holistic comprehension of the intricate cognitive dynamics associated with ADHD across the lifespan. By embracing both self-reporting measures and performance-based assessments, future research endeavors can forge a more robust and multi-dimensional understanding of ADHD, fostering improved diagnostic strategies, tailored interventions, and targeted support for affected individuals of varying ages and contexts.

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APPENDIX A

IRB APPROVAL

EXEMPTION GRANTED

Cristalis Capielo
CISA: Counseling and Counseling Psychology
-
Cristalis.Capielo@asu.edu

Dear Cristalis Capielo:

On 6/15/2023 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Beyond the Dichotomy: Cognitive Proficiency Profiles of Children and Adolescents with ADHD
Investigator:	Cristalis Capielo
IRB ID:	STUDY00018161
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Cognitive Proficiency Profiles in ADHD Sample, Category: IRB Protocol; • Informed Consent- De-identified Data for Research pg 6, Category: Other;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (4) Secondary research on data or specimens (no consent required) on 6/15/2023.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

APPENDIX B

TABLES

Study Sample Statistics

Table 1

Sex

	N	%
Male	123	57.7%
Female	90	42.3%

Table 2

Race

	N	%
White	175	82.2%
Black	6	2.8%
Asian	10	4.7%
Other	22	10.3%

Table 3

Ethnicity

	N	%
Not Hispanic or Latinx	195	91.5%
Hispanic or Latinx	18	8.5%

Table 4

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	213	5	26	12.21	4.256
Current Grade Level	213	0	16	6.62	4.112
Valid N (listwise)	213				

Table 5

Age Group

	N	%
Child	111	52.1%
Adolescent	82	38.5%
Young Adult	20	9.4%

Table 6

ADHD Subtype

	N	%
ADHD-I	48	22.5%
ADHD-H	4	1.9%
ADHD-C	161	75.6%

Table 7

Autism Spectrum Disorder

	N	%
Yes	17	8.0%
No	196	92.0%

Table 8

Number of Specific Learning Disabilities

		Frequency	Percent	Valid Percent
Valid	None	173	81.2	81.2
	One	21	9.9	9.9
	Two	12	5.6	5.6
	Three	7	3.3	3.3
	Total	213	100.0	100.0

Convergent Validity Correlations

Table 9

NIH Toolbox Flanker Test Convergent Validity Correlations

		NTCB Flanker Test	CAS-2 Attention Composite	CAS-2 Expressive Attention	CAS-2 Number Detection
NTCB Flanker	Pearson Correlation	--			
	N	209			
CAS-2 Attention Composite	Pearson Correlation	.329**	--		
	Sig. (2-tailed)	.000			
	N	181	185		
CAS-2 Expressive Attention	Pearson Correlation	.265**	.855**	--	
	Sig. (2-tailed)	.000	.000		
	N	182	185	186	
CAS-2 Number Detection	Pearson Correlation	.295**	.847**	.447**	--
	Sig. (2-tailed)	.000	.000	.000	
	N	181	184	185	185

**. Correlation is significant at the 0.01 level (2-tailed).

Table 10

NIH Toolbox List Sorting Convergent Validity Correlations

		NTCB List Sorting	Wechsler DSb	Wechsler SSb	RIAS-2 Composite Memory	RIAS-2 Verbal Memory	RIAS-2 Nonverbal Memory	CAS-2 WM Composite
NTCB List Sorting	Pearson Correlation	--						
	N	188						
Wechsler Digit Span Backward (DSb)	Pearson Correlation	.270**	--					
	Sig. (2-tailed)	.000						
	N	177	191					
Wechsler Spatial Span Backward (SSb)	Pearson Correlation	.332**	.303**	--				
	Sig. (2-tailed)	.000	.000					
	N	174	188	188				
RIAS-2 Composite Memory Index	Pearson Correlation	.363*	.201	.076	--			
	Sig. (2-tailed)	.021	.191	.622				
	N	40	44	44	49			
RIAS-2 Verbal Memory	Pearson Correlation	.349*	.069	.017	.790**	--		
	Sig. (2-tailed)	.027	.654	.914	.000			
	N	40	44	44	49	49		
RIAS-2 Nonverbal Memory	Pearson Correlation	.179	.243	.106	.623**	.014	--	
	Sig. (2-tailed)	.269	.112	.493	.000	.923		
	N	40	44	44	49	49	49	
CAS-2 Working Memory Composite	Pearson Correlation	.426**	.303**	.380**	.244	.108	.279	--
	Sig. (2-tailed)	.000	.005	.000	.527	.782	.468	
	N	82	84	84	9	9	9	92

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 11

NIH Toolbox Dimensional Change Card Sort Convergent Validity Correlations

		NTCB Card Sort	CAS-2 Planning Composite	CAS-2 Planned Codes	CAS-2 Planned Connections	CAS-2 EF w/o WM	CAS-2 Expressive Attention
NTCB Dimensional Change Card Sort	Pearson Correlation	--					
	N	209					
CAS-2 Planning Composite	Pearson Correlation	.240**	--				
	Sig. (2-tailed)	.001					
	N	182	185				
CAS-2 Planned Codes	Pearson Correlation	.222**	.799**	--			
	Sig. (2-tailed)	.003	.000				
	N	183	185	186			
CAS-2 Planned Connections	Pearson Correlation	.195**	.828**	.460**	--		
	Sig. (2-tailed)	.008	.000	.000			
	N	183	185	186	186		
CAS-2 Executive Functioning w/o Working Memory	Pearson Correlation	.235**	.760**	.501**	.817**	--	
	Sig. (2-tailed)	.002	.000	.000	.000		
	N	166	169	169	169	169	
CAS-2 Expressive Attention	Pearson Correlation	.228**	.429**	.425**	.316**	.773**	--
	Sig. (2-tailed)	.002	.000	.000	.000	.000	
	N	183	185	186	186	169	186

**. Correlation is significant at the 0.01 level (2-tailed).

Table 12

NIH Toolbox Pattern Comparison Convergent Validity Correlations

		NTCB Pattern Comparison	CAS-2 Attention Composite	CAS-2 Expressive Attention	CAS-2 Number Detection	RIAS-2 Speeded Processing Index	RIAS-2 Speeded Naming Task	RIAS-2 Speeded Picture Search
NTCB Pattern Comparison	Pearson Correlation	--						
	N	188						
CAS-2 Attention Composite	Pearson Correlation	.376**	--					
	Sig. (2-tailed)	.000						
	N	161	185					
CAS-2 Expressive Attention	Pearson Correlation	.325**	.855**	--				
	Sig. (2-tailed)	.000	.000					
	N	162	185	186				
CAS-2 Number Detection	Pearson Correlation	.307**	.847**	.447**	--			
	Sig. (2-tailed)	.000	.000	.000				
	N	161	184	185	185			
RIAS-2 Speeded Processing Index	Pearson Correlation	.352*	.438**	.370*	.317*	--		
	Sig. (2-tailed)	.022	.004	.015	.041			
	N	42	42	43	42	49		
RIAS-2 Speeded Naming Task	Pearson Correlation	.213	.458**	.441**	.271	.709**	--	
	Sig. (2-tailed)	.176	.002	.003	.082	.000		
	N	42	42	43	42	49	49	
RIAS-2 Speeded Picture Search	Pearson Correlation	.346*	.344*	.204	.361*	.759**	.205	--
	Sig. (2-tailed)	.025	.026	.190	.019	.000	.157	
	N	42	42	43	42	49	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Discriminant Validity Correlations

Table 13

NIH Toolbox Flanker Test Discriminant Validity Correlations

		NTCB Flanker Test	CAS-2 Matrices	RIAS-2 Verbal Intelligence Index	RIAS-2 Nonverbal Intelligence Index
NTCB Flanker Test	Pearson Correlation	--			
	N	209			
CAS-2 Matrices	Pearson Correlation	.175	--		
	Sig. (2-tailed)	.084			
	N	98	99		
RIAS-2 Verbal Intelligence Index	Pearson Correlation	.061	.525	--	
	Sig. (2-tailed)	.679	.147		
	N	48	9	49	
RIAS-2 Nonverbal Intelligence Index	Pearson Correlation	.239	.020	.400**	--
	Sig. (2-tailed)	.102	.960	.004	
	N	48	9	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

Table 14

NIH Toolbox List Sorting Discriminant Validity Correlations

		NTCB List Sorting	CAS-2 Matrices	RIAS-2 Verbal Intelligence Index	RIAS-2 Nonverbal Intelligence Index
NTCB List Sorting	Pearson Correlation	--			
	N	188			
CAS-2 Matrices	Pearson Correlation	.373**	--		
	Sig. (2-tailed)	.000			
	N	89	99		
RIAS-2 Verbal Intelligence Index	Pearson Correlation	.387*	.525	--	
	Sig. (2-tailed)	.014	.147		
	N	40	9	49	
RIAS-2 Nonverbal Intelligence Index	Pearson Correlation	.101	.020	.400**	--
	Sig. (2-tailed)	.534	.960	.004	
	N	40	9	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 15

NIH Toolbox Dimensional Change Card Sort Discriminant Validity Correlations

		NTCB Card Sort	CAS-2 Matrices	RIAS-2 Verbal Intelligence Index	RIAS-2 Nonverbal Intelligence Index
NTCB Dimensional Change Card Sort	Pearson Correlation	--			
	N	209			
CAS-2 Matrices	Pearson Correlation	-.019	--		
	Sig. (2-tailed)	.854			
	N	98	99		
RIAS-2 Verbal Intelligence Index	Pearson Correlation	.206	.525	--	
	Sig. (2-tailed)	.155	.147		
	N	49	9	49	
RIAS-2 Nonverbal Intelligence Index	Pearson Correlation	.155	.020	.400**	--
	Sig. (2-tailed)	.289	.960	.004	
	N	49	9	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

Table 16

NIH Toolbox Pattern Comparison Discriminant Validity Correlations

		NTCB Pattern Comparison	CAS-2 Matrices	RIAS-2 Verbal Intelligence Index	RIAS-2 Nonverbal Intelligence Index
NTCB Pattern Comparison	Pearson Correlation	--			
	N	188			
CAS-2 Matrices	Pearson Correlation	.117	--		
	Sig. (2-tailed)	.282			
	N	87	99		
RIAS-2 Verbal Intelligence Index	Pearson Correlation	.113	.525	--	
	Sig. (2-tailed)	.475	.147		
	N	42	9	49	
RIAS-2 Nonverbal Intelligence Index	Pearson Correlation	.144	.020	.400**	--
	Sig. (2-tailed)	.365	.960	.004	
	N	42	9	49	49

**. Correlation is significant at the 0.01 level (2-tailed).

Latent Profile Analyses

Table 17

2-Class Model*	3-Class Model	4-Class Model	5-Class Model
Entropy: 0.829 AIC: 6261.479 BIC: 6303.622 aBIC: 6262.444 LMR $p < 0.001$	Entropy: 0.888 AIC: 6244.702 BIC: 6303.054 aBIC: 6246.038 LMR $p = 0.139$	Entropy: 0.888 AIC: 6238.118 BIC: 6312.678 aBIC: 6239.825 LMR $p = 0.642$	Entropy: 0.736 AIC: 6231.124 BIC: 6321.893 aBIC: 6233.202 LMR $p = 0.266$

*Indicates model of best fit

Table 18

2-Class Model	3-Class Model*	4-Class Model
Entropy: 0.952 BIC: 6606.553 AIC: 6648.696 aBIC: 6607.518 LMR $p < 0.001$	Entropy: 0.932 BIC: 6572.957 AIC: 6631.309 aBIC: 6574.293 LMR $p < 0.001$	Entropy: 0.918 BIC: 6548.663 AIC: 6623.223 aBIC: 6550.370 LMR $p = 0.574$

*Indicates model of best fit

Demographic-Based Performance Differences

Table 19

Sex-Based Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
NTCB Flanker	Male	120	89.61	14.155	1.292
	Female	89	87.18	13.015	1.380
NTCB List Sorting	Male	103	101.06	15.145	1.492
	Female	85	100.04	15.018	1.629
NTCB Dimensional Change Card Sort	Male	120	93.83	16.643	1.519
	Female	89	91.53	15.827	1.678
NTCB Pattern Comparison	Male	101	92.75	23.344	2.323
	Female	87	97.74	25.286	2.711
TOVA Commission Errors Total	Male	101	83.49	20.740	2.064
	Female	84	83.19	19.895	2.171
TOVA Omission Errors Total	Male	101	72.22	26.925	2.679
	Female	84	66.64	27.709	3.023

Table 20

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Sex	Statistic	df	Sig.	Statistic	df	Sig.
NTCB Flanker	Male	.126	93	.001	.945	93	.001
	Female	.076	80	.200*	.974	80	.099
NTCB List Sorting	Male	.100	93	.024	.980	93	.167
	Female	.078	80	.200*	.979	80	.224
NTCB Dimensional Change Card Sort	Male	.168	93	.000	.923	93	.000
	Female	.127	80	.003	.958	80	.010
NTCB Pattern Comparison	Male	.066	93	.200*	.974	93	.057
	Female	.085	80	.200*	.965	80	.026
TOVA Commission Errors Total	Male	.108	93	.010	.968	93	.023
	Female	.104	80	.032	.930	80	.000
TOVA Omission Errors Total	Male	.205	93	.000	.830	93	.000
	Female	.284	80	.000	.793	80	.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 21

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
Variance	Equal	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference
NTCB Flanker	Assumed	.329	.567	1.27	207	.206	2.43
	Not Assumed			1.29	197.64	.200	2.43
NTCB List Sorting	Assumed	.085	.771	0.46	186	.644	1.02
	Not Assumed			0.46	179.84	.644	1.02
NTCB Card Sort	Assumed	.649	.421	1.01	207	.315	2.30
	Not Assumed			1.02	194.69	.311	2.30
NTCB Pattern Comparison	Assumed	.178	.674	-1.40	186	.162	-4.98
	Not Assumed			-1.40	176.71	.165	-4.98
TOVA Com Errors	Assumed	.317	.574	0.10	183	.922	.30
	Not Assumed			0.10	179.28	.922	.30
TOVA Om Errors	Assumed	.257	.613	1.38	183	.168	5.58
	Not Assumed			1.38	174.98	.169	5.58

Table 22
ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
NTCB Flanker	Between Groups	285.934	2	142.967	.760	.469
	Within Groups	38767.166	206	188.190		
	Total	39053.100	208			
NTCB List Sorting	Between Groups	2279.453	2	1139.727	5.257	.006
	Within Groups	40109.823	185	216.810		
	Total	42389.277	187			
NTCB Dimensional Change Card Sort	Between Groups	147.353	2	73.677	.275	.760
	Within Groups	55127.747	206	267.610		
	Total	55275.100	208			
NTCB Pattern Comparison	Between Groups	11165.081	2	5582.540	10.382	.000
	Within Groups	99477.276	185	537.715		
	Total	110642.356	187			
TOVA Commission Errors Total	Between Groups	2274.893	2	1137.446	2.813	.063
	Within Groups	73595.270	182	404.370		
	Total	75870.162	184			
TOVA Omission Errors Total	Between Groups	86.437	2	43.218	.057	.944
	Within Groups	137557.380	182	755.810		
	Total	137643.816	184			

Table 23

		N	Mean	Std. Deviation	Std. Error
NTCB Flanker	Child	107	89.48	13.569	1.312
	Adolescent	82	88.13	13.471	1.488
	Young Adult	20	85.55	15.477	3.461
	Total	209	88.57	13.702	.948
NTCB List Sorting	Child	87	96.86	14.052	1.507
	Adolescent	81	103.58	15.218	1.691
	Young Adult	20	104.75	15.559	3.479
	Total	188	100.60	15.056	1.098
NTCB Dimensional Change Card Sort	Child	108	92.15	15.848	1.525
	Adolescent	82	93.89	16.976	1.875
	Young Adult	19	92.32	16.516	3.789
	Total	209	92.85	16.302	1.128
NTCB Pattern Comparison	Child	86	86.84	25.041	2.700
	Adolescent	82	100.95	21.857	2.414
	Young Adult	20	106.25	19.846	4.438
	Total	188	95.06	24.324	1.774
TOVA Commission Errors Total	Child	89	84.11	20.244	2.146
	Adolescent	78	80.36	20.557	2.328
	Young Adult	18	92.56	17.140	4.040
	Total	185	83.35	20.306	1.493
TOVA Omission Errors Total	Child	89	69.33	25.995	2.755
	Adolescent	78	69.63	28.414	3.217
	Young Adult	18	71.72	30.609	7.215
	Total	185	69.69	27.351	2.011

APPENDIX C

FIGURES

Sex-Based Performance Distributions

Figure 1

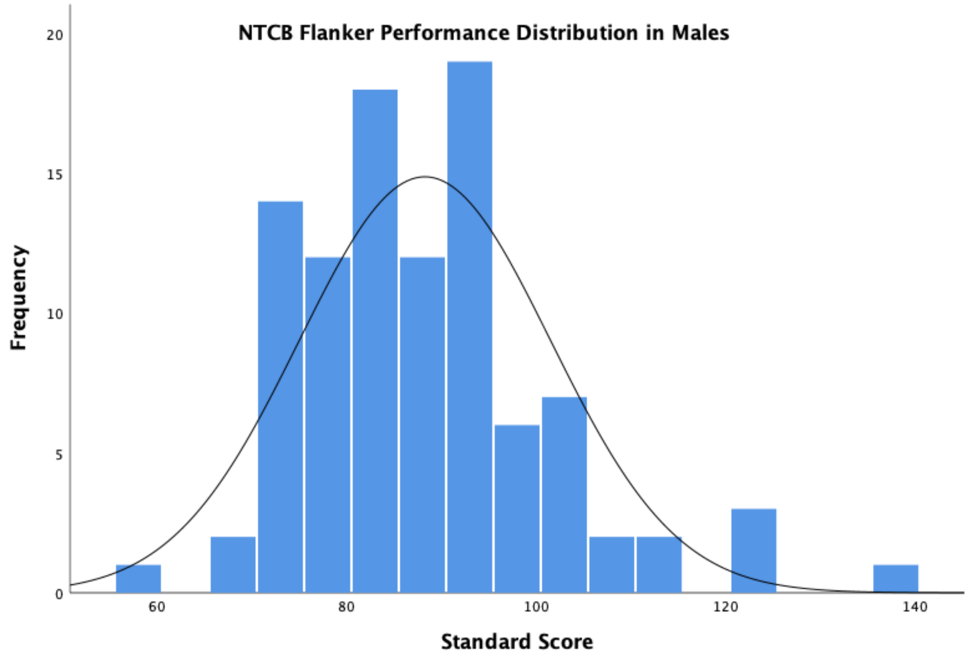


Figure 2

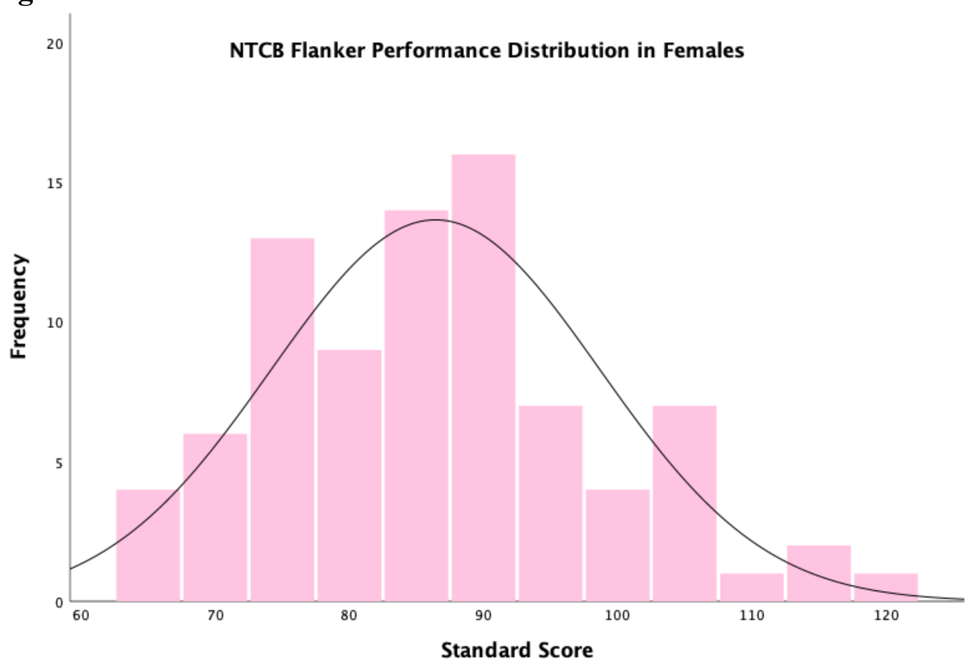
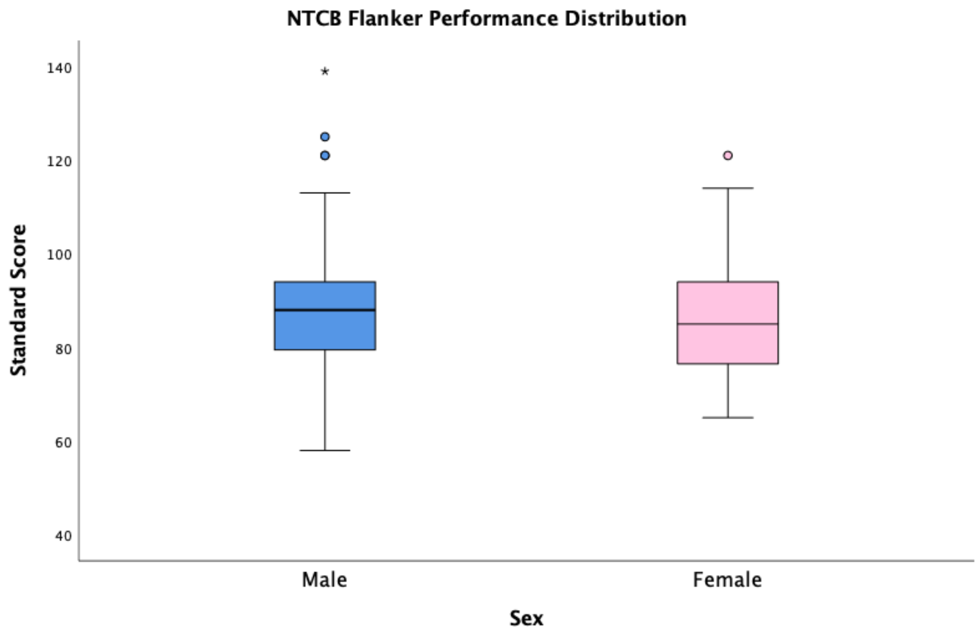


Figure 3



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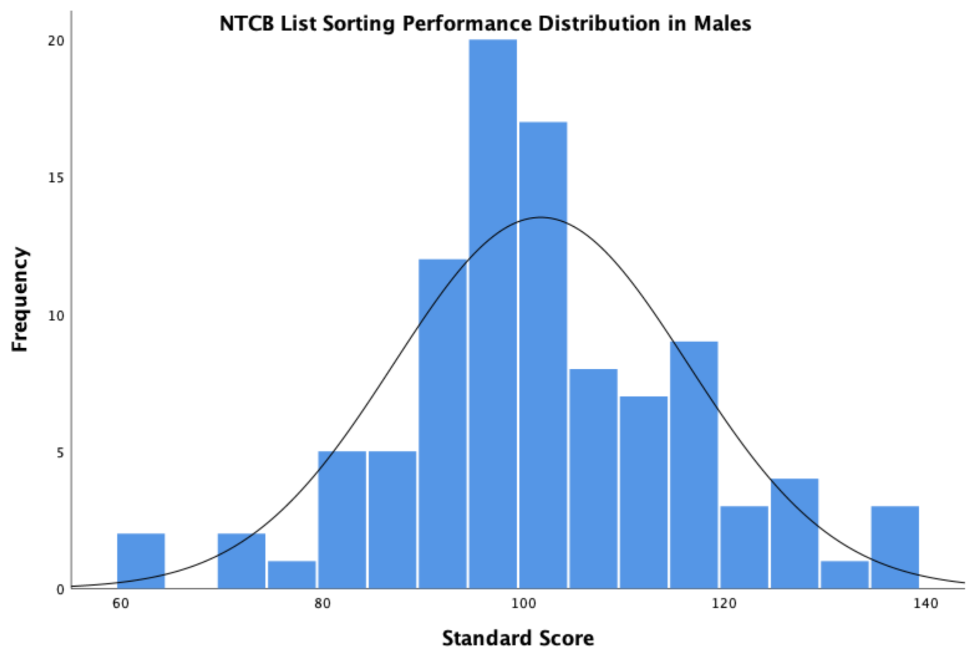

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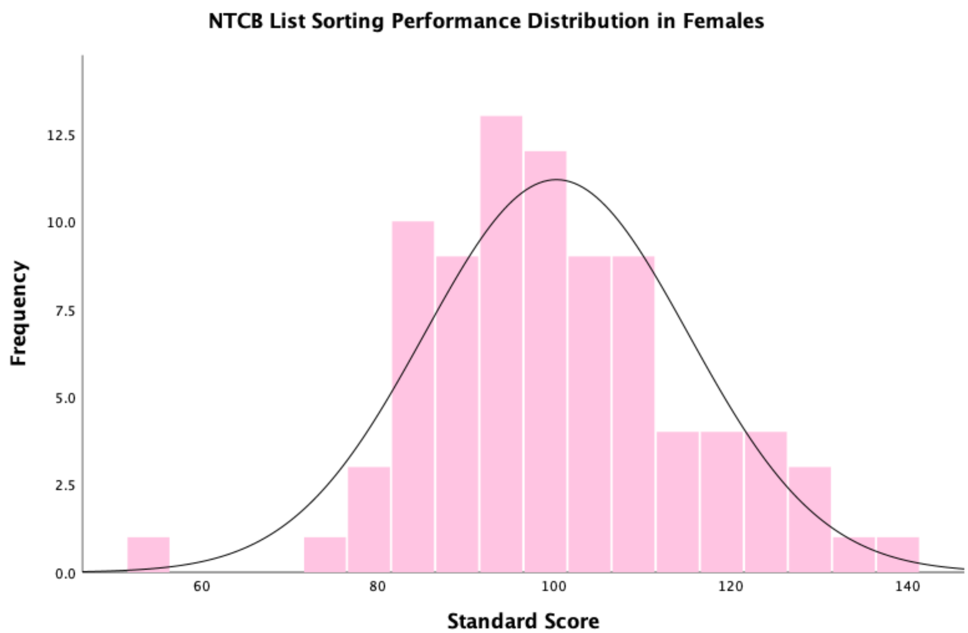


Figure 6

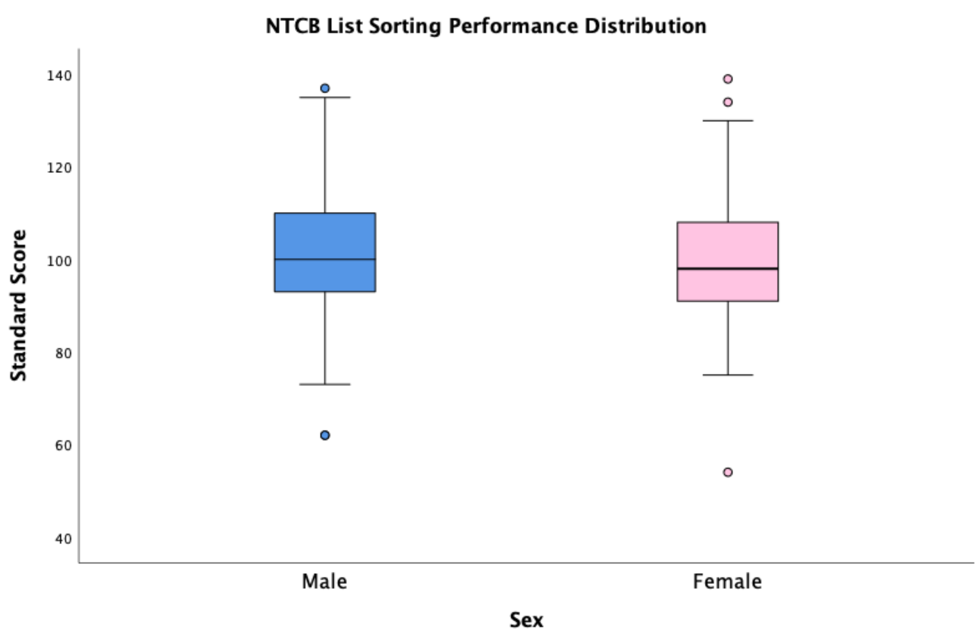


Figure 7

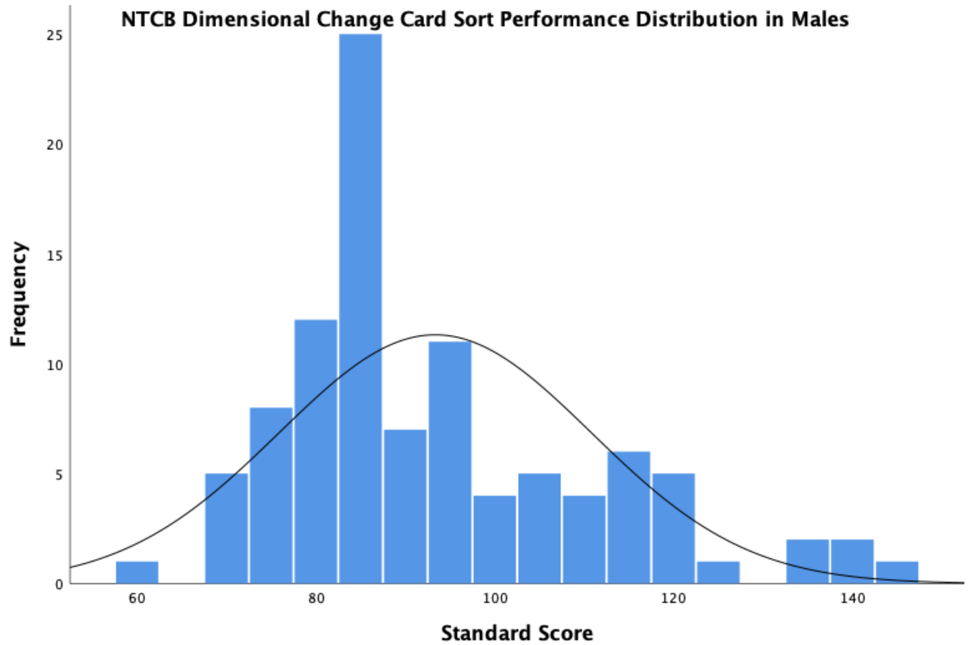


Figure 8

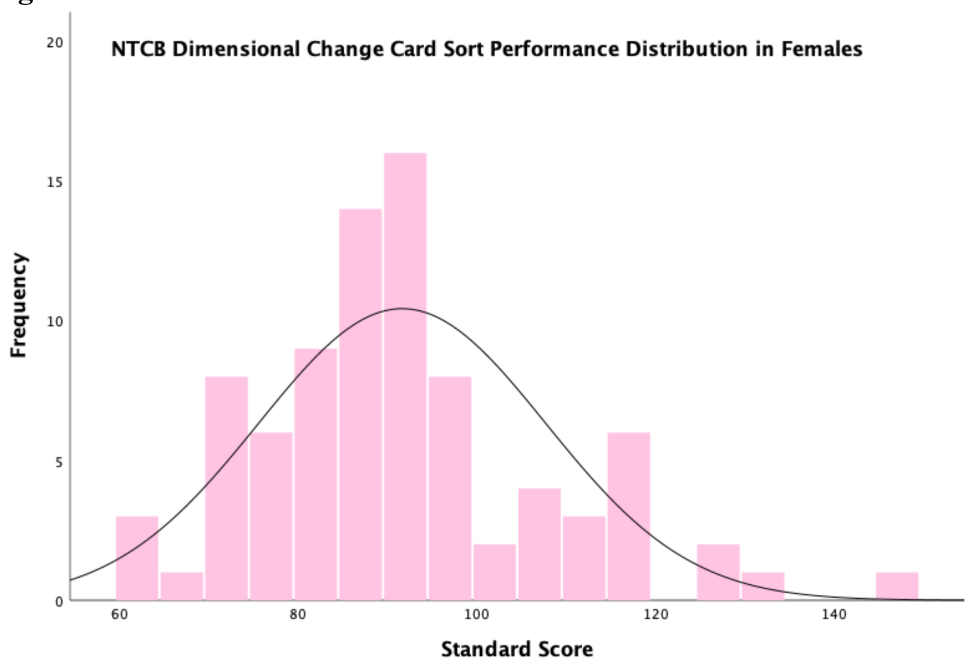


Figure 9

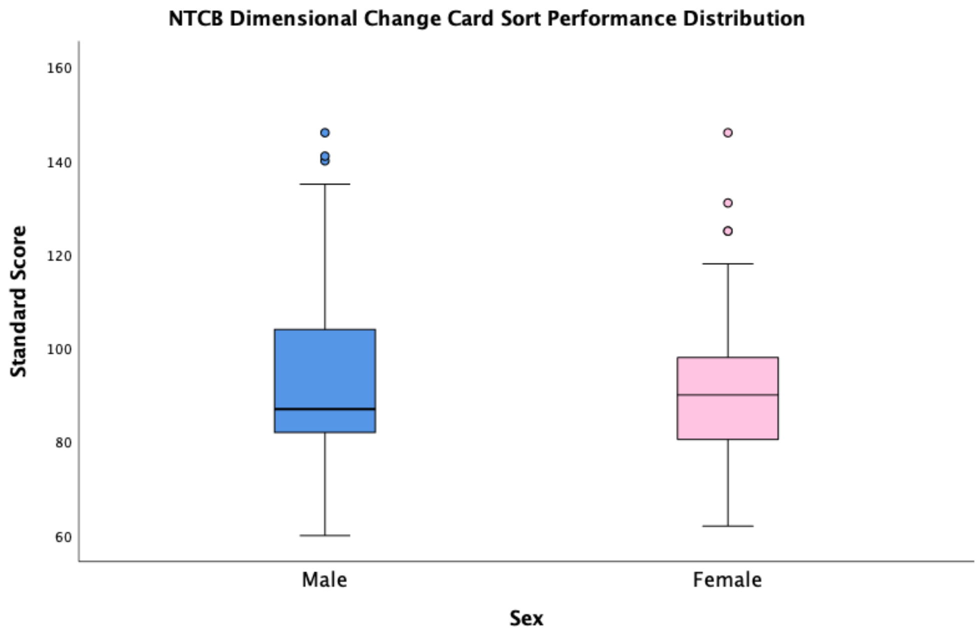
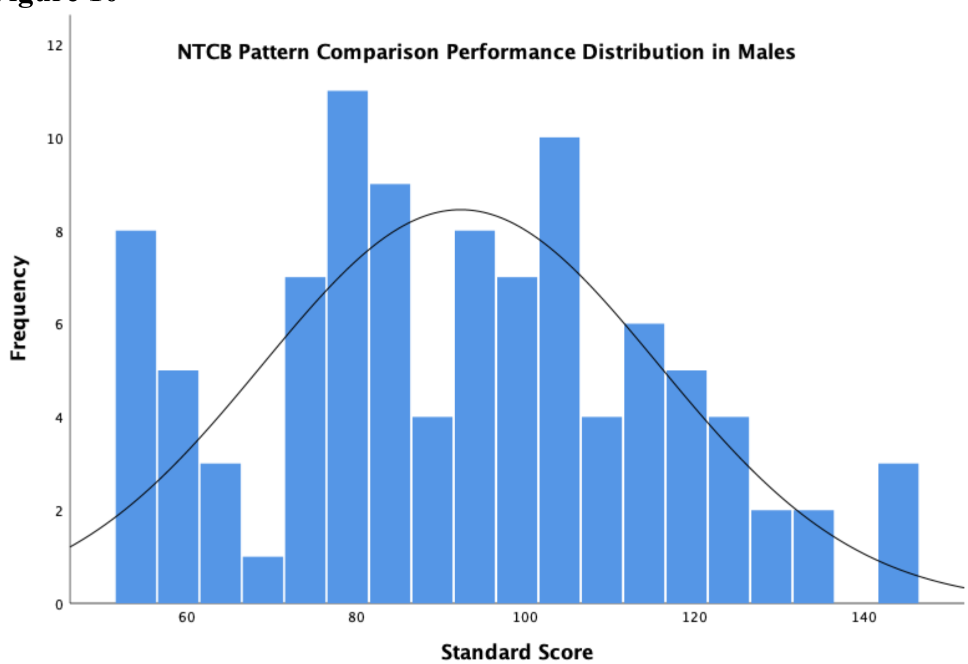


Figure 10



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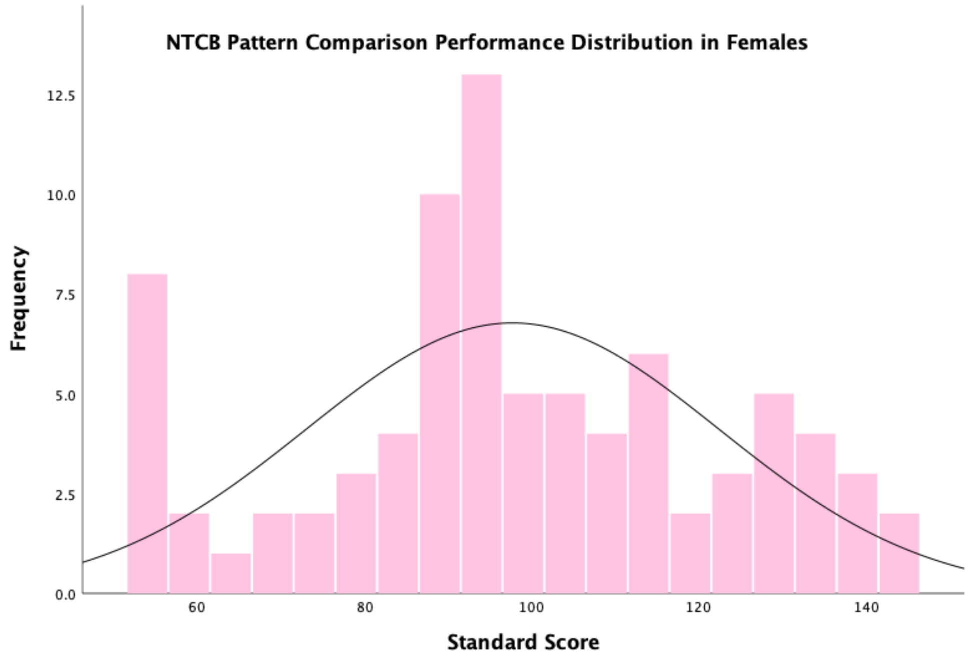


Figure 12

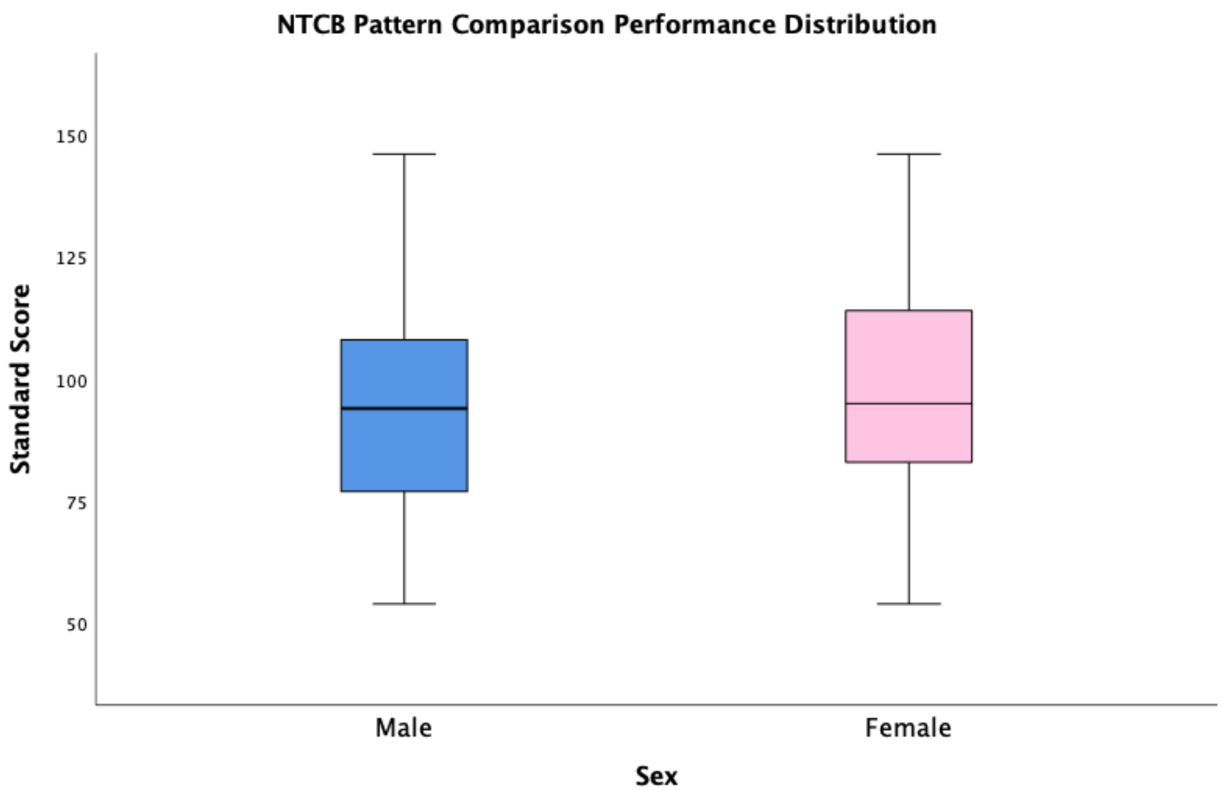
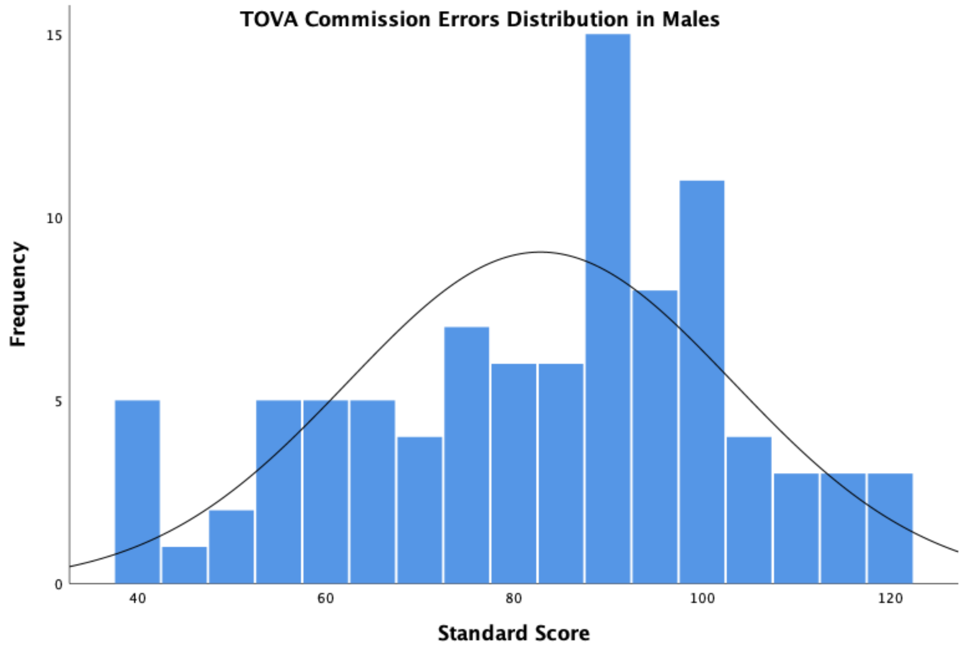


Figure 13



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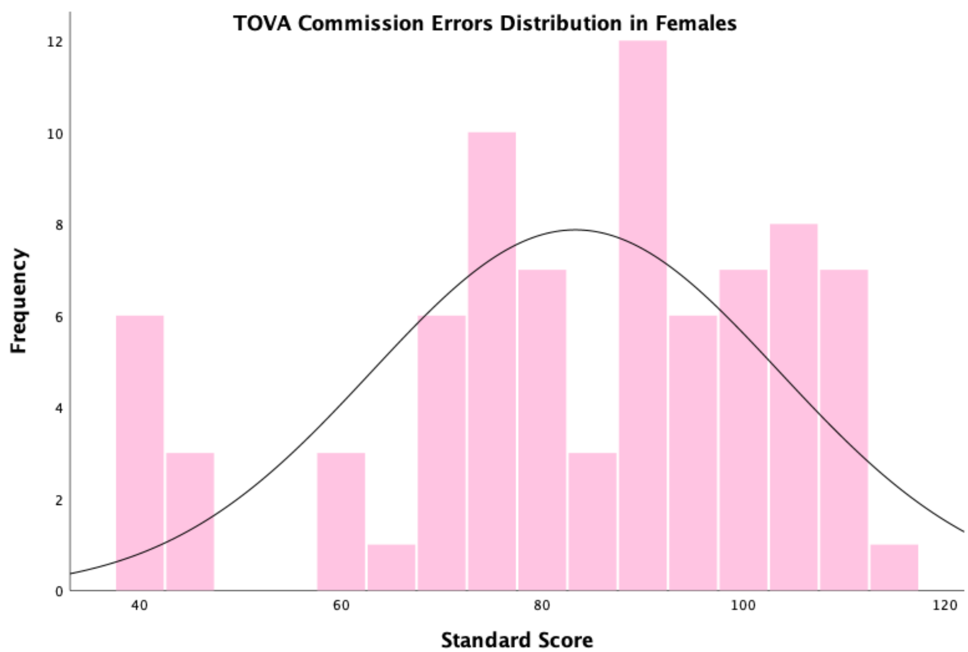


Figure 15

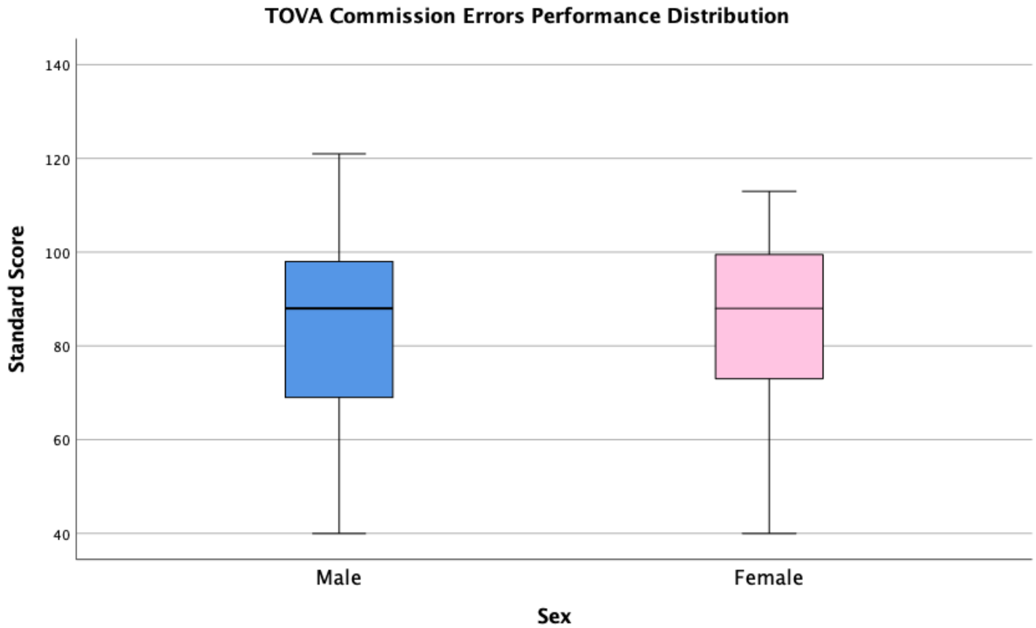


Figure 16

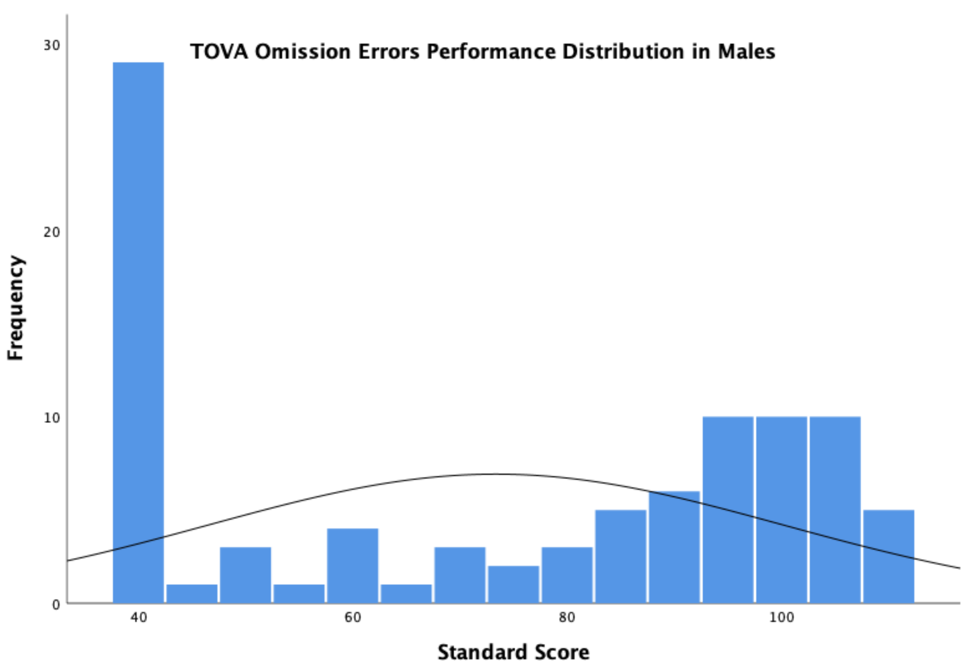


Figure 17

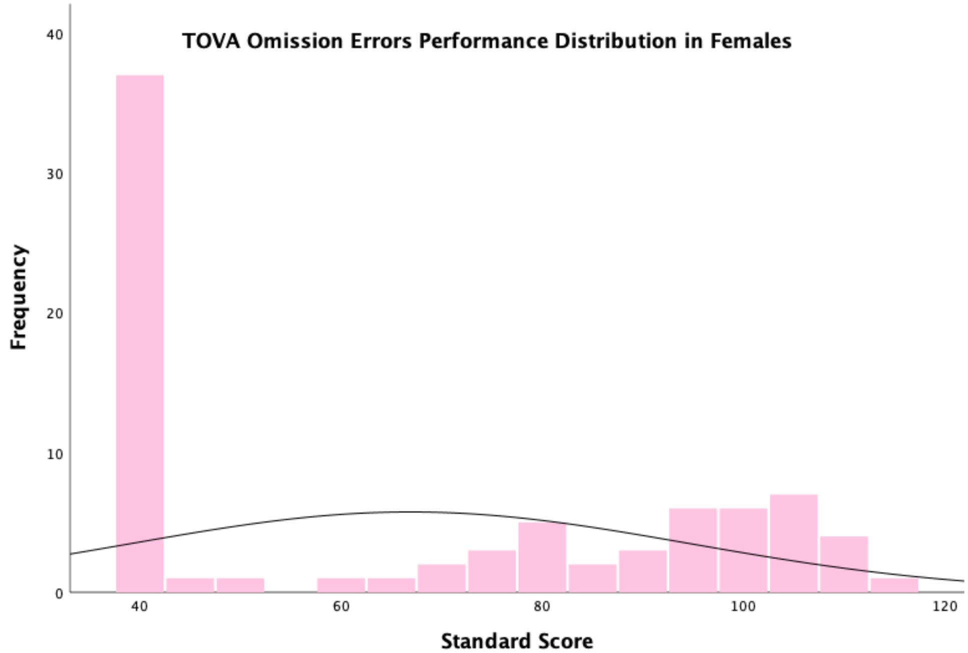
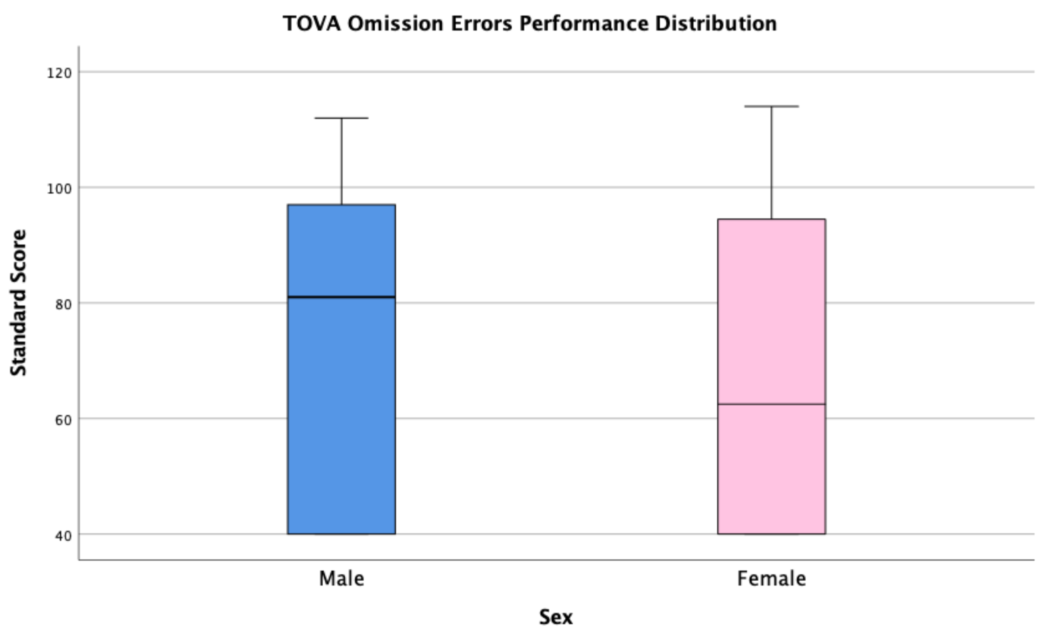


Figure 18



Age-Based Performance Distributions

Figure 19

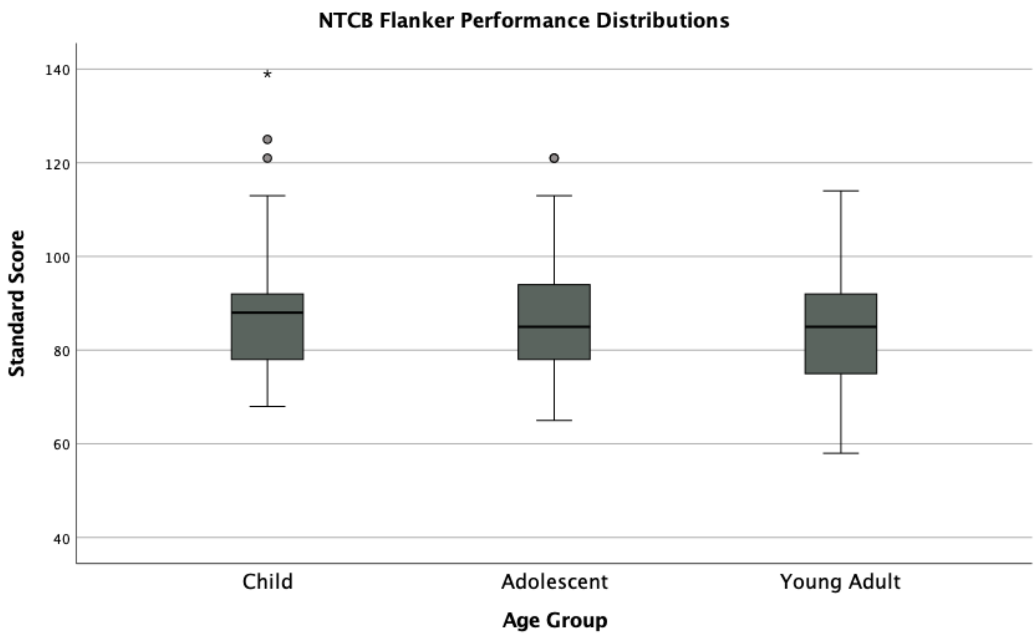


Figure 20

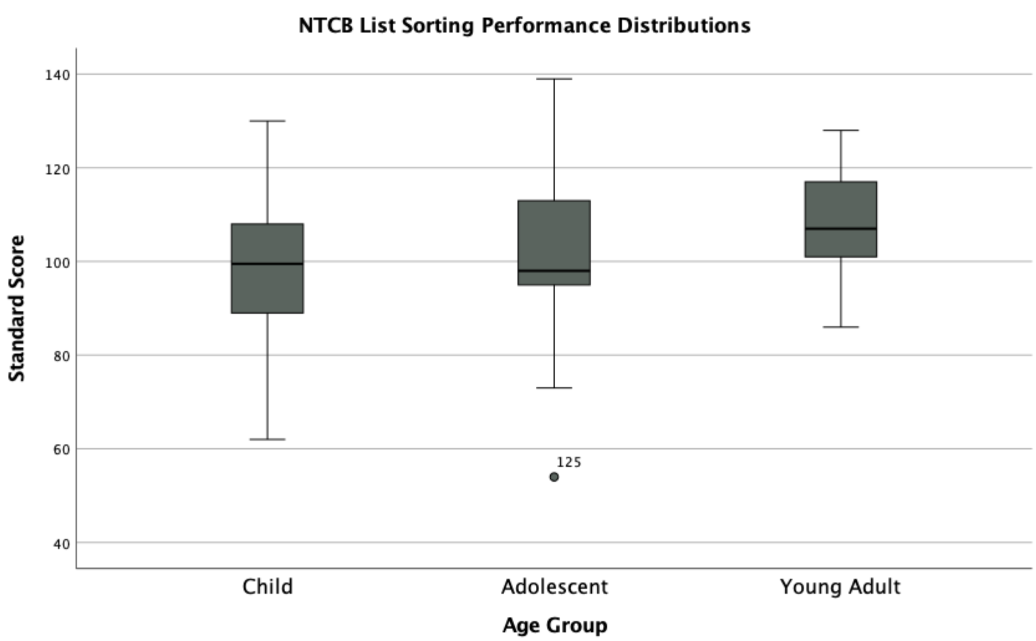


Figure 21

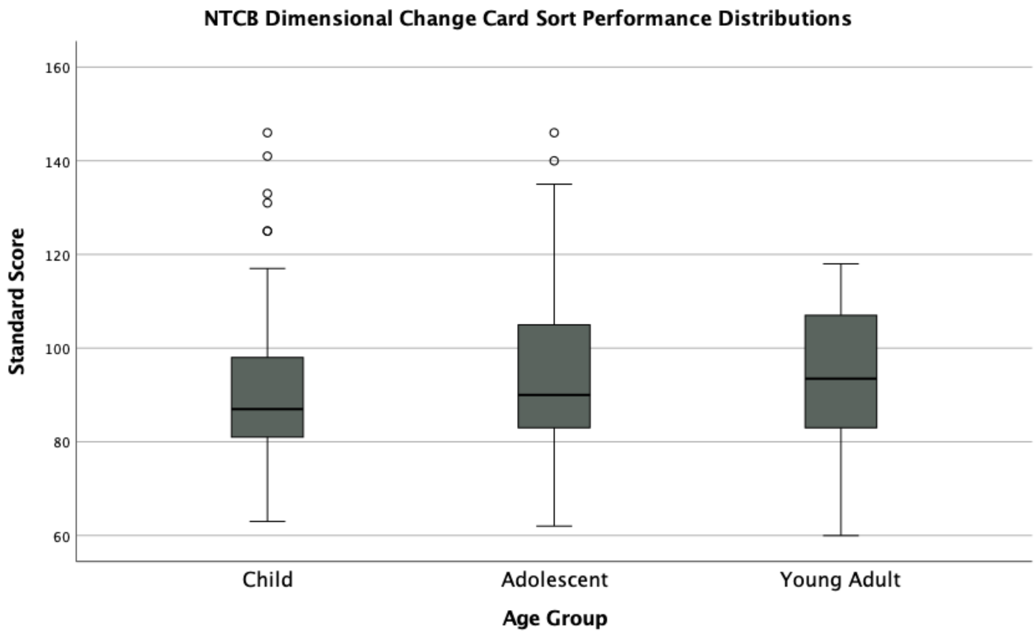


Figure 22

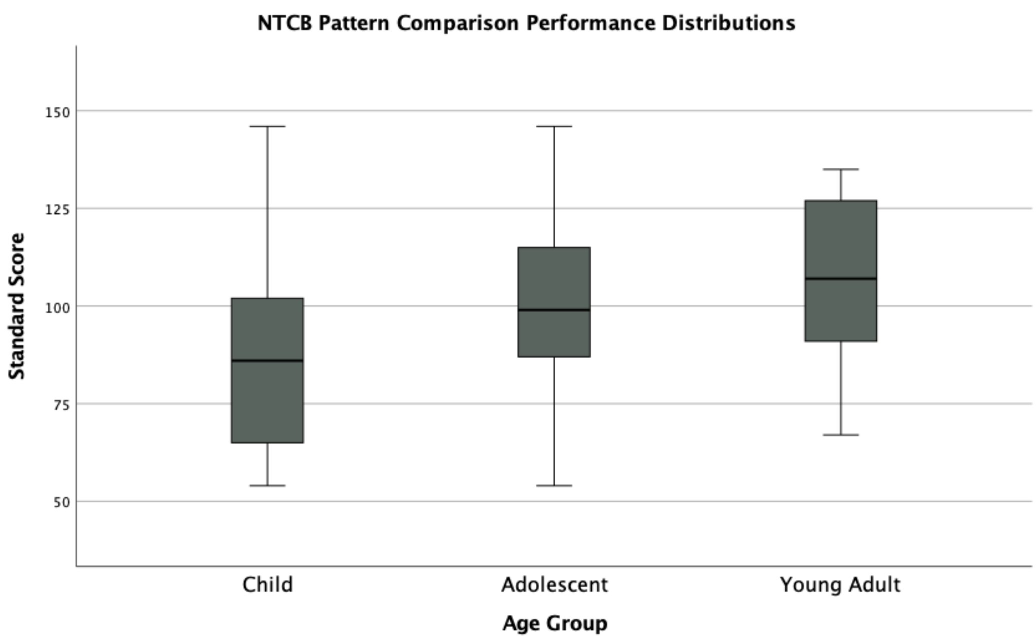


Figure 23

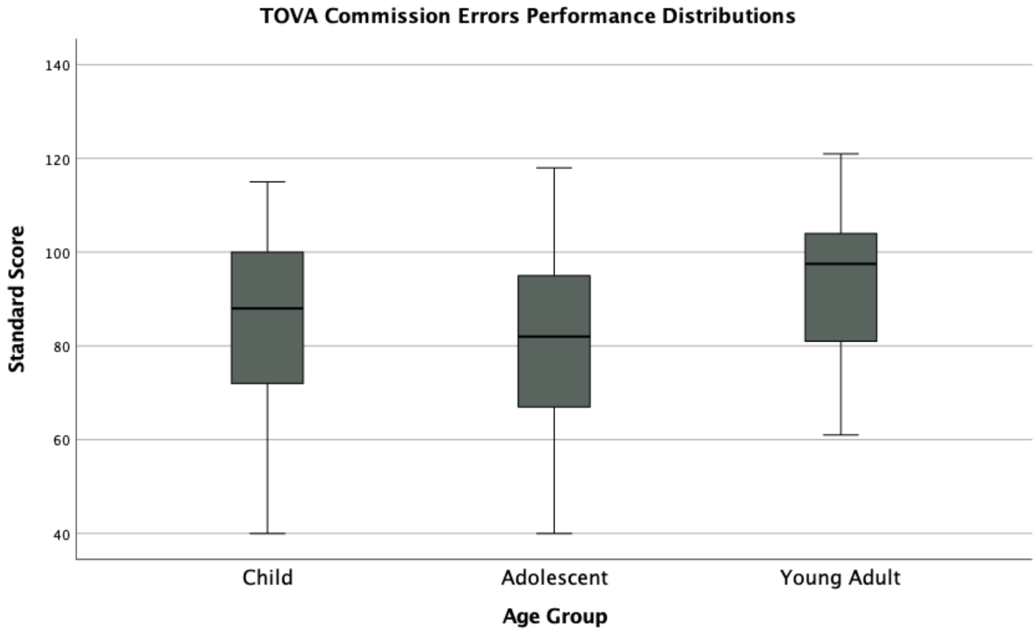
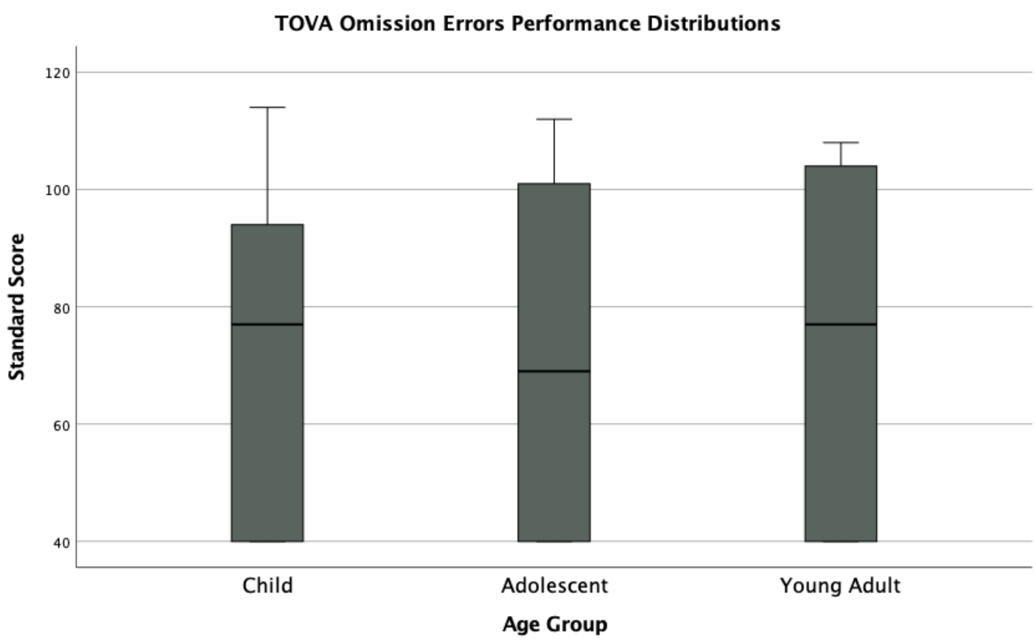


Figure 24



Executive Function Latent Profiles

Figure 25

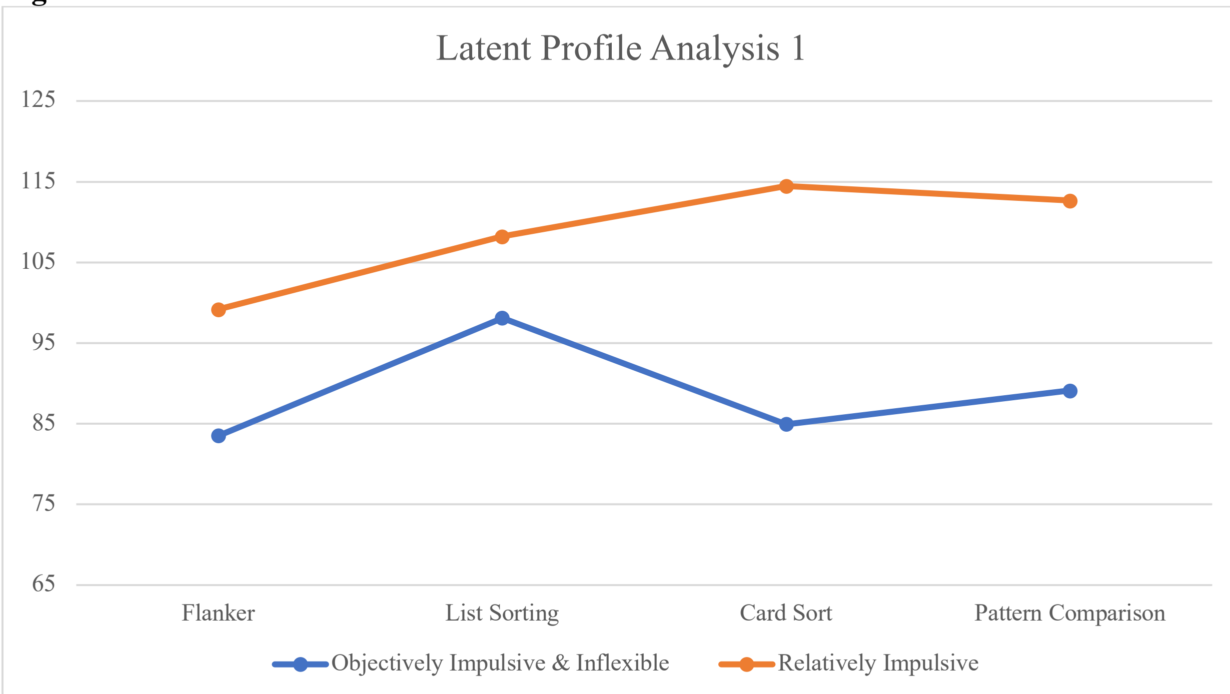


Figure 26