Differences Between Children with Attention Deficit Hyperactivity Disorder and Typically Developing Children in Dual-Task Performance

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Master Thesis - Master program Clinical Neuropsychology

S4690311

02/2022

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Abstract

Introduction: This study aimed to assess differences in the impact of a secondary cognitive or motor task on the motor performance of a primary task in children with ADHD and typically developing (TD) children. ***Methods***: Using the Movement Assessment Battery for Children, 2nd edition (MABC-2), 52 children with ADHD and 36 TD children were assessed on their motor performance within a cross-sectional study design. Next, single-task (Wii Fit-Ski Slalom [WT], finger-crossing [FC], and animal counting [AC]) and dual-task performance were evaluated. Independent samples t-tests and GLM analyses were implied to evaluate motor performance, single and dual-task performance, and to calculate the degree of interference and facilitation of the dual-tasks. ***Results***: Children with ADHD scored below the level of TD children on the MABC-2, classifying 36.5% of the ADHD group with motor problems. Similarly, on all single-tasks, children with ADHD scored significantly below the level of the TD group. The same holds for dual-task performance; however, measures of dual-task costs revealed similar interference and facilitation between single and dual-tasks in both groups. ***Conclusion***: The results reveal that children with ADHD suffer from significant deficits in motor- and cognitive single-task performance and impairments in dual-task performance. However, no differences were found between groups on dual-task costs. These findings could guide teachers and therapists to design adequate education and homework assignments and appropriate therapy sessions. In addition, a multidisciplinary team could help children with their cognitive and motoric problems to plan treatment and support children in handling their ADHD diagnosis.

Keywords: attention deficit hyperactivity disorder, movement problem, dual-task condition, single-task condition, concurrent cognitive-motor task, concurrent motor-motor task

Differences Between Children with Attention Deficit Hyperactivity Disorder and Typically Developing Children in Dual-Task Performance

Many activities of daily life require a child to execute multiple tasks simultaneously. Especially activities like riding a bike to school may loom danger, considering attention has to be paid to traffic and pedestrians, moving the pedals, and possibly talking to friends. The capability to perform these activities with little attentional focus, hence on an automated level, depends heavily on automatization. Automatization occurs after repeated performance until the task or movement becomes routine (Stefanidis et al., 2007; Visser et al., 2003). If no automatization has occurred yet, individuals can divide their attention towards two or more tasks with the help of executive control attention (Jelsma et al., 2021). However, external stimuli might cause a child to become readily distracted due to a lack of automatization, possibly leading to attentional or concentration problems. These problems are often seen in children with attention deficit hyperactivity disorder (ADHD), one of the most diagnosed pediatric disorders (Vassermann et al., 2014). ADHD is characterized by difficulties in early development, negatively affecting various daily life domains, such as interpersonal relationships, academic achievement, and family life (American Psychological Association [APA], 2013). To be diagnosed with ADHD, the Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition (DSM-5) declares that symptoms must persist for more than six months in at least two settings (e.g., school, home, leisure time facilities). The diagnostic profile includes, but is not limited to, a core triad of developmentally inappropriate levels of inattention, hyperactivity, and impulsivity. These cardinal symptoms hamper adaptive functioning and typical development (APA, 2013). As described by Goulardins and colleagues (2013, 2017) and Christiansen and colleagues (2019), inattention is the inability to assemble and remain attentive (e.g., distractibility, forgetfulness, poor organization skills), whereas hyperactivity is marked by excessive motor and mental activity. Impulsiveness is typified by sudden and thoughtless reactions, impatience, and difficulties inhibiting inappropriate motor responses. This conglomerate of symptoms manifests in an excessive and persistent pattern that cannot be attributed to another medical disease (APA, 2013), and 60% to 80% of these symptoms persist into adulthood (Sharma & Couture, 2013). Other deficits may occur in working memory (e.g., visuospatial and verbal), executive functions (EF), emotional regulation (Athanasiadou et al., 2019), and sensory processing (Ghanizadeh, 2011). Sensory processing difficulties influence how the nervous system receives, incorporates, adjusts, and responds to internal and external stimuli. Recent studies show anomalous sensory processing in children with ADHD, negatively influencing visual perception and academic achievements (Kamath et al., 2020). Since the introduction of the DSM-4, the nosology of ADHD accommodates three presentations. These are predominantly *Inattentive* (ADHD-I), predominantly *Hyperactive-Impulsive* (ADHD-HI), and the *Combined* (ADHD-C) type, with different presentations characterized by different types of impairment (Piek et al., 1999; Pitcher et al., 2003). Thus, ADHD is an umbrella diagnosis (APA, 2013; Epstein & Loren, 2013). Christiansen and colleagues (2019) report a total prevalence worldwide between 5% and 10%. However, rates vary considerably across age groups and ADHD presentation (Goulardins et al., 2015). Kaiser and colleagues (2014) state that roughly 11.4% of children between the ages of 6 to 12 are diagnosed with ADHD. The percentage decreases to 8% of adolescents between 13 and 18 and 5% from 19 years into adulthood. Additionally, the researchers report higher prevalence rates for ADHD-I (i.e., 5.1% for age range 6 to 12; 5.7% for 13 to 18 years; 2.4% for 19 years and older) than ADHD-HI and ADHD-C. Prevalence rates decrease with age for ADHD-C (i.e., 3.3% to 1.1%) and ADHD-HI (i.e., 2.9% to 1.6%). Moreover, the disorder occurs more frequently in males than females, with rates varying from 2:1 to 7:1 in children (Goulardins et al., 2015).

Lavasani and colleagues (2010) describe ADHD to have a multifaceted etiology, with intrinsic factors (i.e., genetic and neurological context) playing a substantial role in its onset and extrinsic factors (i.e., shared environmental context) aggravating symptoms and possibly contributing to other related deficits. While many hypotheses try to explain the origin of ADHD, the exact pathogenesis remains unclear. Goulardins and colleagues (2015) reported environmental risk in early development as possible commencement for ADHD. Specifically, complications during pregnancy or birth that predisposed the disorder (e.g., fetal stress, length of delivery, low birth weight) or exposure to lead, smoking, or alcohol were described as possible risk factors (Goulardins et al., 2017). Furthermore, structural abnormalities in the brain have been proposed (Papadopoulos et al., 2013), suggesting multifaceted morphological alterations and divergent neural circuitry (e.g., motor, cognitive and behavioral) underlying ADHD's heterogeneity (Cortese, 2012). For example, research groups identified reduced volume or functionality in the prefrontal cortex (PFC; Valera et al., 2007), basal ganglia, cerebellum (Castellanos et al., 1996; Hill et al., 2003), the thalamus and amygdala (Cortese, 2012). These findings suggest that ADHD's clinical profile results from dysfunctional physiology, usually responsible for EF, receiving sensory and motor input, organizing thoughts and motor planning, coordinating voluntary movement, as well as regulating attention, emotions, and behavior (Kolb et al., 2016, pp. 40-56). However, Klimkeit and colleagues (2005) propose that disrupted brain structures do not necessarily correlate with functional and behavioral deficits. Instead, cognitive deficits (i.e., EF, attention) associated with ADHD mirror macrostructural abnormalities of, for example, the PFC, basal ganglia, and cerebellum. Lastly, neurochemistry is partly proposed to influence the emergence of ADHD. For instance, Cortese (2012) reports that ADHD may result from various malfunctional neurotransmitter systems. Specifically, Sharma and Couture (2013) suggest an imbalance of neurotransmitters (i.e., dopamine (DA), norepinephrine (NE)). DA and NE regulate the activity of the PFC, and disruption may lead to suboptimal functioning. This theory is supported by improved control of inhibition and executive control of attention after increased DA levels in the PFC (Sharma & Couture, 2014).

One of the most significant challenges in understanding and diagnosing ADHD is its complexity, heterogeneity (Luo et al., 2019), and the presence of a comorbidity problem because pure ADHD is rare (Kaplan, 2001). The disorder tends to co-occur with other psychiatric conditions (Kooistra et al., 2015; Tervo 2002), for example, conduct disorder, depression, anxiety disorders, autism spectrum disorder (ASD), or developmental coordination disorder (DCD; Athanasiadou et al., 2019). Specifically, comorbidity with DCD is assumed to be one explanation for motor problems (MP) in individuals with ADHD and is expected to occur in 30% to 50% of ADHD cases (Barkley, 1990; Fliers et al., 2010; Piek et al., 1999; Pitcher et al., 2003). DCD is diagnosed once motor impairment impedes daily life activities (Mokobane et al., 2019). Scandinavian countries refer to combined problems of ADHD and DCD (e.g., motor-coordination issues) as Deficits of Attention and Motor Perception (DAMP; Rasmussen & Gillberg, 1999). Interestingly, medication (i.e., methylphenidate, MPH) improves ADHD symptoms and motor performance, indicating some common grounds (Kaiser et al., 2014). However, despite the evidence, it is unclear what difficulties are intrinsic to ADHD or DCD because motor problems in ADHD cannot be attributed solely to a comorbid DCD (Athanasiadou et al., 2019). A second explanation attributes motor impairments to the core triad of ADHD symptoms (e.g., Brossard-Racine et al., 2012; Fenollar-Cortés et al., 2017; Meyer & Sagvolden, 2006; Piek et al., 1999). For example, Brossard-Racine and colleagues (2012) found that MPH enhanced motor functioning in preserving posture and balance tests. Nonetheless, not all children improve their motor abilities with medication, proposing that attention deficits are not the only explanation for motor deficits (Kaiser et al., 2014).

Even if patients with ADHD do not meet DCD criteria, they show motor problems compared to typically developing (TD) children (Pitcher et al., 2002). However, to date, typical presentations of motor problems in children with ADHD have not received an adequate amount of research attention and are usually not part of ADHD assessment or intervention programs (Sergeant et al., 2006). In 1989, Gillberg and Gillberg were among the first to acknowledge the clinical relevance of motor difficulties as a critical feature in attention disorders, and most researchers agree that ADHD and motor problems are vigorously associated (Brossard-Racine et al., 2012; Harvey & Reid, 2003; Lavasani & Stagnitti, 2011; Pitcher et al., 2003). Specifically, children with ADHD have lower physical fitness levels (Christiansen et al., 2019; Buderath et al., 2008) and poorer fine (du Toit & Pienaar, 2014; Shen et al., 2012; Mendes et al., 2018) and gross motor skills (Chen et al., 2012; Emck et al., 2011; Tseng et al., 2004). However, research on motor deficits in subjects with ADHD has shown divergent results and does not yield an agreement. For example, some researchers declare slower speed for children with ADHD than TD children (i.e., aiming task; Yan & Thomas, 2002), whereas others did not find performance differences (Kooistra et al., 2014; Papadopoulos et al., 2013).

As shown in ADHD populations, automatization deficits may explain lowered performance in dual-task conditions or similar circumstances (Visser, 2003). A DT-paradigm can be used to assess where attentional demands of concurrent task performance interfere. For instance, individuals may be asked to simultaneously perform motor-motor, cognitive-cognitive, or cognitive-motor tasks (Navon & Gopher, 1979). The secondary task would interfere with the primary task if not enough automatization occurred for the primary task (Visser, 2003). Therefore, little to no interference exists between the two tasks if enough automatization occurs (Nicolson & Fawcett, 1990). For example, various studies proved that dual-task conditions affect gait in children with ADHD (Leitner et al., 2007; Papadopoulos et al., 2014; Manicolo et al., 2016), underpinning the necessity of cognitive processes in walking because the performance is not entirely automatic. Instead, EF's such as inhibition, working memory, cognitive flexibility/set-shifting are needed (Miyake et al., 2000; Woollacott &

Shumway-Cook, 2002). Therefore, it is proposed that impaired EF in children with ADHD affects dual-task performance on gait due to the inability to dedicate the right amount of attention towards the walking performance while executing another task (Hausdorff, 2005). For example, Manicolo et al. (2017) observed that children with ADHD had trouble in perpetuating their walking pattern while executing a cognitive (i.e., listening to/recalling digits) or a motor (i.e., fastening/unfastening a button) task. Additionally, divided attention alters gait in children with ADHD within a DT paradigm (Leitner et al., 2007). Thus, the authors conclude that patients with diminished gait automaticity may need additional attention, and attention-demanding tasks may exaggerate walking deficits. This conclusion may be explained by the Multiple Resource Model of Attention, postulated by Wickens and colleagues in 1991, used to describe dual-task outcomes. This model presumes that individuals have different pools of attentional resources for different attentional demands. This idea of multiple attentional pools suggests that performance suffers less if two simultaneous tasks draw on different pools instead of drawing on the same pool of attention (Wickens, 2008). For example, the study by Manicolo and colleagues (2017) mentioned earlier found diminished walking performance during a concurrent motor task, whereas performance was less deficient when a concurrent cognitive task was presented. One way to measure the linkage between cognitive and motor functions takes advantage of the dual-task paradigm within cognitive-motor interference (CMI) research (Schott, 2016), which is additional to Wickens' model that only looked at the similar pools. CMI deals with interference in performance when executing a cognitive and a motor task simultaneously and refers to the amount of attention still needed. Once a motor task is well learned, only a few attentional resources are necessary for successful completion. Thus, sufficient attentional resources are left to complete the concurrent cognitive task (Schott, 2016). However, if the motor task is not automatized, fewer attentional resources exist, and performance on the concurrent cognitive task suffers.

Jelsma and colleagues (2021) recently published a study on divided attention and DCD in children within a dual-task paradigm. For this purpose, the authors included a balance board of the video game Wii Fit (i.e., Nintendo© console) to measure performance in a game of Ski Slalom while performing a concurrent cognitive (i.e., counting cat or cow sounds) and a motor task (i.e., finger crossing). The researchers found that impaired divided attention may be crucial in DCD children's motor performance. Based on the current literature on ADHD and impaired motor performance and the research design by Jelsma and colleagues (2021), the purpose of this study is to understand the associations between ADHD and motor performance in children, within the same dual-task paradigm (i.e., cognitive and motor task), compared to TD children.

For this, it is hypothesized that children with ADHD score lower on the Movement Assessment Battery for Children - Second Edition compared to TD children. These effects are expected because literature repeatedly reports motor impairment in the ADHD population (e.g., Fliers et al., 2008; Pitcher et al., 2003). Additionally, it is hypothesized that children with ADHD perform worse in the single-task conditions than TD children because of their poorer fine and gross motor skills and cognitive impairments (e.g., APA, 2013; Pitcher et al., 2003). Lastly, dual-task performance will be evaluated in two steps. First, similar to Jelsma and colleagues (2021), it is hypothesized that the secondary motor task (i.e., finger crossing) causes greater interference with the primary task (i.e., Wii Fit performance) compared to the secondary cognitive task (i.e., counting animal sounds) in the ADHD group than in the TD group. This is expected because the two concurrent motor tasks rely on the same attentional resource pools, leading to more interference (Wickens et al., 1991). Second, based on Jelsma and colleagues (2021), it is hypothesized that the dual-task costs are higher for children with ADHD than TD children.

The following approach will be put forth: First, differences in the MABC-2 between the ADHD and TD children will be determined. Second, differences in single-task performance of the three tasks will be determined between the two groups. Third, differences in dual-task performances will be evaluated between both groups. Lastly, dual-task costs will be assessed for the ADHD and TD groups.

Methods

Participants

Data used for this project was collected in 2014, 2017, and 2018 as part of a larger study. Recruitment for this part of the study occurred at two schools in Groningen, the Netherlands: Prof. W. J. Bladergroenschool Groningen and CSBO Kimkiel Groningen. Included in this study were typically developing children between seven and twelve years old that have not repeated a class throughout their education or have an IQ higher than 70. Children with ADHD were included on the premise that: 1) a diagnosis or symptoms of ADHD are given according to DSM-5 guidelines, 2) the age is between 6 and 12 years old, and 3) children possess basic counting skills and can put instructions into action. Participants were excluded if an IQ < 70 was reported or a diagnosis of a medical, neurological, or mental disorder was present. In total, a sample of 88 children was recruited, divided into 52 children with a primary ADHD diagnosis and 36 TD children. Overall, 24 children were female, 64 were male, and the total sample did not differ in age, height, or weight (see Table 1). Principally, seven participants with ADHD took medication (i.e., MPH), whereas 34 children did not take medication, and data were missing for 39 children. Eight children consumed other types of medication (e.g., asthma or allergy medication). Moreover, considering all typically developing children, four children repeated a class, whereas 21 did not. The Ethical Committee of Psychology of the University of Groningen (17397-S-NE) approved this cross-sectional study in agreement with university guidelines and ethical standards according to the Declaration of Helsinki. Written assent was obtained previously from all children and consent from their parents.

Table 1

Demographic Data of the TD and ADHD Group With Mean (SD) or Number of Participants (%) and Differences in Test Outcomes Between Groupss

	ADHD (n = 52) (59.1%)	TD (n = 36) (40.9%)	p-value
Gender (n)*			**< 0.000**
Male	45 (86.54%)	19 (52.78%)	
Female	7 (13.46%)	17 (47.22%)	
Age (in years)#	10.40 (1.36)	10.24 (1.45)	0.622
Height (in cm)#	146.73 (9.17)	147.47 (10.76)	0.729
Weight (in kg)#	39.73 (11.82)	36.81 (9.25)	0.222
IQ	89.89 (13.37)	-	-
MABC-2 TSS#	6.33 (2.81)	11.08 (2.53)	**< 0.000**

Note. SD = Standard Deviation, TSS = Total Standard Score, TD = Typically Developing, ADHD = Attention Deficit Hyperactivity Disorder, MABC-2 = Movement Assessment Battery for Children - 2nd edition; Bold indicates significance < *0.05*; #Tested with the independent t-test; *Tested with the chi-squared test.

Instruments

Movement Assessment Battery for Children – Second Edition

Motor impairments were screened using a normative and age-appropriate measure of motor development (Henderson et al., 2007). The Movement Assessment Battery for Children - Second Edition (MABC-2-NL) is norm-referenced for Dutch children aged three to 16 years (Smits-Engelsman, 2010) and has been used in the past for children with ADHD (Papadopoulos et al., 2013). Subjects are divided into three age groups: 3-6, 7-10, and 11-16 years. Each age band comprises eight tasks, divided into three domains: 1) manual dexterity (i.e., fine-motor skills), 2) ball skills (i.e., aiming and catching), and 3) balance (i.e., static and dynamic). Using normative data, cut-off scores can be utilized to identify a child with movement problems (i.e., a score ≤ 5^{th} percentile) or at risk for such issues (i.e., score between the 5^{th} and 15^{th} percentile). A higher percentile rank or age-adjusted standard score indicates better accomplishment, thus better motor proficiency (Smits-Engelsman, 2010). The MABC-2 proves to have good validity (i.e., construct and discriminative) and good reliability for the total score (i.e., Pearson's coefficient (r) = 0.8), manual dexterity (i.e., $r = 0.77$), ball skills (i.e., $r = 0.84$) and balance (i.e., $r = 0.75$; Henderson et al. 2007).

Kinderversion der Testbatterie zur Aufmerksamkeitsprüfung

The Kinderversion der Testbatterie zur Aufmerksamkeitsprüfung (KiTAP) for sustained attention, divided attention and distractibility was used as part of a larger study. However, the test battery was not used for this specific research project.

Primary Task

The Wii Fit-Ski Slalom Task (WT) was implemented as a dynamic balance task and used for the single-task (ST) and DT conditions (i.e., primary task). The Wii Fit is a video game console by Nintendo © requiring a controller and a balance board connected to a TV with a Bluetooth connection. During a game session, the player stands on the balance board that detects, using four sensors, the gamers weight, center of pressure, and weight distribution. The software tracks movement forward, backward, and sideways. The player is represented by an animated avatar displayed on the screen. For example, the avatar speeds up if the child moves forward or slows down if moving backward. During the ski slalom game, the child must pass 19 gates as fast as possible, allocated at different positions along the slope. The videogame distributes scores by adding the *run duration in seconds* to the *number of missed gates * 7 seconds*, whereby a higher score indicates poorer performance. According to Jelsma and colleagues (2016), the Wii Fit balance board proves to be a valid assessment device for balance.

Secondary Tasks

Two STs were implemented to compare ST performance with dual tasking. First, an animal counting task (AC) was executed as a cognitive task. The sound of 15 to 17 cats and cows was played in random order for 20 seconds, whereby a child had to count either the cats or cows. The outcome measure of the AC task is the number of incorrect or missed counts (errors, hereinafter). Therefore, a higher score indicates poorer performance. Second, a fine-motor task, precisely a finger crossing (FC) task, was performed. This task requires a child to create a starting position in which the thumb of one hand is placed on the other hand's index finger (see Appendix 1). Then, the lower thumb and index finger detach and move upwards to attach again (see Appendix 2). This procedure is repeated for 60 seconds and as fast as possible. The outcome measure of the FC is the finger crossings per second. Therefore, a higher score indicates better performance. A training session was conducted until the child performed the correct movement and understood the task.

Procedure

Participation in this research study was voluntary. Information material and the informed consent forms were distributed in the participating schools in Groningen. Children provided with signed informed consent by their parents were allowed to participate. All subjects were tested in two sessions, each with a duration of 40 minutes. In session one, the children were instructed to execute the MABC-2. Moreover, the KiTAP for sustained attention was implemented. In session two, the KiTAP was completed once more, this time for divided attention and distractibility. Additionally, three STs were performed: 1) ST-cognitive, 2) ST-motor, and 3) ST-WT were performed. Further, the secondary tasks were combined with the primary task into two dual-tasks: 1) DT-cognitive (WT + AC) and 2) DT-motor (WT + FC). The procedure was as follows. First, the children performed the animal counting task three times as a ST. Second, the finger-crossing task was performed three times as a ST, each for 60 seconds. The finger movements were video recorded for later evaluation (i.e., to count the number of crossings). Third, a calibration process of the balance board was performed based on the child's weight. Third, ten Wii Fit game trials alternated with a ST to avoid bias due to learning effects. Specifically, the children started with two ST trials of the WT, followed by two DT-cognitive trials and two ST trials. Then two DT-motor trials were performed, followed by one DT-cognitive trial and one DT-motor trial. The DT-motor was also video recorded for later evaluation.

Previous master students already evaluated the FC and WT for the Dutch sample. To become familiar with the data, a Brazilian sample (i.e., TD, DCD children) was similarly assessed as part of the thesis project by another team researcher. First, the number of finger crossings per second was counted until consensus was reached between the two researchers of Groningen University. Then, the scores of 80 children were compared with those of the Brazilian supervisor. Finally, differences in outcomes were re-counted by all parties involved until consensus was reached. This reliability procedure resulted in a percentage of agreement of 89% (see Appendix 3).

Statistical analysis

All data for this study were provided by the supervisor of this master thesis, Dr. L. D. Jelsma. First, the data were checked for normality. Descriptive statistics were used to examine the raw data and check whether groups (TD, ADHD) were comparable; t-tests and a chi-squared test were used. Next, to calculate the mean as an outcome measure for the analysis of the Wii Fit-Ski Slalom Task, the following runs were used: 1) For the Wii ST: Runs 3 (WT) and 8 (WT). 2) For the Wii DT-Cognitive: Runs 5 (Errors + WT) and 6 (Errors + WT). 3) For the Wii DT-Motor: Runs 9 (FC + WT) and 10 (FC + WT). 4) For the ST-Cognitive: Runs 2 (Errors) and 3 (Errors). 5) For the DT-Cognitive: Runs 5 (Errors + WT) and 6 (Errors + WT). 6) For the ST-Motor (per second): Runs 2 (FC) and 3 (FC). 7) For the DT-Motor (per second): Runs 9 (FC + WT) and 10 (FC + WT). Next, to compare the number of crossing fingers per second, the mean number of crossing fingers in the ST was divided by 60 seconds and in the DT by the duration in seconds of the WT. Then, the mean scores of the WT were calculated.

To test the first hypothesis, an independent t-test was performed to compare ADHD and TD children regarding their performance in the MABC-2. Additionally, a chi-square test of independence was performed to examine the relation between group (i.e., TD, ADHD) and MABC-2 performance (i.e., movement problem, at risk, no movement problem). Another independent t-test was performed to compare the TD children and children with ADHD regarding their performance in the ST-cognitive and ST-motor to test the second hypothesis. For the third hypothesis, two GLM Repeated Measures were performed to assess both groups' differences between single and dual-task performance. A first GLM analysis assessed WT performance between groups on three levels (ST-WT vs. DT-M vs. DT-C). A second GLM analysis assessed ST and DT performance between groups on two levels (ST-C vs. DT-C; ST-M vs. DT-M). Moreover, based on Hall and colleagues (2011), change of performance in each

DT condition (DT-costs) was calculated. The difference between ST and DT conditions was calculated using the following formulas.

Wii Cognitive Costs=MeanWiiST3_8 - MeanWiiCDT5_6 (1)

Wii Motor Costs=MeanWiiST3_8 - MeanWiiMDT9_10 (2)

Error Costs=MeanST2_3Errors - MeanDT5_6Errors (3)

FC Costs=MeanFC2_3PerSecST - MeanFC9_10perSecDT (4)

Accordingly, a negative value of the mean suggests performance interference, whereas a positive value indicates performance improvement within the DT condition. Furthermore, another t-test was carried out to compare the costs of the dual-task conditions (i.e., DT-C and DT-M) and to compare the ADHD and TD groups. Lastly, the effect sizes for independent samples t-tests were calculated by hand using the following formula by Pallant (2013):

$$\text{Eta squared } (n^2) = \frac{t^2}{t^2+(N1+N2-2)} \quad (5)$$

The guidelines proposed by Cohen (1988, pp. 284-287) for interpreting effect sizes are: small effect (=0.01), moderate effect (=0.06), and large effect (=0.14). All analyses were performed in SPSS 26.0 and applied an α level of 0.05.

Results

Group differences in MABC-2 performance

An independent samples t-test revealed significant group differences of MABC-2 scores between TD (*M* = 11.08, *SD* = 2.53) and ADHD (*M* = 6.33, *SD* = 2.81; *t*(86) = 8.117, *p* = 0.000, 95% CI [3.59;5.92]) children, which was a small effect (η^2 = 0.434). All eta squared values are presented in Appendix 4. A chi-square test of independence showed no movement problems within the TD group, whereas 50% of the ADHD group showed motor impairment.

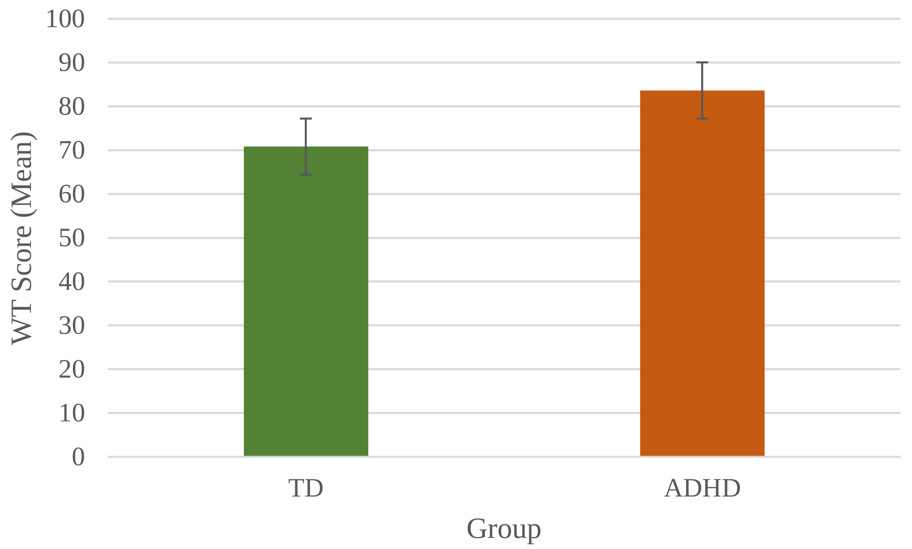
Specifically, 36.5% (n = 19) of the children showed movement problems and 13.5% (n = 7) were at risk of a movement problem ($X^2(2, n = 88) = 25.548$, $p < 0.001$).

Group differences in ST performance

Groups differed significantly in all ST's. Within the WT-condition (see Figure 1), the TD group ($M = 70.80$, $SD = 18.71$) performed significantly better, compared to the ADHD group ($M = 83.63$, $SD = 18.44$, $t(86) = -3.193$, $p = 0.002$, 95% CI [-20.83;-4.84]), with a small effect size ($\eta^2 = -0.134$).

Figure 1

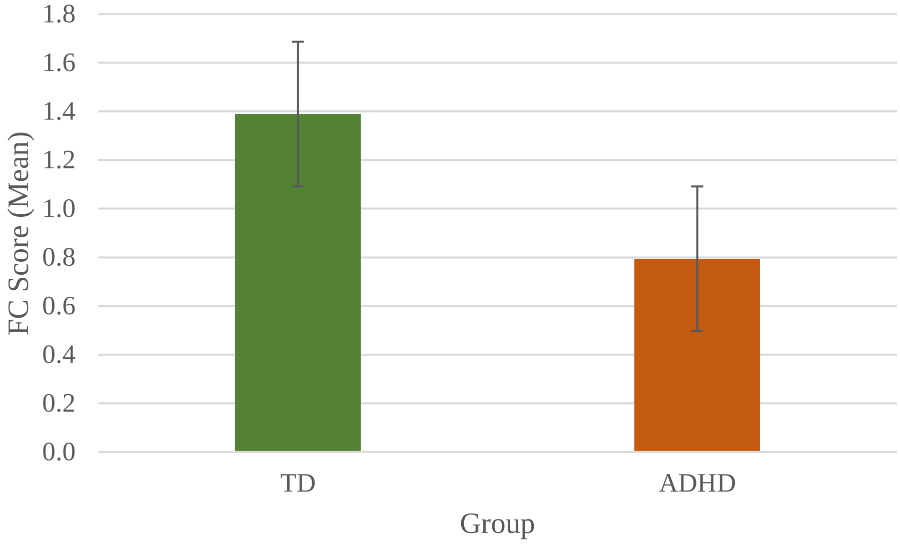
Performance Differences on the WT Between Groups (TD, ADHD)



Note. The lower the WT score, the better the performance. Error bars represent standard errors. TD = Typically Developing, ADHD = Attention Deficit Hyperactivity Disorder, WT = Wii Fit-Ski Slalom Task

Figure 2

Performance Differences of FC per Second Between Groups (TD, ADHD)

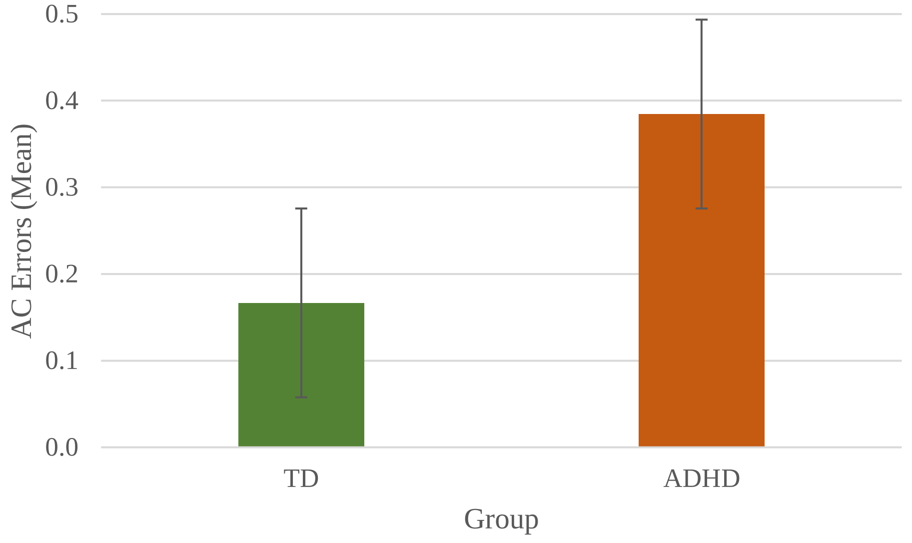


Note. The higher the FC score, the better the performance. Error bars represent standard errors. TD = Typically Developing, ADHD = Attention Deficit Hyperactivity Disorder, FC = Finger Crossing Task

Within the FC-condition (see Figure 2), the TD group (*M* = 1.49, *SD* = 0.61) performed significantly better, compared to the ADHD group (*M* = 0.80, *SD* = 0.42, $t(27.95) = 3.910$, $p < 0.001$, 95% CI [0.39;0.91]), with a large effect size ($\eta^2 = 0.203$). Lastly, within the AC-condition (see Figure 3), the TD group (*M* = 0.27, *SD* = 0.30) made less errors, compared to the ADHD group (*M* = 0.38, *SD* = 0.47, $t(85.165) = -2.674$, $p = 0.009$, 95% CI [-0.38;-0.06]), with a small effect size ($\eta^2 = -0.091$).

Figure 3

Performance Differences of AC Errors Between Groups (TD, ADHD)



Note. The number of errors is a mean of the errors across two runs. The lower the errors, the better the performance. Error bars represent standard errors. TD = Typically Developing, ADHD = Attention Deficit Hyperactivity Disorder, AC = Animal Counting Task

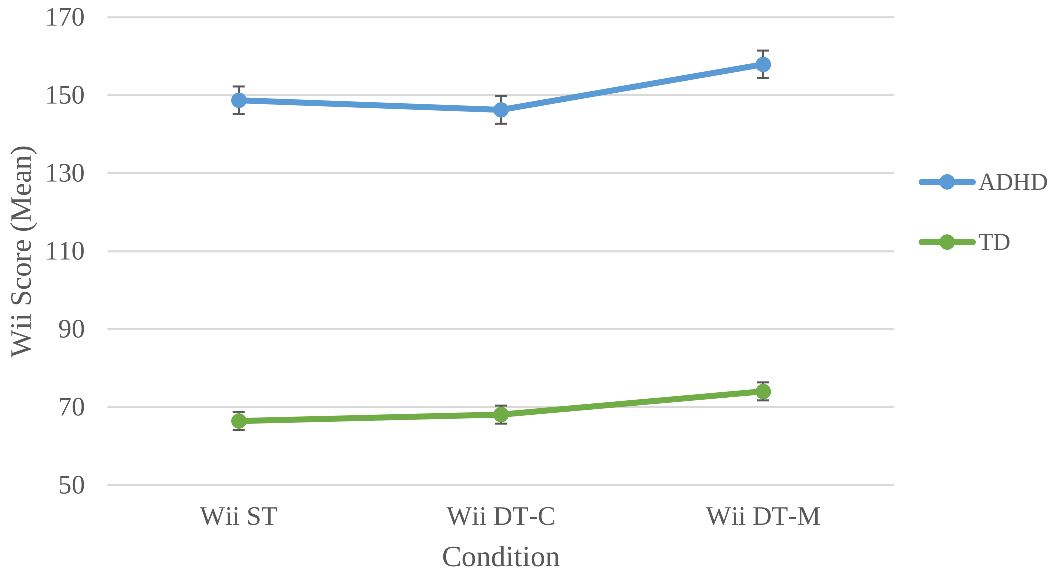
Group differences in DT performance and DT-costs

DT performance

A first GLM repeated measure analysis revealed a significant main effect of conditions ($F(1.807, 115.671) = 4.065$, $p = 0.023$), with a moderate difference of means ($\eta^2 = 0.060$; see Figure 4). No interaction effect between group and condition ($F(1.807, 115.67) = 1.232$, $p = 0.293$) was found. The difference in means was small ($\eta^2 = 0.019$). Moreover, a main effect for group ($F(1) = 9.933$, $p = 0.002$) was found. The difference in means was large ($\eta^2 = 0.134$). Overall, children with ADHD performed worse (WT: *M* = 82.27, *SD* = 18.68; DT-C: *M* = 78.18, *SD* = 15.67; DT-M: *M* = 83.89, *SD* = 19.48) than TD children (WT: *M* = 66.44, *SD* = 17.85; DT-C: *M* = 68.08, *SD* = 16.67; DT-M: *M* = 74.04, *SD* = 16.52) in all three conditions.

Figure 4

Performance Differences of the Wii Conditions per Group (TD and ADHD)



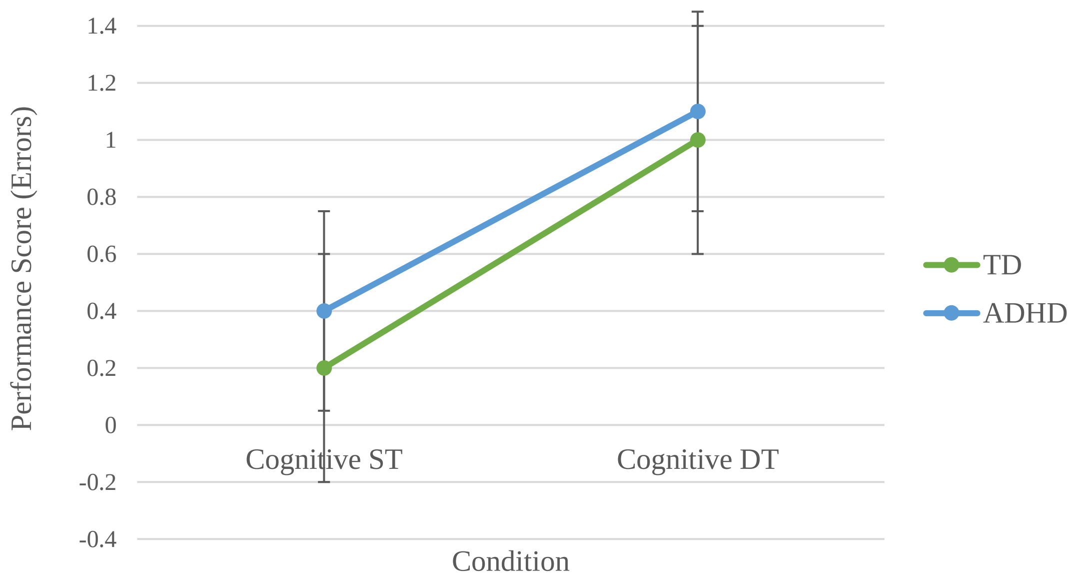
Note. The lower the WT score, the better the performance. Error bars represent standard errors. TD = Typically Developing, ADHD = Attention Deficit Hyperactivity disorder, Wii ST = Wii Single-Task, Wii DT-C = Wii Dual-Task-Cognitive, Wii DT-M = Wii Dual-Task-Motor

Another GLM repeated measure analysis revealed a significant main effect for the DT-C condition ($F(1, 59) = 23.048$, $p = 0.000$), with a large difference in means ($\eta^2 = 0.281$; see Figure 5a). No interaction effect between group and condition ($F(1, 59) = 0.325$, $p = 0.571$) was found. The difference in means was small ($\eta^2 = 0.005$). Both groups performed better in the ST condition (TD: $M = 0.16$, $SD = 0.29$; ADHD: $M = 0.37$, $SD = 0.46$), compared to the DT-C condition (TD: $M = 0.97$, $SD = 1.10$; ADHD: $M = 1.40$, $SD = 1.44$). Overall, TD children performed better in both conditions.

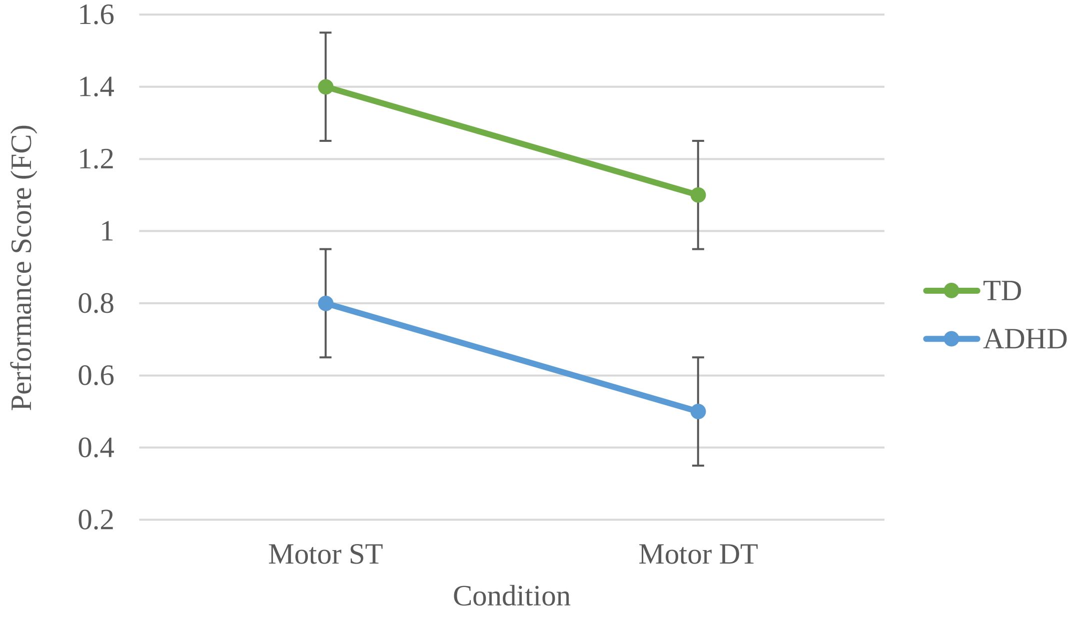
Figure 5

Estimated Marginal Means of ST-Cognitive versus DT-Cognitive and ST-Motor versus DT-Motor per Group (TD and ADHD)

5a)



5b)



Note. This figure demonstrates the performance differences between each group per cognitive (5a) and motor (5b) condition. Error bars represent standard errors.

For motor performance, the GLM repeated measure analysis revealed a significant main effect for the DT-M condition (i.e., FC versus DT-M; $F(1,59) = 50.528$, $p = 0.000$) with a small difference in means ($\eta^2 = 0.005$; see Figure 5b). No interaction effect between group and condition ($F(1,59) = 0.620$, $p = 0.434$) was found. The difference in means was small ($\eta^2 = 0.010$). Both groups performed worse in the ST condition (TD: $M = 1.39$, $SD = 0.63$; ADHD: $M = 0.79$, $SD = 0.42$) compared to the DT-M condition (TD: $M = 1.13$, $SD = 0.68$; ADHD: $M = 0.46$, $SD = 0.27$). Additionally, there was a main effect for group within the DT-M condition ($F(1) = 26.717$, p = 0.000) with a large difference in means ($\eta^2 = 0.312$). Overall, children with ADHD performed better in both conditions.

DT costs

An independent samples t-test indicated no significant difference (see Table 3) in costs (i.e., Wii cognitive costs, Wii motor costs, Error costs, FC costs) between the TD and ADHD group. The largest difference between groups in costs was found in the Wii motor costs condition ($\eta^2 = -0.026$); however, this effect was not significant ($p = 0.212$).

Table 2

Mean Values of DT and ST Performance Improvement (Positive Value) and Performance Interference (Negative Value) Within Each Group

DT-Costs	Group	Mean	SD	t	p-value	95% CI	η^2
Wii cognitive costs	TD	1.603	12.407	-0.543	0.589	[-7.13, 4.07]	0.003
	ADHD	3.133	13.386				
Wii motor costs	TD	-7.604	18.287	-1.262	0.212	[-15.47, 3.50]	-0.026

	ADHD	-1.616	18.689				
Error costs	TD	-0.875	0.9664	1.109	0.271	[-0.24, 0.83]	0.014
	ADHD	-1.173	1.553				
FC costs	TD	0.2644	0.26988	-0.787	0.434	[-0.23, 0.10]	-0.011
	ADHD	0.3303	0.31587				

Note. DT-costs = Dual-task Costs; FC costs = Finger Crossing Costs; TD = Typically Developing; ADHD = Attention Deficit Hyperactivity Disorder

Discussion

For this study, a dual-task paradigm based on a recent study published by Jelsma and colleagues (2021) was used to gain insight into the associations between ADHD and motor performance in children. Specifically, the main goal was to assess whether children with ADHD and TD children differ in single and dual-task performance. The following was hypothesized: 1) the ADHD group scores lower on the MABC-2 compared to the TD group, 2) the ADHD group performs worse in all three ST conditions compared to the TD group, 3.1.) the secondary motor task causes greater interference with the primary task than the secondary cognitive task, 3.2) the ADHD group performs lower in the DT condition than the TD group. The main findings support the hypothesis that children with ADHD express significantly increased motor impairments compared to TD children, which is in line with the literature (e.g., Brossard-Racine et al., 2012; Fliers et al., 2008; Harvey & Reid, 2003; Lavasani & Stagnitti, 2011; Pitcher et al., 2003). Moreover, children with ADHD performed worse on the ST-cognitive (in line with, e.g., McLeod et al., 2014; Kolb et al., 2016, pp. 40-56), ST-motor (in line with, e.g., du Toit & Pienaar, 2014; Harvey & Reid, 2003; Shen et al., 2012; Mendes et al., 2018; Pitcher et al., 2003) and WT (in line with, e.g., Jelsma et al., 2021;

Pitcher et al., 2003; Tseng et al., 2004). Regarding DT-performance, performance on the WT improved from Wii ST to Wii DT-cognitive for the ADHD group and slightly decreased for the TD group. Performance in the WT decreased from Wii ST to Wii DT-motor for both groups (i.e., the ADHD group deteriorated more than the TD group). Additionally, errors in the DT-C condition increased, and finger movements of the DT-M condition decreased. Lastly, no significant differences in DT-costs (i.e., Wii cognitive costs, Wii motor costs, Error costs, FC costs) were found for either group. Therefore, the present findings confirm the first and second hypotheses and the first part of the third hypothesis.

Motor behavior

In line with the previous literature, the present study shows that a substantial proportion of children with ADHD have motor problems compared to TD children. For example, Piek and colleagues (1999) reported that 50% of children with ADHD present movement problems. The results of this study are similar but somewhat lower. 36.5% of the ADHD group show movement problems severe enough to confirm a DSM diagnosis for DCD (Kirby et al., 2007), and 13.5% are at risk of movement problems. Explanations for the lower results might be that seven children with ADHD were prescribed MPH. By inhibiting the reuptake of DA and NE, MPH could have positively affected motor problems and ADHD symptoms in the sample. For example, Brossard-Racine and colleagues (2012) found that MPH enhanced motor functioning in preserving posture and balance tests. For the group of TD children, no child presented motor problems, as indicated by the MABC-2. Generally, the high percentage of children with ADHD and motor problems highlights the need to assess movement problems in ADHD clinics and target these deficits in intervention programs (Sergeant et al., 2006).

Single-task behavior

On all three single-tasks (i.e., WT, FC, AC), the ADHD group performed below the level of the TD group. Group differences in the primary ST-motor and secondary ST-motor were expected since impaired motor performance is common among children with ADHD (Fliers et al., 2010). The WT is a dynamic balance task, requiring children to navigate an avatar on the TV screen by moving their bodies forward, backward, and sideways. Deficits in gross motor skills might account for the significant performance differences between groups (Pitcher et al., 2003; Tseng et al., 2004). Moreover, activities requiring fine and gross motor skills might be negatively impacted by visual perceptual problems (Jung et al., 2014). Recent literature suggests dysfunctional physiology, for instance, responsible for receiving sensory and motor input, for playing a role in ADHD symptomatology (Kolb et al., 2016). Thus, the influence of sensory processes on visual perception might explain WT performance decrements in children with ADHD, as different visual perceptions of the WT exist compared to TD children (Jung et al., 2014). The FC task required the children to move their fingers in a specific fashion for one minute. Although this task was considered easy because all children started with a testing round to practice the movements supports problems with manual dexterity, and fine motor performance might account for the significant group differences (du Toit & Pienaar, 2014; Harvey & Reid, 2003; Shen et al., 2012; Pitcher et al., 2003). The differences in the ST-cognitive condition were expected since cognitive problems are core characteristics of ADHD. The AC task required the children to pay attention to the animal sounds and count these. Although this task was considered easy since all participating children had an IQ of >70, cognitive deficits (i.e., working memory, EFs, and attention), possibly due to anatomical changes in the PFC, might account for these significant differences (Manicolo et al., 2016; Klimkeit et al., 2005).

Dual-task behavior

The impact of the DTs on the WT performance was significantly different between the TD and ADHD groups, albeit the trend was similar, suggesting similar performance patterns in both groups. Similar to Jelsma and colleagues' (2021) findings, WT scores were hampered if the concurrent task recruited resources from the same attentional domain (i.e., motor), suggesting greater dual-task interference for a concurrent motor than a concurrent cognitive task. This finding can be interpreted based on Wicken's (1991) Multiple Resource Model of Attention. It seems like the recruitment of resources of the same (i.e., motor) domain slows down the finger movements and WT performance, independent of groups. The model proposes that attentional resources are divided into several pools. Here, the WT and FC require visual input and control of body movements as a response. However, additional auditory input and verbal responses are needed when the AC is performed. The implication of this is a greater interference between the motor-motor tasks than between the cognitive-motor task leading to greater dual-task interference within the motor condition (Cherng et al., 2007). Contrary, once the concurrent task recruited its attentional resources from a different domain than the primary task (i.e., cognitive), scores on the WT improved or stayed the same. This finding can be interpreted based on the CMI model (Schott et al., 2016), suggesting that a concurrently performed cognitive-motor task leads to performance decrements in one or both tasks. For example, Manicolo and colleagues (2017) found that a concurrent cognitive-motor task affects the primary motor task, suggesting that gait in children with ADHD requires executive functions and is not performed entirely automatically. Lower automatization levels might require children with ADHD to use a greater amount of attentional resources resulting in cognitive overload. Additionally, Leitner and colleagues (2007) found attention to influence gait in children with ADHD, suggesting that dual tasking affects gait in the control and ADHD groups. Problems in dedicating the right amount of attention towards the WT while executing another task possibly affect DT performance due to impaired EF in children with ADHD (Hausdorff, 2005). Lastly, this study compared costs between the ADHD and TD groups, yielding no significant results. Therefore, DT-costs appear to not differ significantly between TD and ADHD groups, implying that, although ST and DT performance differ across groups, DT-costs interfere and facilitate similarly in children with ADHD and TD children.

Clinical relevance

The findings of this study have several clinical implications that could guide teachers and therapists to design adequate education and homework assignments and appropriate therapy sessions for children with ADHD. First, the high prevalence of motor problems in the ADHD group highlights the need for multidisciplinary collaboration to help children with their attentional and motoric deficits. Therefore, the inclusion of pediatric occupational therapists and physiotherapists is highly recommended. These professionals are internationally working with children with DCD and play an essential role in assessing motor problems in the target group (Kirby et al., 2007). Occupational therapists might train psychologists about core symptoms of DCD and introduce screening tools such as the MABC-2 to identify comorbid motor difficulties early on. Children with ADHD should therefore be screened routinely for motor problems and those with motor problems for ADHD. Consequently, when children with ADHD have motor problems, they have to start therapy on a different motor task level than agile children. For problems with, for example, divided attention or distractibility, interventions might be adjusted to train these areas too. Second, one explanation for the findings on decreased DT-C and DT-M performance in children with ADHD suggests that impaired sensory processes in ADHD negatively impact visual perception and, consequently, motor performance and academic achievements. This is in line with findings by Jung et al. (2014). Therefore, visual support, such as color codes, flashcards, or visual maps, may better support children with ADHD in understanding school assignments and theoretical concepts. Additionally, agendas at school and home support their attention and working memory problems and might help integrate structures and routines into daily life (Children and Adults with Attention-Deficit/Hyperactivity Disorder, 2018). Third, the results of the present study suggest that the ADHD group's motor performance on the primary task suffered when a concurrent motor task was performed (i.e., Wii motor cost had the greatest deterioration). This finding is in line with Wickens' Multiple Resource Model of Attention (Wickens, 1991), implying that a child should first automatize a motor task before being presented with another task drawing from the same attentional resource pool; specifically in school settings and daily life activities. Additionally, teachers could provide shorter task instructions throughout school settings and divide big assignments into smaller chunks that allow more breaks, considering attentional and concentration problems in children with ADHD (Vassermann et al., 2014). Moreover, shorter sessions and switching between topics may help keep children with ADHD engaged. Lastly, seated activities could alternate with activities requiring the children to move around the classroom by incorporating physical activities into the lessons. Physical activities positively affect ADHD core symptoms, suggesting that frequent exercise decreases symptom severity and improves cognitive functioning in class (Mehren et al., 2020). Therefore, based on the present study's findings, it could be indicated that if these physical activities involve repetitive execution (e.g., to pedal while cycling), children with ADHD could be trained in automatizing this motor skill.

Strengths and limitations

Although the findings should be interpreted with caution, this study has several strengths. First, this research has an ecological value, as it was conducted in the children's school environment. At first, the schools' bell noises or screaming children appeared distracting; however, an environment was chosen what a child is exposed to daily. Secondly, the thorough reliability procedure guaranteed a high percentage of agreement (i.e., 89%)

between the two researchers because past research showed that multiple researchers increased the consistency of how the raters evaluated a participant's behavior (Goodwin, 2001). Third, the single-tasks were thoroughly designed, meaning that only children with an IQ higher than 70 were included in the study. This inclusion criterion ensured an intellectual capability high enough to understand and complete the AC and FC tasks. Additionally, children could practice the movements for the FC task, and then a testing round was done. Therefore, a child's motor ability was tested and not their learning ability. Fourth, the Wii Fit Balance Board as part of the WT tool evinced as a helpful measure to assess motor performance without too high demands for children with ADHD, as the inclusion of the Balance Board was already shown to be a successful measure of motor performance in children with DCD (Bonney et al., 2017; Jelsma et al., 2021). Lastly, movement problems were formally assessed using the M-ABC-2. This standardized test battery is the most used international norm-referenced test and an age-appropriate measure of motor problems. It also proves to have good validity (i.e., construct and discriminative) and good reliability for the total score (Henderson et al., 2007).

This study is also subject to certain limitations. The first limitation is the lack of standardization. For instance, some children ate during the assessment procedure, whereas others had longer breaks between each FC trial. Second, the study protocol did not include a precept of how long a break could last between tasks. Also, breaks were not recorded or monitored. These inconsistencies may have caused different procedures between groups of students that tested the children, which could be improved by adjusting the study protocol to ensure consistency in future studies. Third, some participants completing the FC task appeared distracted by the Wii noises of other children completing the WT because children were in the same room. Therefore, children might have had difficulties controlling their attention and screening out distractions such as the Wii sounds. Consequently, these noises might result in losing focus and thus not performing the task adequately, such as forgetting to count while performing the WT. This limitation could be improved by organizing separate rooms for testing.

Conclusion

Children with ADHD performed below the level of typically developing children regarding M-ABC and single-task performance and simultaneously performing a cognitive-motor and motor-motor task. Many activities of daily life require a child to execute multiple tasks simultaneously. Especially activities like riding a bike to school may loom danger, especially for a child with ADHD, considering attention has to be paid to traffic and pedestrians, moving the pedals, and possibly chatting with friends. Pediatric physical therapists work internationally with children having DCD. Therefore, a collaboration between clinicians, psychotherapists, and physical therapists is recommended to assess motor performance in children with ADHD early on and understand the child's whole system.

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Appendix

Appendix 1

Figure 8

Step 1 of the Finger Crossing Single-Task

Note. The connection between the bottom thumb and index finger is about to disconnect to turn in opposite directions.

Appendix 2

Figure 9

Step 2 of the Finger Crossing Single-Task

Note. The fingers disconnected and turned upwards to connects again between thumb and index finger.

Appendix 3

Calculation of percentage of agreement between two researchers based on CTSpedia (2010).

Percentage of agreement = Total number of agreements ÷ total number of ratings × 100

71 ÷ 80 = 0.8875

0.8875 × 100 = 88.75%

Appendix 4

Calculations of eta squared = n^2 per hypothesis based on Pallant (2013).

Hypothesis 1

$$n^2_{MABC\text{-}2} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{8.117^2}{8.117^2+(36+52-2)} = 0.434$$

Hypothesis 2

$$n^2_{\mathrm{WT}} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{-3.193^2}{-3.193^2+(36+52-2)} = -0.134$$

$$n^2_{\mathrm{FC}} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{8.117^2}{8.117^2+(20+24-2)} = 0.203$$

$$n^2_{\mathrm{Errors}} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{8.117^2}{8.117^2+(36+52-2)} = -0.091$$

Hypothesis 3

$$n^2_{\mathrm{WiiCognitiveCosts}} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{-0.543^2}{-0.543^2+(36+52-2)} = 0.003$$

$$n^2_{\mathrm{WiiMotorCosts}} = \frac{t^2}{t^2 + (N1+N2-2)} = \frac{-1.262^2}{-1.262^2+(24+42-2)} = -0.026$$

$$n^2_{\text{ErrorCosts}} = \frac{t^2}{t^2 + (N1+N2-2)} \quad = \frac{1.109^2}{1.109^2+(36+52-2)} = 0.014$$

$$n^2_{\text{FCCosts}} = \frac{t^2}{t^2 + (N1+N2-2)} \quad = \frac{-0.787^2}{-0.787^2+(19+41-2)} = -0.001$$