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Differences Between Children with Developmental Coordination Disorder and Typically Developing Children in Dual-Task Performance: A Cross-Cultural Comparison

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Abstract

Developmental coordination disorder (DCD) is a neurodevelopmental disorder characterized by motor impairments that negatively influence daily life and academic performance, assumed to originate from a deficit in automatization of motor skills. Previous research has demonstrated that children with this disorder have significant problems with dual-task performance, possibly due to cognitive-motor interference and contending attentional resources. Cultural differences regarding the prevalence, gender distribution, and etiology of the disorder were found by previous research. The present study compares the dual-task performance of 140 children from the Netherlands and Brazil, of which 64 were classified as having DCD and 76 as typically developing children, on motor-motor and cognitive-motor dual-task paradigms. The performance on single-tasks was significantly lower in children with DCD than typically developing children in the entire sample, the Dutch sample, but not in the Brazilian sample. Analyses comparing dual-task performance with single-task performance across groups and cultures remained insignificant; however, it was found that performance patterns did differ across cultures. Dual-task costs were found to facilitate and interfere with performance similarly across groups and cultures. Based on the statistical results and behavioral observations made during assessments, the present study found evidence for the automatization deficit hypothesis in children with DCD, evidence for competing attentional resources, and cognitive-motor interference in the entire sample. Future interventions should be aimed at the automatization deficit and incorporate visual feedback. The cultural differences found, highlight the need for ecological studies and aimed interventions in developing countries, not only towards children with DCD but also for typically developing children.

Keywords: developmental coordination disorder, DCD, single-task performance, dual-task performance, dual-task costs, automatization deficit hypothesis, cultural differences

Developmental coordination disorder (DCD) is a chronic neurodevelopmental disorder characterized by motor impairments affecting academic achievement and daily life functioning (American Psychiatric Association [APA], 2013), presumably caused by an automatization deficit (Visser, 2003). Moreover, the disorder impairs not only the motor performance of affected children but also the dual-task performance of affected children. DCD affects around 6% of children worldwide and is typically identified between the ages of 6 to 12 years; boys are diagnosed more frequently than girls with a ratio of 2:1 (Cairney et al., 2005; Missiuna et al., 2008). These gender differences may be due to higher referral rates for boys, as their motor deficits may lead to more apparent problems in their daily life. The symptoms of DCD remain persistent during adolescence and adulthood (Cousins & Smyth, 2003). Multiple diagnostic criteria stated by the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM–5; American Psychiatric Association, 2013) need to be fulfilled to diagnose DCD. These include the absence of any other developmental disorder or disturbances of muscle tone that may explain the present dysfunctions. Also, the presenting symptoms must affect the child's daily life negatively. In addition, the child's motor performance and coordination must be significantly lower than assumed based on age and intelligence level. Moreover, if a substantially low intelligence is present, the motor problems must exceed those expected at this intelligence level.

Most of the impairments associated with DCD negatively affect gross and fine motor skills, as well as psychosocial functioning (Zwicker et al., 2012). Gross motor dysfunctions entail neurological soft signs, including subtle abnormalities in neurological functioning that lead to problems in motor coordination, sensory integration, and the sequencing of motor acts (e.g., balance problems, frequent falling, dropping off items, slow reaction times, perseverance of primitive reflexes) (Barnhart et al., 2003; Marinov et al., 2015). Fine motor dysfunctions encompass problems with planning and performing fine motor tasks (e.g., handwriting) (Smits-Engelsman et al., 2001). The category of psychosocial dysfunction mainly comprises problems at school and with peers (Chen et al., 2009), often caused by problems in reading, learning disabilities, and poor motor performance (Draghi et al., 2020). In addition, children with DCD were found to have higher rates of loneliness, low self-worth, and fewer friends (Barnhart et al., 2003). Apart from the characteristic motor dysfunctions, around 68% of the children with DCD are diagnosed with comorbid disorders (Cardoso et al., 2014), such as attention deficit hyperactivity disorder (ADHD) (Goulardins et al., 2015), learning disorders (Kaplan et al., 2006), behavioral and emotional disorders (Crane et al., 2017; Green et al., 2006), and speech and language problems (Archibald & Alloway, 2008; Gaines & Missiuna, 2007).

Hitherto, no consensus has been found regarding DCD etiology; however, heterogeneous causes are propounded, and multiple theoretical models were proposed. For example, Gilger and Kaplan (2001) assert that atypical brain development is an underlying brain deficit for DCD and ADHD. Other researchers suggest that the disorder develops secondarily to neuronal damage or prenatal, perinatal, or neonatal insults (Vaivre-Douret et al., 2011). Accordingly, it is suggested that the gender distribution of DCD may affect more males than females, predicated on the higher incidence of premature delivery and perinatal difficulties in male neonates (Barnhart et al., 2003). The most strongly supported hypothesis to explain the underlying mechanisms for DCD is the *automatization deficit hypothesis* established by Nicolson & Fawcett (1990), stating that affected children experience problems in automatizing motor skills. Automatization is an essential factor in performing motor actions smoothly (e.g., handwriting, typing, cycling) without imposing significant attentional demands on the person while doing them (Tsai et al., 2009). Children with DCD seem to have deficits in automatizing skills, meaning that high cognitive and attentional demands are imposed during simple motor actions. This theory links the presented motor automatization problems to the cerebellum, as this specific brain area is recognized to play an essential role in the automatization of skills. Support for this hypothesis was found by Zwicker and colleagues in 2012, demonstrating that children with DCD show microstructural differences in the cerebellum compared to typically developing (TD) children.

Additionally, the cerebellar dysfunction in children with DCD is in line with neurological soft signs typical for the disorder (Volman & Geuze, 1998). As an automatization deficit occurs in DCD and disorders such as ADHD or dyslexia, this hypothesis can elucidate a possible underlying mechanism for these highly comorbid disorders and their prominent problems with dividing attention and performing multiple tasks simultaneously (Visser, 2003). Various studies have identified multiple brain regions allegedly involved in DCD. Most of these studies report diverging results; however, a consensus was found about brain regions as the cerebellum, basal ganglia, and parietal lobe. In line with the *automatization deficit hypothesis*, various researchers predicted the involvement of the cerebellum. It plays a crucial role in motor performance, coordination of movements, balance, motor learning, and automatization; between-group differences between children with DCD and TD children were found using functional MRI (Debrabant et al., 2016; Zwicker et al., 2010; Zwicker et al., 2012). The basal ganglia involved in planning, motor control, movement initiation, and automatization were consequently expected to play a substantial role in DCD. Multiple studies found atypical activation patterns of the basal ganglia (i.e., striatum) in children with DCD and ADHD, suggesting an underlying shared brain structure for both disorders (Debrabant et al., 2016; McLeod et al., 2014; Querne et al., 2008). Researchers have identified the parietal lobe as the central brain region implicated in proficient motor functioning (Culham et al., 2006). Kashiwagi and colleagues (2009) found parietal lobe involvement in children with DCD, characterized by less activation in children with DCD than in TD children.

Children with DCD do not only show impairments in their motor functions, but diversified studies revealed deficient cognitive abilities, precisely in executive functioning (EF) (Schott & Holfelder, 2015; Wilson et al., 2012). Numerous researchers discovered deficits in EF and fine and gross motor skills of children with DCD, and the correlation between those variables to be significant (Alloway et al., 2009; Asonitou et al., 2012; Best & Miller, 2010). Dual-task paradigms are an innovative approach to investigate this reciprocal relationship between cognitive and motor functions. Here, two tasks, one being a motor and the other being a cognitive task, or both being of the same kind, are performed simultaneously by the testee to assess whether one of the task's attentional demands interferes with performance on the other. Wickens' 4-D multiple resource model manages to explain this interference. This model proposes that attentional resources can be divided into multiple pools instead of just one individual pool for all attentional demands (Wickens, 2008). Thus, different attentional pools are activated during task performance depending on the processing stage, codes, input modalities, and required response. Adopting Wickens' theory, two tasks would interfere when they require resources from the same attentional pool, and the available resource is not sufficient for both tasks. Opposing this assumption, Cherng and colleagues (2009) found that children with DCD performed worse on a cognitive-motor dual-task paradigm. These findings propose that those children may require more attention and are negatively affected by a concomitant task than TD children, even though cognitive and motor tasks require resources from two distinct attentional pools. It is also possible that pathologies, as neurodevelopmental disorders, may diminish the general attentional capacity due to structural changes to the brain (McIsaac et al., 2015). When applying the *automatization deficit hypothesis* on dual-task paradigms, the secondary task interferes with the primary task when there is no sufficient automatization of the primary task (Visser, 2003). If the primary task is automatized, there would be little or no interference between it and the secondary task (Nicolson & Fawcett, 1990).

Another critical aspect of dual-task paradigms is cognitive-motor interference (CMI). It states that if a motor and a cognitive task are performed concomitantly, they interfere with each other and thus lead to inferior task execution on one or both tasks (Abbruzzese et al., 2014; Mitra et al., 2013). However, CMI also states that if a motor task is sufficiently trained and thus automatized, fewer attentional resources are required to perform the task and consequently leaves more resources for the simultaneous tasks (Schott et al., 2016). The principle of CMI leads back to the *automatization deficit hypothesis*, stating that children with DCD have deficient automatization of skills even after training. The lack of automatization leads to higher CMI in dual-task paradigms, even when one of the tasks was trained, while TD children would show less interference after training. This notion is in line with later findings by Schott (2019), stating that stronger CMI is common in neurodegenerative and neurodevelopmental disorders. Although much research was conducted on dual-task performance in children with and without neurodevelopmental disorders, findings remained inconsistent and yielded contradictory results. Schott (2019) examined brain regions explicitly involved in dual-task performance, comparing children with DCD and TD children. Apparently, problems with motor-cognitive functioning result from poor connectivity and deficient communication between various areas in children with DCD. Also, during dual-task performance, children with DCD exhibited microstructural brain abnormalities and differential activation patterns, specifically in the cerebellum. These findings support the *automatization deficit hypothesis* indicating the cerebellum as the primary source for motor deficits in children with DCD (Zwicker et al., 2012). The disparity between children with DCD and TD children in automatization, dual-task performance, and CMI raises the question of whether these group differences can be considered universal.

To gain insight into the universality of the behavior of both groups, the present study adopts a cross-cultural design examining differences in DCD between the Netherlands and

Brazil. Cardoso and colleagues (2014) estimated a prevalence of DCD of 4.3% in Brazil, while Souza and colleagues (2007) found a similar prevalence in rural areas but striking 11.8% in urban areas. Previous research suggests that among children in families with low socioeconomic status (SES), the prevalence of DCD is as high as 20% due to the complex interaction between genetic makeup and factors such as SES, parental care, parental health status, and housing conditions (Prinsloo & Pienaar, 2003). These factors seem to contribute to a heightened risk of developing mild neurological and neurodevelopmental disorders (Hadders-Algra, 2002). Also, Bobbio and colleagues (2009) found a higher prevalence of motor delays among Brazilian children from low-income families. The present study may clarify questions about the prevalence in Brazil and cross-cultural and socioeconomic differences. As opposed to findings in European countries, more girls than boys are diagnosed with DCD in Brazil (Cardoso et al., 2014). Researchers found a similar pattern in Colombia, with a significantly higher rate of girls diagnosed with DCD than boys (Pineda et al., 2003). A possible explanation for this significant difference is that access to physical activities may be distributed more evenly in European cultures than in Latin-American ones. Based on gender roles, Brazilian girls are likely to be advocated less to participate in physical activities, specifically gross motor activities, than boys, not only at home but also in schools (Cardoso et al., 2005). Following this notion, a study found that Brazilian girls from age 3 to 10 had deficient motor skills, resulting from fewer opportunities at school for developing motor skills (Spessato et al., 2013). Additionally, girls from low-income families in Brazil are kept at home more often and miss school to help in the household and care for relatives and siblings (Emerson & Souza, 2007). Therefore, these constraints may circumvent girls from developing motor skills at the same level as their male counterparts (Valentini et al., 2014).

Based on the uncertainty about dual-task performance in children with DCD due to conflicting research results in multiple areas (e.g., etiology, neurophysiological underpinnings, cultural differences) and proposals of various hypotheses for underlying mechanisms, the present study investigates the differences among children with DCD and TD children on a dual-task paradigm across cultures. Following this notion, the present study aims to gain more insight into the differences in dual-task performance in children suffering from developmental coordination disorder compared to TD children. A deeper understanding of the motor problems of children with DCD could guide future research and help establish a solid theoretical background and treatment implications for patients.

First, it is hypothesized that the groups differ on single-task performance. Precisely, it is predicted that children with DCD perform worse on all single-task measures than TD children, based on their general motor dysfunction (APA, 2013) and associated cognitive impairments (Schott & Holfelder, 2015; Wilson et al., 2012). Second, it is hypothesized that secondary tasks interfere with the primary task in a dual-task paradigm more strongly in children with DCD when compared to TD children. Precisely, it is predicted that children with DCD show a higher amount of dual-task interference and, therefore, performance abatements than TD children. Third, based on previous findings, it is hypothesized that children with DCD will perform differently from TD children on the motor-motor dual-task paradigm (Schott, 2019). It is predicted that children with DCD attain lower scores on this motor-motor dual-task paradigm than TD children, as children with DCD are expected to have deficient automatization abilities based on the *automatization deficit hypothesis* in children with DCD (Nicolson & Fawcett, 1990). Moreover, it is expected that children with DCD attain lower scores on the cognitive-motor dual-task than TD children based on CMI; however, this decrease is not expected to be as strong as the decrements produced in the motor-motor dual-task paradigm, as required attention for the two tasks is derived from separate attentional pools (Wickens, 2008). Additionally, dual-task costs are hypothesized to be higher in children with DCD than in TD children, based on recent literature suggesting that children with DCD experience higher dual-task costs than peers and that these costs increase with enhanced complexity (Liebherr et al., 2018, Patel et al., 2014). Lastly, it is hypothesized that no cultural differences are found on single- and dual-task performance, and dual-task costs between groups, as past research has obtained similar results within both cultures (Cardoso et al., 2014; Souza et al., 2007).

The current study used the following approach. First, TD children and children with DCD were compared on single-task performance. Next, dual-task performance is compared between cognitive-motor and motor-motor dual-tasks as well as between groups (TD & DCD). Then, dual-task costs are assessed between TD children and children with DCD. Lastly, cultural differences in single-task performance, dual-task performance, and dual-task costs are investigated in children with DCD and TD children.

Method

2.1 Participants

The participants were recruited in the Netherlands and Brazil as part of a more extensive study conducted in Groningen, the Netherlands, and in São Carlos, Brazil. The total sample was composed of 140 children, 65 being male and 53 being female. Participation was voluntary; no reimbursement was granted.

The Netherlands: The Dutch sample consisted of 60 children aged between 7 to 12 years, divided into subgroups of TD children (N_{TD-NL}= 36) and children with DCD (N_{DCD-NL} = 24). All children classified as having DCD were recruited via a pediatric physical therapy practice or special education schools. The sample was composed of 39 male and 21 female children, with a mean age of ten years (M = 10.27, SD = 1.49). In the Dutch DCD group, two children were previously diagnosed with an autism spectrum disorder (ASD), one child with attention deficit hyperactivity disorder (ADHD), and one child had dyslexia. In the Dutch TD group, one child had dyslexia. However, none of these children has been prescribed medication for behavioral problems.

Brazil: The Brazilian sample consisted of 80 children aged 7 to 12 years, divided into the subgroups of TD children ($N_{TD\text{-}BR}$ = 40) and children with DCD ($N_{DCD\text{-}BR}$ = 40). Brazilian children were recruited via teachers from their schools. The sample consisted of 44 male and 36 female children, with a mean age of nine years (M = 8.6, SD = 1.088).

The Ethical Committee approved this research in the Netherlands of Psychology of the University of Groningen (17379-S-NE) in agreement with university guidelines and ethical standards according to the Declaration of Helsinki. Furthermore, the Brazilian research project was approved by the Research Ethics Committee (process number 89993118800005504) and by the board of education and the elementary school directors in São Carlos.

Children were allocated in the subgroup of developmental coordination disorder (DCD-group) if they conformed to multiple selection criteria proposed by the APA in the DSM-5. Criterion A: On the Movement Assessment Battery for Children 2nd edition (MABC-2) and subtest balance, a score at or below the 16th percentile was needed to fulfill the requirements. Criterion B: teacher's identification of the child having motor coordination problems, assessed in a physical exercise class or while playing, problems with handwriting, and motor problems during eating and drinking while being at school. Criterion C: Children whose parents, teachers, and age confirmed early onset of motor problems. Criterion D: The child's parents needed to confirm that there is no other medical or neurological condition present that affects motor behavior and no significant intellectual and cognitive impairments based on information provided by teachers and the school. Children were allocated in the subgroup of TD children, serving as controls, when their teacher confirmed no behavioral or intellectual problems, when their parents confirmed that there is no medical or neurological diagnosis present, and when they scored above the 16^{th} percentile on the MABC-2.

Table 1

Demographic Data of the TD and DCD Group with Mean Values or Frequency and Test Outcomes of Differences Between Groups in the Netherlands and Brazil

		TD	DCD	p-value
Mean age (SD)*	NL	10.3 (1.4)	9.8 (1.4)	.185
	BR	8.57 (1.09)	8.58 (1.12)	.889
Sex Boys:Girls (n)#	NL	19:17	20:4	**.015**
	BR	21:19	23:17	.427
Height in cm (SD)*	NL	147.5 (10.8)	143.5 (10.4)	.165
	BR	136.1 (8.1)	131.5 (22.2)	.251
Weight in kg (SD)*	NL	36.8 (9.3)	36.0 (9.2)	.730
	BR	35.46 (9.7)	35.6 (13.7)	.388
IQ	NL	-	84.0 (11.1)	-
	BR	-	-	-
MABC-2 TSS*	NL	11.1 (2.5)	3.4 (2.0)	**<.001**
	BR	11.1 (2.5)	5.4 (1.2)	**<.001**
MABC-2 balance*	NL	10.6 (2.1)	5.1 (2.4)	**<.001**
	BR	10.3 (2.8)	5.8 (2.3)	**.026**

Note. TSS=Total Standard Score; SD=Standard Deviation; NL=the Netherlands; BR=Brazil; * tested with the independent t-test; # tested with the chi-squared test; bold indicates significance<.05

2.2 Instruments

2.2.1 DCD-Q: The DCD-Q is a screening tool assessing coordination disorders in children (Parmar et al., 2014). This popular questionnaire is a parent-report measure used to identify children at risk for developmental coordination disorder. In the Netherlands, the Dutch version of the questionnaire was used (DCD-Q-NL; Schoemaker et al., 2006), whereas, in Brazil, the DCD-Q-Brazil was employed (Prado et al., 2009). The questionnaire consists of three subscales (*Control During Movement*, *Fine Motor/Handwriting,* and *General Coordination*) with a total of 15 items. The child's parents are asked to rate their child's motor performance compared to children of the same age on a 5-point Likert scale ranging from "*1 = not like your child"* to "*5 = extremely like your child".* The scores of all individual items are added to obtain the total score, giving possible total scores between 15 to 75. A score below 46 indicates the tendency to have developmental coordination disorder (Wilson et al., 2009). Participants were grouped depending on their scores.

2.2.2 MABC-2: The Movement Assessment Battery for Children - 2nd Edition (MABC-2) (Henderson et al., 2007) is a norm-referenced test used to identify motor impairments in children of age 3 to 16. It consists of eight tasks subdivided into three subtests: *Manual Dexterity*, *Aiming and Catching,* and *Balance*. The test material is available for three age bands within the range of 3 to 16 years of age, namely three to six years and 11 months, seven to ten years and 11 months, and 11 to 16 years and 11 months. In the Netherlands and Brazil, the same edition of this test battery was used. The Dutch sample outcomes were compared to Dutch norms, and the Brazilian sample outcomes were compared to norms from the UK. Although a validated cross-cultural adaption of the MABC-2 for Brazil exists, no norms are available to date (Valentini et al., 2014). Therefore, the available UK norms were used. The raw scores are converted into percentile scores and standard scores per subtest, and the total test. Children are categorized as having movement difficulty when falling at or below the 16th percentile or having no movement difficulty when scoring above this cut-off score. Raw scores for subtests, raw total scores, standardized scores, and percentile scores were calculated.

2.2.3 Single-Tasks (ST)

2.2.3.1 Primary Task: Wii Fit Ski Slalom Game (Wii ST)

The Wii Fit Ski Slalom game is played on the Nintendo© Wii™, using the 'Balance Board' accessory. The Balance Board is formed like a scale on which a player can stand while playing a video game to measure the player's balance and weight and manipulate the game with these measures. The Ski Slalom game requires the player to stand on the Balance Board while playing and move the avatar on skis by shifting their center of balance. Players can lean to the left or to the right during the game to shift the avatar's direction and lean forward to accelerate. In addition, the game presents gates, which the player is supposed to pass through; if the gate is missed, a penalty of seven seconds is added to the total amount of time. In the current research, children with DCD and TD children are asked to play the Wii Fit Ski Slalom game. Outcome measures of the final 'Wii score' on the game, 'missed gates', and game duration in seconds are determined. It is important to note that a lower score implies better performance in the game.

2.2.3.2 Cognitive Single-Task: Counting Animal Sounds (C-ST)

The participants are presented with a recording carrying multiple animal sounds, specifically cat and cow sounds. The participants are required to count the animal sounds of one animal while ignoring the sounds produced by the other animal. The outcome measure recorded is the number of errors done while counting. A higher error score indicates lower performance.

2.2.3.3 Motor Single-Task: Finger-Crossing (M-ST)

The finger-crossing task is a fine motor task in which participants are required to touch the index fingers of one hand with their thumbs of the respective other hands as a starting position. Next, the finger pair on the underside is supposed to be separated, make an upward motion, and reconnect above the other finger pair. Now, this motion is repeated with the next finger pair. For a visualization of this task, see Appendix A. The outcome measure is finger-crossing per second. A higher score in finger-crossing per second indicates better performance.

2.2.4 Dual-Tasks (DT)

2.2.4.1 Cognitive-Motor Dual-Task (C-DT): WiiFit Ski Slalom + Counting Animal Sounds

In the motor-cognitive dual-task paradigm, the primary task the participants must again perform is the Wii Fit Ski Slalom game (see section 2.2.3.1). Meanwhile, participants must simultaneously count animal sounds (see section 2.2.3.2) as the secondary task. Outcome measures of this condition are the recordings from the Wii Fit game (i.e., ‘Wii score’, ‘missed gates’, and duration of the game) and the total number of errors made while counting the animal sounds.

2.2.4.2 Motor-Motor Dual-Task (M-DT): WiiFit Ski Slalom + Finger-Crossing

In the motor-motor dual-task paradigm, the primary task the participants must perform is the Wii Fit Ski Slalom game (see section 2.2.3.1). During this game, participants are required to simultaneously perform the finger-crossing (see section 2.2.3.3) as a secondary task. Outcome measures of this condition are the recordings from the Wii Fit game (i.e., ‘Wii score’, ‘missed gates’, and duration of the game), as well as the number of finger-crossings per second.

2.3 Procedure

In the Netherlands, information sheets, informed consent letters, and the parent-questionnaire DCD-Q were given to students of Prof. W.J. Bladergroenschool Groningen and the CSBO Kimkiel Groningen, which are special education schools. In Brazil, the information sheets, consent letters, and DCD-Q were distributed to children from a public school in São Carlos. The children that submitted informed consent signed by their parents, gave written assent, and returned a completed DCD-Q, took part in the current study. They were tested in two sessions of each 40 minutes. The participating children were first assessed for demographic data, including date of birth, age in years and age in months, nationality, gender, height, weight, and BMI. Additionally, the children were tested on the MABC-2 and the subtest of the KiTAP measuring sustained attention. The findings on the KiTAP are of no interest for the present study as it was assessed for an ongoing research project. In the second session, the children completed the subtests of distractibility and divided attention of the KiTAP, a single cognitive and motor task, and a Wii Ski Slalom game as an ST condition and a DT condition. In the DT condition, the Wii Fit Ski slalom game was combined with either a cognitive task (C-DT) or a motor task (M-DT). The single cognitive task consisted of the children counting animal sounds (cats or cows). After completing this task, the children performed the single motor task of crossing their fingers. This single motor task was assessed three times for one minute each. The finger-crossing was video recorded to assess the performance afterward. Before starting the Wii Fit Ski Slalom game, every child had to participate in the Wii Fit Balance Board calibration process, which measures the child's weight and pressure. Next, two ST trials of the Wii Fit Ski Slalom game were performed. Then, two C-DT trials were performed, followed by two ST trials of the Wii Fit Ski slalom game. The alternation of DT and ST was applied to obviate learning biases. After, the M-DT was performed twice, followed by one trial of the C-DT and one more trial of the M-DT. In total, all participants completed ten Wii Ski Slalom game trials.

All trials were videotaped and scored following the realization of the assessments. Videos from the Netherlands were scored by multiple student assistants, while the videos from Brazil were scored by the author of the present study and a colleague. Interrater reliability was assessed to warrant the quality of scores imputed by two different expert raters. A percentage of agreement of 88.75 percent was accounted for. Furthermore, the videotapes from Brazil were analyzed for behavioral differences between children with DCD and TD children.

2.4. Statistical analysis

All statistical analyses were completed using SPSS 25.0. First, the procured data were checked for normality. Subsequently, descriptive statistics were obtained to examine the raw data. A t-test and a chi-squared test were applied to test demographical data (age, height, weight, BMI, gender) for significant differences to ascertain whether the groups of children (TD and DCD) can be compared. To determine whether children from both cultures (NL and BR) can be compared, a t-test and a chi-squared test were applied to demographical data (age, height, weight, BMI, gender). The percentage of agreement was calculated as an indicator for interrater reliability (Appendix B).

To obtain the number of finger-crossings per second of each participant, the number of finger-crossings in the ST was divided by 60 seconds and in the DT by the duration of the Wii Fit slalom game. Furthermore, the mean was calculated between two runs for each condition to obtain outcome measures, namely: (1) ST Wii Fit, run 3 (Wii Fit) and run 8 (Wii Fit); (2) C-DT, run 5 (Wii Fit & counting) and run 6 (Wii Fit & counting); (3) M-DT, run 9 (Wii & finger-crossing per second) and run 10 (Wii & finger-crossing per second); (4) C-ST: run 2 (Counting) and run 3 (Counting); (5) C-DT; run 5 (Wii Fit & Counting) and run 6 (Wii Fit & Counting); (6) M-ST (per second): runs 2 (finger-crossing per second) and 3 (finger-crossing per second); (7) M-DT: run 9 (finger-crossing per second & Wii Fit) and run 10 (finger-crossing per second & Wii Fit).

To test the first hypothesis, an independent samples t-test was applied to contrast both groups (TD, DCD) on their ST performance for C-ST (counting animal sounds), M-ST (finger-crossing per second), and Wii Fit ST (Wii Fit Ski slalom game). The data file was split to investigate whether cultural differences can be found in single-task performance in both groups. To investigate the second hypothesis, a GLM Repeated Measures was performed to assess Wii Fit Ski slalom performance in all three conditions (ST, C-DT, M-DT) by group (TD, DCD). In addition, the three conditions were also assessed for differences between cultures using another GLM Repeated Measures. A further GLM Repeated Measures was executed to compare C-ST performance versus C-DT performance (Animal Counting Errors ST versus DT) as well as M-ST performance versus M-DT (Finger-Crossing ST versus Finger-Crossing DT) and with group (TD, DCD) as a within-subject factor. Another GLM Repeated Measures assessing cultural differences was also performed for this analysis. Next, the DT costs were calculated to ascertain how the DT performance has changed. The DT Wii-Cognitive, DT Wii-Motor costs, DT Animal Sound Counting-Error costs, and DT Finger-Crossing costs were calculated by following formulas (Hall et al., 2011):

$$DT\ Wii - Cognitive\ costs = (Mean\ Wii\ ST - Mean\ Wii\ Cognitive\ DT) \tag{1}$$

$$DT\ Wii - Motor\ costs = (Mean\ Wii\ ST - Mean\ Wii\ Motor\ DT) \tag{2}$$

$$DT\ Error\ Costs = (Mean\ ST\ Errors - Mean\ DT\ Errors) \tag{3}$$

$$DT\ Finger - crossing\ costs = (Mean\ ST\ FC\ per\ second - Mean\ DT\ FC\ per\ second) \tag{4}$$

A t-test of independent samples was used to assess differences between groups (TD, DCD) on all dual-task cost measures. All analyses mentioned above were also performed with a split file comparing differences and similarities in children from the Netherlands and Brazil to assess cultural differences in dual-task performance.

Effect sizes were interpreted based on the guidelines by Cohen (1988, pp. 284-287), with effect size values equal to 0.01 interpreted as a small effect, values of 0.06 interpreted as a moderate effect, and values of 0.14 interpreted as a large effect.

2.5 Behavioral Observations

The video recorded assessments of children with DCD and TD children in single- and dual-task performance were analyzed for behavioral differences between groups.

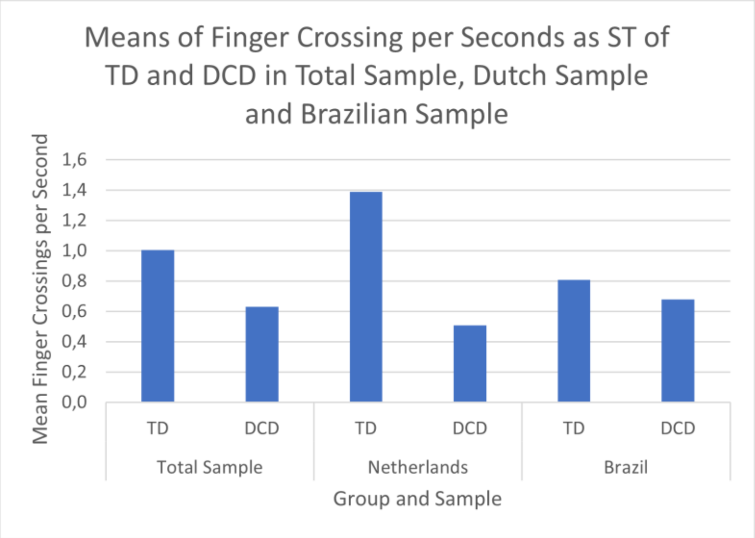
Results

3.1 Results of statistical analysis

Regarding the M-ST, a significant effect for group, $t(97.903) = 4.682$, $p < 0.001$, was found in the total sample. The TD children (M = 1.01, SD = 0.52) had significantly higher means of finger-crossings per second than the children with DCD (M = 0.63, SD = 0.32), indicating worse fine motor performance across children with DCD. Further, a t-test of independent samples was conducted with a split file to assess performance on the ST measure of finger-crossing among groups between cultures. In the Dutch sample, the difference between groups on ST measures of finger-crossing was significant, with $t(34) = 5.055$, $p < 0.001$, Cohen's d = -1.245. However, in the Brazilian sample, the ST measure of finger-crossing yielded an insignificant effect between groups, with $t(77) = 1.865$, $p = 0.066$, Cohen's d = -0.329. For visualization of M-ST means in the total sample, Dutch sample, and Brazilian sample, see Figure 1.

Figure 1.

Means of Finger-Crossing per Second in Single-Task Condition per Group in all Samples

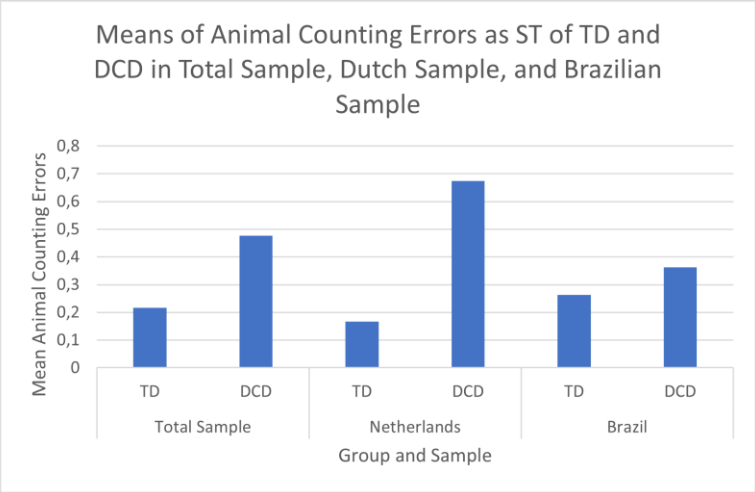


Note: ST = Single-Task, TD = Typically Developing, DCD = Developmental Coordination Disorder; A lower mean indicates fewer finger-crossings per second and thus worse performance.

For the performance on the C-ST, a significant effect was found in the total sample, with $t(137) = -2.873$, $p = 0.005$. The TD children (M = 0.22, SD = 0.41) showed significantly fewer counting errors when compared to the children with DCD (M = 0.48, SD = 0.64), indicating worse cognitive performance across children with DCD. A t-test of independent samples with a split file was used to assess performance on the C-ST among groups between cultures. It revealed a significant effect of group in the C-ST in the Dutch sample, with t(25.9) = -2.945, $p = 0.007$, Cohen's d = -1.266. Again, an insignificant effect on this ST measure between groups was found in the Brazilian sample, with t(78) = -0.883, $p = 0.380$, Cohen's d = -0.345. For visualization of C-ST means in the total sample, Dutch sample, and Brazilian sample, see Figure 2.

Figure 2.

Means of Animal Counting Errors in Single-Task Condition per Group in all Samples

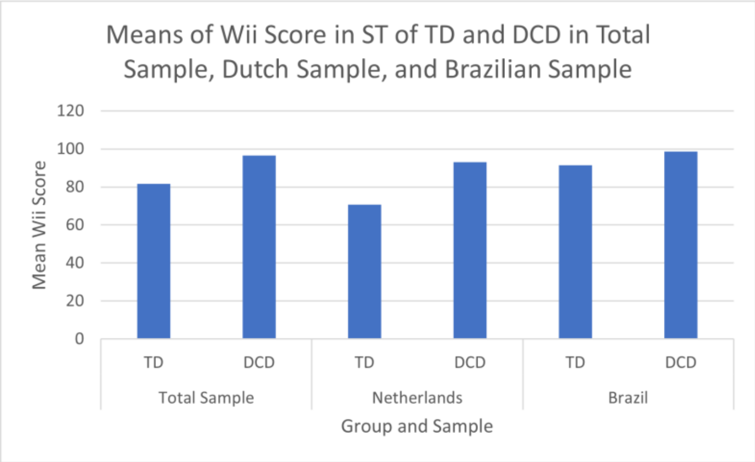


Note: ST = Single-Task, TD = Typically Developing, DCD = Developmental Coordination Disorder; A lower mean indicates fewer counting errors and thus better performance. A higher mean indicates more counting errors and thus a worse performance.

The performance on the Wii ST also showed a significant effect for group in the total sample, with $t(138) = -4.059$, $p < 0.001$. The TD children (M = 81.61, SD = 22.43) showed a significantly lower Wii Fit score when compared to the children with DCD (M = 96.46, SD = 20.51), indicating poorer gross motor performance across children with DCD. A significant difference between groups was found on Wii ST performance in the Dutch sample, with t(58) = -4.726, $p < 0.001$, Cohen's d = -1.823. Nonetheless, no significant differences between groups were found in the Brazilian sample, with t(78) = -1.471, $p = 0.145$, Cohen's d = -0.220. For visualization of Wii ST means in the total sample, Dutch sample, and Brazilian sample, see Figure 3.

Figure 3.

Means of Wii Fit Score in Single-Task Condition per Group

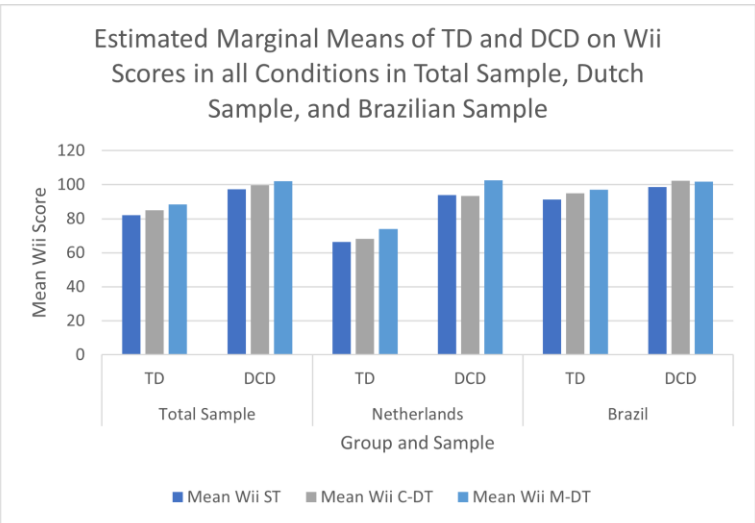


Note: TD = Typically Developing, DCD = Developmental Coordination Disorder; A higher score indicates poorer performance.

The GLM Repeated Measures with a Greenhouse-Geisser correction yielded a significant main effect of condition (Mean Wii score ST, Mean Wii score C-DT, Mean Wii score M-DT), with F(1.894, 223.437) = 7.649, $p < 0.001$. The difference between means was moderate (partial $\eta^2 = 0.061$). The analysis yielded a non-significant interaction effect of condition*group, with F(1.894, 223.437) = 0.184, $p = 0.820$, connoting a similar pattern of performance decrements in TD children and children with DCD across all conditions (see Figure 4). The difference between means was relatively small (partial $\eta^2 = 0.002$). To compare the results across cultures (NL, BR), a further GLM Repeated Measures was performed using participants' country of origin as a further between-subject factor besides group (TD, DCD). The analysis yielded an insignificant main effect for the Wii condition (mean of Wii Fit ST, C-DT, and M-DT) with F(2, 114) = 0.778, $p = 0.462$. The difference between means was small partial (partial $\eta^2 = 0.013$). There was no interaction effect between Wii condition and group (TD, DCD) found with F(2, 114) = 0.060, $p = 0.942$. The difference between means was small (partial $\eta^2 = 0.001$). Also, there was no interaction effect for Wii condition and culture (NL, BR) with F(2, 114) = 2.515, $p = 0.085$. The difference between means was small (partial $\eta^2 = 0.042$). However, in tests of within-subjects contrast, the interaction between Wii condition and culture (NL, BR) had a significant quadratic relation, with $F(1, 115) = 4.475$, $p = 0.037$. The difference between means was small (partial $\eta^2 = 0.037$). This quadratic relation indicates that the direction of scores differs across cultures. From these results, it can be deduced that the Dutch sample remained consistent in performance from Wii ST to C-DT but showed decreased performance in the M-DT. On the other hand, the Brazilian sample showed decrements in performance in both DT conditions (C-DT and M-DT) compared to the ST condition. Between-subjects effects showed that culture (NL, BR) itself had a significant effect with $F(1,115) = 5.193$, $p = 0.025$. The difference between means was small (partial $\eta^2 = 0.043$). Also, the between-subject effects of group were significant with $F(1,115) = 19.806$, $p < 0.001$. Here, the difference between means was large (partial $\eta^2 = 0.147$). Further, the between-subjects interaction effect of study and group was significant as well, with $F(1,115) = 6.570$, $p = 0.012$. The difference between means was small (partial $\eta^2 = 0.054$). These results suggest that both groups differ significantly per culture in their performance.

Figure 4.

Estimated Marginal Means on Wii Fit Scores Across all Wii Fit Conditions per Group and Sample

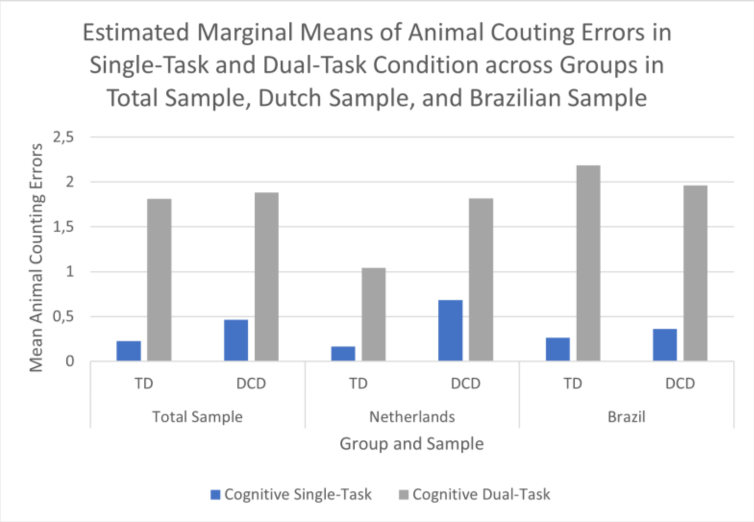


Note: TD = Typically Developing, DCD = Developmental Coordination Disorder, ST = Single-Task, C-DT = Cognitive Dual-Task, M-DT = Motor Dual-Task; A higher score indicates poorer performance.

To assess group differences in animal counting errors between the C-ST versus C-DT, a repeated-measures ANOVA with assumed sphericity yielded a significant main effect for the condition, with $F(1, 111) = 136{,}672$, $p < 0.001$, indicating worse performance in the DT compared to the ST condition. The difference between means was large (partial $\eta^2 = 0.552$). However, no interaction effect of condition*group, with $F(1, 111) = 0.427$, $p = 0.515$, was found, showing that the pattern of decreased performance in the C-DT compared to the C-ST remained similar in both groups. The difference between means was minimal (partial $\eta^2 = 0.004$). To assess cultural differences and group differences in animal counting errors between the C-ST versus the C-DT, a repeated-measures ANOVA was performed to compare the effects. It yielded a significant main effect for condition (C-ST, C-DT), with $F(1,113)=6.924$, $p = 0.010$. The difference between means was small (partial $\eta^2 = 0.049$). Also, a significant interaction effect between condition and study was found, with $F(1,113) = 6.617$, $p = 0.011$. The difference between means was small (partial $\eta^2 = 0.047$). However, the interaction effect between condition and group was insignificant, with $F(1,113)=0.053$, $p = 0.817$. The difference between means was small (partial $\eta^2 = 0.000$). Tests for between-subjects effects show that culture (NL, BR) yielded insignificant results, with $F(1,133) = 0.787$, $p = 0.377$. The difference between means was small (partial $\eta^2 = 0.006$). However, a significant between-subjects effect for group (TD, DCD) was found, with $F(1,133) = 4.714$, $p = 0.032$. The difference between means was small (partial $\eta^2 = 0.034$). Lastly, the interaction effect between culture and group yielded significant results, with $F(1,133) = 7.117$, $p = 0.009$. The difference between means was small (partial $\eta^2 = 0.05$).

Figure 5.

Estimated Marginal Means of Cognitive Single- and Cognitive Dual-Task per Group and Sample



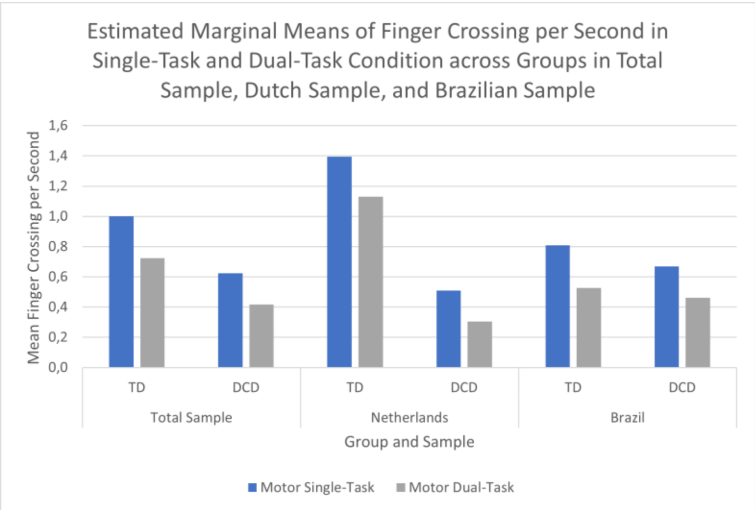
Note: TD = Typically Developing, DCD = Developmental Coordination Disorder; A higher score indicates more errors made.

Regarding the assessment of group differences in finger-crossing per second between the M-ST versus the M-DT, the GLM Repeated Measures with assumed sphericity also found a significant main effect in finger-crossing per second for condition (M-ST versus M-DT), with $F(1, 111) = 107.984$, $p < 0.001$, indicating poorer performance on the DT condition than on the ST condition. The difference between means was large (partial $\eta^2 = 0.493$). No interaction effect of condition*group $F(1,111) = 2.253$, $p = 0.136$ was found, suggesting similar performance patterns across groups. The difference between means was small (partial $\eta^2 = 0.020$). A further GLM Repeated Measures was performed to compare the effects of M-ST versus M-DT across cultures. The analysis yielded an insignificant main effect for condition, with $F(1, 108) = 2.583$, $p = 0.111$. The difference between means was small (partial $\eta^2 = 0.023$). Also, the interaction effect of condition*culture was insignificant, with $F(1, 108) = 2.653$, $p = 0.106$. The difference between means was also small (partial $\eta^2 = 0.024$).

Moreover, the interaction between condition and group showed no significant effect, with $F(1, 108) = 0.878$, $p = 0.351$. The difference between means was small (partial $\eta^2 = 0.008$). Tests for between-subjects effects reveal that culture (NL, BR) has no significant effect, with $F(1, 108) = 0.591$. $p = 0.444$. The difference between means was small (partial $\eta^2 = 0.005$). However, a significant effect of group was found, with $F(1, 108) = 45.706$, $p < 0.001$. The difference between means was large (partial $\eta^2 = 0.297$). Lastly, the interaction effect between study and group yielded significant results, with $F(1, 108) = 25.450$, $p < 0.001$. The difference between means was moderate (partial $\eta^2 = 0.191$).

Figure 6.

Estimated Marginal Means of Motor Single and Motor Dual-Task per Group



Note: TD = Typically Developing, DCD = Developmental Coordination Disorder; A higher score indicates better performance.

In the t-test for independent samples assessing the DT costs, no significant effect was found between groups for cognitive costs in the entire sample or the Dutch or Brazilian sample (see Table 2). These results imply no significant difference between TD children and children with DCD in the cognitive costs while playing the Wii Fit ski slalom game.

Likewise, no significant group differences were found for motor costs in either sample. Moreover, there was no significant effect between groups for animal counting error costs in either sample. Correspondingly, no significant group differences were found for finger-crossing costs in the total sample, the Dutch sample, and the Brazilian sample. Although no significant effect was found for any of the DT-costs, it should be noted that the effect size for finger-crossing costs was more prominent than those for the other cost variables (Cohen's d = 0.282). Thereupon, no significant difference in costs between groups nor across cultures was found.

Table 2.

Mean (SD) of DT costs (Wii Cognitive Costs, Wii Motor Costs, Animal Counting Error Costs, and Finger-Crossing Costs) and the corresponding t-values, p- values, and Cohen's d effect sizes of the juxtaposition of groups (TD and DCD) in all samples.

Costs	Sample	TD	DCD	t-value	p-value	Effect size (Cohen's d)
Wii Cognitive Costs	Total	-1.17 (13.46)	-2.12 (14.69)	0.400	0.690	0.068
	NL	1.6 (12.41)	0.7 (16.06)	0.243	0.809	0.064
	BR	-3.7 (14.03)	-3.8 (13.74)	0.050	0.961	0.011
Wii Motor Costs	Total	-6.46 (16.16)	-4.81 (16.19)	-0.559	0.577	- 0.102
	NL	-7.6 (18.29)	-8.7 (19.19)	0.184	0.855	0.059
	BR	-5.8 (14.95)	-3.3 (14.82)	-0.761	0.449	-0.170
Error Costs	Total	-1.43 (1.17)	-1.44 (1.47)	0.035	0.972	0.006
	NL	-0.9 (0.97)	-1.1 (1.51)	0.666	0.510	0.218
	BR	-1.9 (1.12)	-1.6 (1.45)	1.365	0.176	-0.251
Finger-crossing costs	Total	0.28 (.25)	0.21 (.24)	1.501	0.136	0.282
	NL	0.3 (0.27)	0.2 (0.26)	0.807	0.423	0.226
	BR	0.3 (0.25)	0.21 (0.24)	-1.124	0.264	0.309

Note: NL = the Netherlands, BR = Brazil, TD = Typically Developing, DCD = Developmental Coordination Disorder

3.2 Results of Behavioral Observations

Behavioral observations of the video recordings of the Brazilian sample revealed that TD children showed a higher capability of performing the M-DT assignments (Wii Fit Ski Slalom game + finger-crossing) simultaneously. In contrast, children with DCD switched back and forth between tasks. Precisely, multiple children with DCD paused the finger-crossing movements when focusing on the Wii Fit Ski Slalom game and then switched their attention to the finger-crossing but stopped movements on the Wii Fit. This behavior of switching between tasks did not occur in the TD children, who performed both tasks at the same time.

Discussion

The present study assessed differences between TD children and children with DCD on dual-task performance and compared results across cultures. The present study found significant differences between TD children and children with DCD in ST performance in the entire sample, in the Dutch sample, but surprisingly not in the Brazilian sample. Further, analyses revealed no differences in performance patterns between TD children and children with DCD in DT, although the performance was on a different level between groups. However, differences in performance patterns were found in DT performance abatements across cultures. Also, behavioral observations of the DCD sample on DT performance provide endorsement of the *automatization deficit hypothesis* (Nicolson & Fawcett, 1990). Nonetheless, differences in performance between ST, C-DT, and M-DT were found in the entire sample, supporting the notion of Wicken's 4D multiple resource model (Wickens, 2008) and CMI (Abbruzzese et al., 2014; Mitra et al., 2013). No differences in dual-task costs were found in either sample, indicating that even though performance is on a lower level in children DCD, the patterns of facilitation and deteriorating remain the same across groups.

As previously stated, the results of this study support the first hypothesis, namely that children with DCD exhibit significantly diminished performance on all ST measures (Wii ST, C-ST, and M-ST) than TD children. TD children have significantly higher means in the M-ST condition, indicating better performance. The inferior scores of children with DCD are in line with previous literature attributing such deficits to decreased fine motor skills (APA, 2013; Smits-Engelsman et al., 2001). The TD group also exhibits significantly fewer errors in the C-ST, suggesting better performance than children with DCD. The aforementioned cognitive deficits experienced by children with DCD, specifically in EFs (Schott & Holfelder, 2015; Wilson et al., 2012), likely account for these significant differences in a cognitive task. TD children also show significantly lower scores on the Wii ST, implying better attainment on this measure when compared to children with DCD. This finding aligns with the general assumption that children with DCD experience gross motor deficits (Barnhart et al., 2003; Marinov et al., 2015). Unexpectedly, when comparing both groups' single-task performance across cultures, the Brazilian sample showed no significant differences between groups in all ST conditions, while the Dutch sample did. These results show that while differences were found in the whole sample, this was not the case when looking into more detail within subgroups. However, the discrepancy between effects per culture can be explained by various factors. The results show that the TD group in Brazil did not perform as well as the TD group in the Netherlands, while the DCD groups of both cultures performed similarly on all ST measures. These findings indicate that the differences do not lie between the DCD groups; instead, the findings imply that the TD groups differ across cultures. One possible explanation is that TD children from Brazil may get fewer opportunities to engage in motor behavior

(Spessato et al., 2013) than Dutch TD children and are thus hindered in reaching similar motor proficiency levels compared to children from Western cultures (Saccani & Valentini, 2013; Santos et al., 2001). Previous literature suggests that more than 200 million children in developing countries, including Brazil, are unable to achieve the anticipated level of development appropriate for their age (Grantham-McGregor et al., 2007; Walker et al., 2011). Moreover, more than 11 percent of births in Brazil are premature, which is a significant risk factor for subsequent developmental abnormalities resulting in cognitive and motor problems (Panceri et al., 2020). Children were grouped into the TD and DCD groups based on their scores on the MABC-2. Thus, the STs and DTs may require additional resources responsible for the differences in TD groups across cultures than the motor tasks of the MABC-2. These factors may explain why Brazilian children initially considered as TD might have more problems on all single-task measures than TD children in the Netherlands.

Surprisingly, the results of this study cannot provide supporting evidence for the second hypothesis; thus, for performance pattern differences between groups on the Wii score in an ST condition, Wii score in a C-DT condition, or Wii score in an M-DT condition. Thus, children with DCD do not show significantly different performance patterns in different conditions than TD children; however, children with DCD generally show significantly lower performance levels. However, a significant effect of condition (Wii Fit ST, C-ST, and M-DT) was found, showing that the single-task is less difficult for both groups, followed by increasing performance decrements with the added cognitive task, and most significant difficulty with the added motor task. It was expected that children with DCD differ significantly from TD children in the M-DT, while there are also group differences in the C-DT, although to a lesser extent as in the M-DT, which is in line with the present findings. Moreover, no evidence for group differences between TD children and children with DCD was found in the performance patterns of the secondary task in ST or DT conditions (C-ST &

C-DT, M-ST & M-DT), while the performance of children with DCD is generally lower than that of TD children. Although a significant effect between conditions was found, no interaction effect between group (TD, DCD) and condition emerged. Since there were differences in the C-DT and M-DT in both investigations of the primary and secondary tasks but with no differences between groups, the third hypothesis cannot be confirmed either. However, these findings align with the general assumptions of CMI and Wicken's 4-D multiple resource model for the entire sample. Both groups showed decreased performance in the C-DT compared to the C-ST; thus, the assumption of both attentional exigencies competing is supported. The assumption of Wicken's 4D multiple resource model is in line with the present study's findings as well, as both groups showed the strongest performance abatements in the M-DT. Conversely, Cherng and colleagues (2009) opposed Wicken's 4D multiple resource model and found higher performance decrements on cognitive-motor dual-task paradigms in children with DCD than motor-motor dual-task paradigms, implying that CMI has a more substantial influence on performance outcomes than competing attentional resources from the same pool. The present study's findings contradict Cherng et al.'s (2009) conclusions; therefore, further research into whether CMI or interference due to contending attentional demands as stated by Wicken's 4D multiple resource model has more potent effects on TD children and children with DCD is warranted to investigate this question. Comparing the results on DT performance across cultures has shown that multivariate tests remained insignificant; notwithstanding, a significant quadratic interaction between Wii condition and culture was found. This finding strongly indicates that the direction of performance improvements and decrements differ between cultures. While the Dutch sample showed consistent performance between the Wii ST and C-DT but performance aggravation in the M-DT, the Brazilian sample showed similarly strong deterioration patterns of performance in both DT conditions compared to the ST. Further, between-subject effects have shown a significant effect for culture (NL, BR) and a significant effect between groups (TD, DCD). Also, a significant interaction between culture and group was found, demonstrating that both groups differ significantly per sample.

The third hypothesis involving DT costs could not be confirmed. In all measures of DT costs, namely cognitive costs, motor costs, error costs, and finger-crossing costs, no significant differences were found between groups. This finding implies that even though general performance differs significantly between groups, the pattern of interference or facilitation imposed by secondary tasks did not differ. A recent study by Jelsma and colleagues using an identical dual-task paradigm set-up in their study achieved similar results, indicating no significant difference in dual-task costs between children with DCD and TD children. The same findings were reported when comparing these effects across cultures, with no significant differences in dual-task costs across groups and cultures. These findings suggest that even though significant cultural differences can be found in performance patterns, the costs imposed by the respective task do not differ across cultures.

The present study's results seem to present evidence for the *automatization deficit hypothesis* (Nicolson & Fawcett, 1990), stating that children with DCD exhibit problems in automatizing motor skills. Effect sizes found in analyses of the DT costs revealed that finger-crossing performance suffered most from an additional task, marking the automatization deficit. Also, behavioral observations of the children's performance show that they stopped crossing fingers when focusing on the Wii Fit ski slalom game and subsequently stopped movement on the Wii Fit when focusing on the finger-crossing. A repetitive movement as finger-crossing can be automatized to some extent in TD children even after a few training sessions, while children with DCD require constant visual feedback to monitor their movements. Thus, it might be highly advantageous to present children with DCD with more visual input and provide constant visual feedback to facilitate their performance in everyday life settings and academic performance. In school and therapeutic settings, it might be possible to implement visual feedback via a screen (e.g., smartphone, tablet, laptop) in a manner that they can purely focus on the task they are working on and do not need to switch back and forth between tasks to monitor their behavior visually. Such interventions could also help to encounter the lack of automatization in motor performance of children with DCD, which can become apparent in school settings (e.g., handwriting). It may also be crucial raising awareness in parents and teachers about these findings as they may have significant consequences in daily life activities. For example, caution might be needed when letting a child with DCD drive a bike without consistent monitoring. Although TD children may automatize the leg movements when cycling, this repetitive movement might not be automatized in a child with DCD. Thus, when attention is drawn to the movement and even visually controlled for, the child is possibly unable to focus on the surrounding environment (e.g., traffic, pedestrians), and accidents may occur. As children with DCD seem to suffer from deficits in automatization and thus experience problems in directing attention to multiple tasks simultaneously, it may also be beneficial to present them with only one task or topic at a time, as well as finishing one task before starting a new one, specifically in school settings. Additional tasks may be presented once the initial task is practiced sufficiently. Further, recent literature suggests presenting variable tasks to children with DCD to enhance favorable conditions for learning how to coordinate behavior on two simultaneous tasks (Jelsma et al., 2021). The suggestions based on the present study's findings can assist caretakers, therapists, and teachers when making decisions about possible interventions for children with DCD. Future research investigating the involvement of the cerebellum in dual-task performance in TD children and children with DCD is warranted to investigate the relationship between DCD symptomatology and the automatization hypothesis.

The cultural differences found between the Netherlands and Brazil suggest the need for further research centered around cultural differences not only in children with DCD but also in TD children. First, an urgent demand for ecological studies must be noted to establish the epidemiological prevalence of DCD but also of atypical development in general across different countries. As the present study's findings showed, single-task performance did differ between children with DCD and TD children in the Dutch sample but not in the Brazilian sample. These differences lie between the typically developing children across both cultures, not between the disorder groups. Unexpected findings like these can aid culture-appropriate interventions aimed at the specific desideratum of different countries. For example, in Brazil, it may be desirable to introduce screening tools for atypical development available to all children in preschool age, as a high number of children considered to be typically developing actually suffers from developmental shortcomings in motor and cognitive abilities (Grantham-McGregor et al., 2007; Walker et al., 2011). Thus, screening for such problems and intervening at an early, possibly even preclinical stage, could help to reduce the enormous prevalence of developmental complications in developing countries. Subsequently, it is also of great importance to establish the prevalence of DCD in developing countries instead of relying solely on the incidence in Western, high-SES countries. Also, socioeconomic, and sociocultural factors may cause children to have distinct experiences in different countries. For instance, children from very low-income families in developing may have no experience with playing video games on non-mobile devices like the Wii Fit (Ghedin, 2021) compared to children from industrialized countries (De Vet et al., 2012). None of the Brazilian children had previous experience with the Wii Fit in the present study.

A vital strength of the present study involves its methodology, specifically the well-selected research design. As previously mentioned, the present study is part of a larger research project involving further measures on children with DCD. The selection and composition of all STs, the C-DT, and the M-DT were conducted with great care and based on previous literature findings. For example, the Wii Fit Balance Board was employed, as previous literature has found it to yield high reliability and validity for measuring balance (Jelsma et al., 2021; Jelsma et al., 2016) and, therefore, gross motor abilities. The finger-crossing task was chosen as it assesses fine motor skills, while the animal counting task assesses cognitive ability. Both measures are feasible for children with typical development and DCD, with an IQ above 70. All measures used have been applied in recent research on the dual-task performance in children with DCD (Jelsma et al., 2021). A further strength of the study is the high interrater percentage of agreement. Multiple researchers evaluated the videotapes of participants performing the finger-crossing single-task and the motor dual-task to count the number of finger-crossing, and a percentage of agreement of 89 percent was obtained. When multiple raters are involved in evaluating participants, a high agreement is of enormous significance, as this indicates consistency across the raters' appraisals of participants' behavior (Goodwin, 2001). Lastly, a further advantage of the study design is the high ecological value. All assessments took place in the children's own school environment, for both groups (TD, DCD) and in both cultures (NL, BR). Consequently, the participating children knew the environment, and it did not feel unfamiliar or intimidating. Especially in research involving children, it is valuable to conduct assessments in familiar environmental contexts resulting in unconstrained and confident behavior during assessments which is often not the case when assessing children in unfamiliar laboratory settings (Fargas-Malet et al., 2010; Sbordone & Long, 1996).

Although the assessment in the children's school implicates a considerable advantage for the study, it also provoked limitations of the present research. First, in the Brazilian sample, the implementation of assessments was inconsistent. Through observation of the videos, it was discovered that in Brazil, irregular duration of breaks between assessments occurred, some children ate during breaks or even during assessments, and there were numerous disturbing background noises. The irregular duration of breaks and incidences of eating during assessments cause the assessment procedure to be unstandardized in the Brazilian sample. Also, in Brazil, some children's single-task assessments were conducted in the same room and at the same time as other children performed on dual-task assessments. This distraction may have affected children's performance in single-task measures as they possibly also paid attention to different stimuli in their environment (e.g., Wii noises, other children, instructors talking to different children). As the single-task performance was assessed, no distractors were supposed to direct the participants' attention to other stimuli; hence, it is difficult to determine whether the single-task measures were not an unintentional dual-task as attention was divided between the ST and the distractors. A further shortcoming of the present study involves that IQ scores were only assessed for the children with DCD in the Netherlands but not in Brazil. However, as the children in Brazil were recruited from a public school and not a special education school as in the Netherlands and had not repeated a class, it can be strongly assumed that the participants had the intellectual capabilities to partake in the study. Thus, it is possible that in the public school with no focus on special education, the prevalence of children with cognitive deficits caused by abnormal development, and possibly a lower IQ, may be higher than in public schools in Western, wealthy countries such as the Netherlands. Further, classification into the group of TD children required teacher and parent reports indicating an age-appropriate developmental course. Nonetheless, future research should incorporate all inclusion criteria in all assessed groups to accomplish certain comparability of groups. Also, it is possible that the DCD group was mixed, more precisely, that children were included in the present study that only satisfied inclusion criteria because of impaired development predicated on socioeconomic, sociocultural, or environmental factors. Lastly, it may be a shortcoming that the scores of Brazilian children on the M-ABC 2 were compared to UK norms. Although a validated cultural adaptation of the MABC-2 exists for Brazil (Valentini et al., 2014), there are no reference norms for the country available to date. The literature suggests that using norms from different countries to assess other cultures is possibly inappropriate and results in bias, even when both countries lie closely together (Dunn et al., 1994; Niemeijer et al., 2015). In the case of the present study, the UK is a highly industrialized, wealthy, European country, while Brazil is a developing, emerging country in Latin America. Thus, cultural differences between the actual norm values may be present.

The present study investigated differences in single- and dual-task performance and dual-task costs in typically developing children and children with DCD and compared results across cultures. The statistical results and behavioral observations found in the present research provide indications for an automatization deficit as an etiological basis of DCD. The evidence for the *automatization deficit hypothesis* can aid future interventions, as providing visual feedback to children with DCD, specifically in school and home settings. Analyses of dual-task performance revealed evidence for Wicken's 4-D multiple resource model and CMI in the entire sample, but no differences were found between TD children and children with DCD. Comparing dual-task performance in children from the Netherlands and Brazil revealed distinct performance patterns. These differences across countries suggest a crucial demand for further ecological studies involving different cultures, specifically including samples from developing countries. Screening tools for developmental abnormalities within children with DCD but also typically developing children are needed to provide valuable interventions at an early and possibly preclinical stage.

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Appendix A

Visualization of the finger-crossing task

Figure 7.

Starting position in the finger-crossing task

Figure 8.

Finger-crossing position after one completed movement

Appendix B

Calculation of the percentage of agreement

The total number of agreements is divided by the total number of ratings. Finally, the result is multiplied by 100 to calculate the percentage (CTSpedia, 2010).

$$71 \div 80 = 0.8875$$

$$0.8875 \times 100 = 88.75\%$$