Exploring the Complexities of Divided Attention in Children with Developmental Coordination Disorder: A Multisensory Approach.

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Abstract

Introduction: This study aims to investigate the intricate relationship between divided attention and developmental coordination disorder (DCD). Firstly, children were assessed whether they have difficulties with divided attention and if performance differs between an auditive-auditive divided attention task and an auditive-visual divided attention task. Additionally, the relationship between divided attention and motor performance was investigated, and whether cognitive dual tasks were related to motor dual tasks.

Method: Twenty-three children, aged between 6 to 12 years, who were diagnosed with or showing symptoms of DCD participated in this study. Participants were assessed on divided attention measured by TEA-Ch and motor assessments measured by MABC-2 and PER-FIT.

Results: Children with DCD performed significantly below norm groups on divided attention. More children with DCD performed worse on the auditive-auditive divided attention task compared to auditive-visual divided attention tasks. However, no significant correlation was found between divided attention and motor performance. Additionally, no correlation was found between cognitive dual tasks and motor dual tasks, although a trend was found between 'Stepping in Ladder' and the single sensory divided attention task.

Conclusion: Clinical implications suggest educating parents and teachers about the challenges children with DCD face with divided attention, taking this into account they can create supportive learning environments using the multi-sensory approach. Overall, while this study sheds light on the complexity of divided attention and DCD, further research is needed for a comprehensive understanding and possibly develop an effective treatment for divided attention in children with DCD.

Keywords: Developmental coordination disorder, divided attention, multiple resource model, motor dual tasks.

Introduction

Developmental Coordination Disorder (DCD) affects one in twenty children. It is a neurodevelopmental disorder characterized by an impaired ability to learn and execute coordinated motor skills effectively (DSM-5; American Psychiatric Association, 2013). Children with DCD have problems with daily activities, school performance, and play. These difficulties in motor and psychosocial functioning in children with DCD can have significant impact on children's quality of life (Caçola & Killian, 2018; Zwicker et al., 2012; Zwicker et al., 2017), and tend to persist in adulthood (Kirby et al., 2013; Kirby et al., 2014). While DCD is mostly associated with motor impairments, children with DCD also show problems with cognitive functions as planning, working memory, inhibitory control, and cognitive flexibility (Asonitou et al., 2012; Sartori et al., 2020). Cognitive challenges have a notable impact on the interference experienced in daily activities (APA, 2013). The relationship between attention and motor performance shows a substantial relationship, as evidenced by Fliers et al. (2010) and Kaiser et al. (2015), reporting a significant co-occurrence rate of 50% with Attention Deficit Hyperactivity Disorder (ADHD).

Divided attention

Divided attention refers to the cognitive ability to simultaneously focus on and process multiple tasks, without a significant performance decline. In situations where diverse information demands sources concurrently, divided attention is crucial. Most children use divided attention combined with motor tasking easily in daily situations, such as stair walking while talking to peers. Over time, typically developing children become accustomed to the regular height of stairs. However, when faced with unexpected change in height, like encountering a step that is taller or shorter than usual, they often stumble. This is because their internal model of the expected sensory feedback is a mismatch with the actual sensory feedback. This misstep demands rapid adjustment of movement, which requires extra attention to foot placement. Typically developing children have sufficient motor and attention skills and therefore can walk stairs without falling under normal circumstances. However, when their attention is divided due to talking, their performance on the physical task may be compromised, especially when unexpected changes in step height are introduced. This dual-task paradigm shows that divided attention is crucial for individuals to effectively allocate cognitive resources to multiple simultaneous tasks.

However, according to the multiple resource model, dual task performance is often compromised when two tasks are using the same processing resources (Wickens, 2002). For instance, when two tasks require the use of the same processing resources, such as visual or auditory processing, it can lead to a decline in overall performance. To illustrate this point, consider the scenario where a driver is attempting to multitask. If both the tasks require visual processing, such as reading instructions and paying attention to the road, the demands on the visual processing resources are intensified. The driver may experience a decline in driving performance because attention must be divided between multiple visual tasks. Whereas dual tasking can be more successful when tasks utilize different processing resources. For example, when a driver is listening to instructions rather than reading them visually.

Divided attention and DCD

In children with DCD, poor motor performance is associated with attention and executive functioning (Asonitou et al., 2012; Bernardi et al., 2017; Leonard & Hill, 2015; Pratt et al., 2014). Recent studies by Jelsma et al. (2021, 2023) showed that children with DCD exhibit more omissions of visual and auditory stimuli during divided attention tasks, indicating an attention deficit in DCD. A possible explanation for the relation between attention and DCD is provided by the automatization hypothesis. This suggests that tasks become automatic for typically developing children but remain effortful for those with DCD. Reduced automatization in children with DCD leads to an increased demand on attentional resources and potential cognitive overload, resulting in attention deficits and difficulties with dual tasks (Zwicker et al., 2010).

For this thesis, children with DCD will undergo two cognitive dual tasks, involving one auditive-auditive task and one auditive-visual task. Following the multiple resource model, children with DCD may perform worse on the auditive-auditive dual task, due to shared resource modalities, resulting in cognitive overload and thus performance will be compromised on one or both tasks. Conversely, the automatization theory posits that children with DCD, lacking automatization, experience increased demands on attentional resources during motor tasks. The non-automated motor component in the auditive-visual dual task may lead to an increased demand on attentional resources and cognitive overload, which in turn can lead to attention deficits and difficulties in dual tasking.

In summary, the multiple resource model predicts worse performance on auditive-auditive dual tasks for children with DCD, while the automatization theory suggests poorer performance on auditive-visual dual tasks due to the motor component in this task. Although previous research has established that children with DCD perform worse on divided attention task compared to typically developing children (Jelsma et al., 2012; 2023), an exploration into the various recourse modalities is lacking. This gap is addressed by examining whether children with DCD will perform worse on the auditive-auditive dual task and auditive-visual dual task than typically developing children and whether children with DCD seem to have more problems with one of the dual tasks compared to the other one.

Divided attention and motor performance

It is widely known that children with DCD are less attentive in general than their peers (Dewey et al., 2002; Tseng et al., 2007). Inattention in children with DCD may have a negative influence on their gross and fine motor performance. For example, children with DCD exhibited more postural sway (Laufer et al., 2008) and compromised walking pattern

(Cherng et al., 2009) during walking while being distracted with a cognitive task. Other research showed that greater mental focus during functional tasks of the Movement Assessment Battery for Children was positively associated with better motor performances in children with DCD (Fong et al., 2016). This relationship might be explained by overlapping brain regions in attention and motor functioning. Children with DCD show alterations of functional connectivity between M1 and several brain regions involved in motor functioning (e.g., insular cortices, caudate, putamen, globus pallidus, and inferior frontal gyrus) compared to typically developing children (McLeod et al., 2014). Abnormal connectivity between these different brain regions may contribute to the attention difficulties in this group of children. This may explain the relationship between divided attention tasks and motor performance. While it is widely recognized that children with DCD encounter problems related to both motor performance and attention deficits, the relationship between divided attention tasks and motor performance remains yet an unexplored area. This study will investigate whether children who exhibit poorer performance on divided attention tasks also demonstrate poorer results on motor performance.

Motor dual tasks and cognitive dual tasks

Children with DCD struggle to multi-task effectively when a challenging cognitive task disrupts performance in a physical task (Schott et al., 2016). When thinking about the previous mentioned example, where a child with DCD walks the stairs (physical task) while also engaging in a conversation with peers (cognitive task). Typically developing children may walk the stairs smoothly and talk without any issues. However, a child with DCD might encounter difficulties. They may stumble or lose their balance as they focus on keeping up with the conversation due to the lack of automaticity in stair walking. This example demonstrates how a cognitive challenge may disrupt physical performance, highlighting difficulties in children with DCD facing multi-tasking scenarios. Despite existing literature shedding light on challenges of both motor dual tasks and cognitive dual tasks independently, a comprehensive understanding of their potential relationship remains absent. This study will investigate the relationship between motor dual tasks and divided attention tasks, while also differentiating between the two types of divided attention tasks (cognitive dual tasks): auditive-auditive and auditive-visual. Through this exploration, we aim to explain the relationship between motor dual tasking and cognitive dual tasking.

Current study

It is crucial to understand the relationship between divided attention and DCD as it highlights the specific challenges faced by children with DCD in multitasking scenarios. The goal of this study is to have a better understanding of the complex relationship between divided attention and DCD, which may contribute to a more targeted comprehension of the cognitive-motor difficulties associated with DCD. Gaining insight of the multiple resource model on divided attention in children with DCD and understanding the relationship between divided attention and motor performance is essential for developing targeted interventions that enhance the daily functional skills of these children. Moreover, insight into this relationship can contribute to the development of more effective educational approaches and therapeutic strategies to improve the overall quality of life for children with DCD.

This study aims to explore divided attention in children with DCD. Therefore, the research questions for this research are (1) 'Do children with DCD perform worse on divided attention tasks, differentiating between different resource modalities, compared to typically developing children', (2) 'Is there a relationship between divided attention and motor performance in children with DCD?', and (3) 'Is there a relationship between motor dual tasks and cognitive dual tasks in children with DCD?'.

Methods

Participants

Twenty-three participants were eligible and actively took part in the study. One participant dropped out due to personal issues. The demographic details of the remaining participants are presented in Table 1. Recruitment was carried out through pediatric physiotherapy practices and (special) primary schools in the northern region of the Netherlands, constituting a non-randomized convenience sample. All participants ranged between 6 years and 12 years old. This age range was chosen with the recommendation to diagnose children with Developmental Coordination Disorder (DCD) at or after the age of six, as suggested by Blank et al. (2019). Inclusion criteria involved an IQ score above 70 points to avoid the potential impact of low intellectual functioning on neuropsychological test outcomes. Children were included in the study by screening their motor skills using the Movement Assessment Battery 2nd edition (MABC-2), with inclusion criteria being a score below the 17th percentile. Diagnosis of DCD was made based on meeting specific criteria including significant impaired coordination for their age, which impacted daily activities, with onset in early development, and not explained by another medical condition. These criteria are in line with the guidelines in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) for DCD (APA, 2013). Some children received confirmed DCD diagnoses, while others exhibited symptoms consistent with these criteria. Exclusion criteria encompassed the presence of medical diseases or neurological disorders, aside from DCD, influencing motor abilities. Many of these children already received physiotherapy. Upon receiving both oral and written explanation of the study, all parents of the participants provided written consent. Ethical approval was obtained from the Ethical Committee, (Code: PSY-2223-S-0438) and was conducted in accordance with the Helsinki Declaration.

Table 1:

Demographic information about the participants (N=23)

n	23
Mean age (years)	9 (1.8)[a] [6;12][b]
Mean length (cm)	143 (12.9)[a] [123;176][b]
Mean weight (Kg)	37.9 (11.2)[a] [21.3;63.3][b]
Gender (m)(%)	56.6
Type of school (%)	
Regular	47.8
Special	52.2

Note. Abbreviations: n (sample size), kg (kilogram), cm (centimeter).
[a] Standard deviation. [b] Range of data.

Design

Regarding the current research question, this study followed a cross-sectional research design. The variables in this research were divided attention (auditive-auditive, visual/auditive), motor performance and cognitive dual tasking. The data for these variables were assembled through field research.

Materials

This study is part of an intervention study where multiple neuropsychological tests, observation lists, and questionnaires were conducted. Only the tests that are relevant for these research questions are being reviewed and described in this thesis.

Neuropsychological Assessment

Divided attention

The Test of Everyday Attention for Children (TEA-Ch) is a norm-referenced performance task that measures four aspects of attention, including response inhibition, divided attention, sustained attention, and selective attention. The TEA-Ch consists of nine subtests with auditive as well as visual tasks. These tasks can range from simple listening tasks to more complex activities, like searching for specific symbols among distractors on a page. For this thesis, two subtests of the TEA-Ch are used to measure divided attention, called 'Sky Search Dual Task' and 'Score Dual Task'. In the 'Sky Search Dual Task' (auditive-visual), a child has to find and circle all the pairs of spaceships on a paper among unpaired spaceship distractors (visual task), while also counting the number of scorings sounds they hear (auditive task). The second dual task is the 'Score Dual Task' (auditive-auditive), where children again must count the scoring sounds (auditive), while also listening to a news report and calling the animal's name mentioned in the news report (auditive). Raw scores on these items are converted into scaled scores, which are determined by a corresponding normative table with the correct age range and gender. The higher the raw scores, the better children perform divided attention tasks. A detailed description of the TEA-Ch subtests is provided in Table A1, Appendix A. To estimate the reliability of the subtests, the intraclass correlation coefficient (ICC) is being used. Interpretation of the ICC is <0.4 poor, 0.5-0.75 moderate, 0.75-0.9 good, and >0.9 excellent reliability (Koo & Li, 2016). The ICC for 'Sky Search Dual Task is 0.4 and for 'Score Dual Task' is 0.66 (Fathi et al., 2016) which indicate poor reliability (.4) and moderate relatability (0.66). According to the 'Commissie Testaangelegenheden Nederland' (COTAN) the reliability and validity of the TEA-Ch are insufficient (Table B1, Appendix B). However, due to no other neuropsychological test available with the same measurement validity, the TEA-Ch was ultimately chosen.

Motor Skills Assessment

Children were included in the study by classification with the DCD criteria according to the DSM-5 (APA, 2013). DCD is characterized by the acquisition and execution of coordinated motor skills substantially below expected compared to peers. This deficit must significantly interfere with activities of daily living and the onset must be in the early developmental period. Additionally, the motor skill deficits should not be better explained by another impairment or disorder. To assess whether the child had motor impairments, the Movement Assessment Battery for Children-second edition (MABC-2) was used (Henderson, Sugden & Barnett, 2007). It comprises 8 items across three age bands, evaluating manual dexterity, ball skills, and dynamic balance. Performance was measured in terms of time taken and the number of correct and incorrect performances across the three areas. This research used standard scores, calculated by raw scores were transforming into standard scores using normative tables based on age and gender, with the highest raw score utilized for analysis. These standard scores were then converted to derive total and percentile scores, where a child had to perform below the 16^{th} percentile to be included in the study. The MABC-2 demonstrates robust reliability and validity, with excellent test-retest reliability (Wuang, Su & Su, 2012). Further details on the MABC-2 subtests can be found in Appendix B. Not all children who participated in the study were diagnosed with DCD, where some children only met the DSM-5 criteria for DCD.

Motor dual tasking

The results taken for motor dual tasks were derived from The Performance and FITness test (PER-FIT). This performance tasks discriminates between two subscales including: 'Agility and Power' and 'Motor Skill Performance' in children with and without DCD (Smits-Engelsman, 2018) Based on our research question, only exercises from the PER-

FIT that required divided attention in motor tasks were being used. These included ‘Running in Ladder’, ‘Stepping in Ladder’, ‘Side Jump’, ‘Jumping’, and ‘Hopping’. These exercises were included as a dual task, because children had to pay attention to the movement performed, but also had to pay attention to the foot placement in the agility ladder. In the exercises ‘Running in Ladder’, ‘Stepping in Ladder’, ‘Side Jump’ every child had two attempts, with a 15-second rest period between attempts. In the study, the best scores (fastest times adjusted for the number of errors with an additional 0.5 seconds per error) on these exercises were being used. An error for these exercises could have been, touching the yellow bar of the ladder with your foot, which indicated wrong foot placement. For the exercises ‘Jumping’, and ‘Hopping’, each child started at the easiest level. When achieving the maximum score on the first attempt, they did not have to do another attempt and proceeded to the next level. If not meeting the criterion after two attempts, the series ended. Each item on the PER-FIT included a practice trial along with two test trials, with the analysis based on the best score achieved. For further explanation of the exercises see Appendix C. The PER-FIT shows an exceptional reliability, with an excellent intraclass correlation coefficient (ICC) of 0.99, and an excellent test–retest reliability with an ICC of 0.80 (Smits-Engelsman et al., 2021). The assessment tool also has an excellent content validity and a good structural validity (Smits-Engelsman, Bonney, et al., 2020; Smits-Engelsman, Cavalcante Neto, et al., 2020).

Procedure

After the children were selected via exclusion and inclusion criteria and receiving informed consent. The tests were conducted in a small (class) room or in the gym at school. All testers were trained. The tests were conducted over approximately two days, each lasting between 40 to 50 minutes, within a two-week period. The assessment of the PER-FIT was conducted in pairs, while the MABC-2 and the TEA-Ch were administered individually.

Data-analysis

The data was processed using IBM SPSS Statistics 28. Initially, the descriptive statistics were computed to summarize participant characteristics, describing the mean, standard deviation, range, demographics, and clinical characteristics. The data was checked for normality using graphs across all variables, confirming overall normal distributions. The first research question is (1) whether children with DCD perform worse on divided attention tasks and whether performance varied across different resource modalities. To calculate this, the standard scores for both the auditive-auditive and auditive-visual dual tasks were categorized into 'normal', 'at risk' and, 'problem' groups. The range of the standard scores were between 1 and 20, with scores 1-5 indicating the 'problem group', 6-7 indicating 'at risk' group and 8-20 indicating the 'normal' group. The frequencies were then calculated for each group. The relationship between (2) divided attention and motor performance was measured with a Pearson correlation. The goal was to measure whether children who perform worse on divided attention also perform worse on motor performance. This relationship is calculated by the correlations of the two divided attention tasks (auditive-auditive and auditive-visual) (standard scores) and the variables of the MABC-2 (standard scores), including manual dexterity, ball skills, and dynamic balance and a total standard score. To measure whether there is a relationship between (3) cognitive dual tasks and motor dual tasks, the Pearson correlation was used. This was calculated by the correlations between the two cognitive dual tasks (auditive-auditive and auditive-visual) (standard scores) and motor dual tasks (in time and score), including 'Running in Ladder', 'Stepping in Ladder', 'Side Jump', 'Jumping', and 'Hopping'. A significance threshold of $\alpha < 0.05$ was applied. Missing data in the auditive-auditive dual task (1) and in the auditive-visual dual task (4), was not replaced with the item mean, because it did not make any difference to the results.

Results

Divided attention and DCD

Children with DCD scored worse on divided attention compared to the norm scores. However, the distribution of scores was large, where some children with DCD performed in the normal range on the divided attention tasks. Children with DCD seemed to perform worse on the auditive-auditive task compared to the auditive-visual task (table 2).

Table 2

Frequencies of children with DCD based on their scores on divided attention tasks.

	Auditive-visual (19)	Auditive-auditive (22)
Normal	6	5
At Risk	5	6
Problem	8	11

Divided attention and motor performance

The Pearson correlation analysis was used to examine the relationship between the results of children with DCD on the two divided attention tasks and the results on the MABC-2 subtests. The analysis revealed no statistically significant correlations (table 3). There was found a negative relationship between auditive-auditive divided attention task and 'Ball Skills' (r = -0.305, p = 0.168) auditive-auditive divided attention and the 'Total score' (r = -0.048, p = 0.833), auditive-visual task and 'Dexterity'(r = -0.071, p = 0.772), auditive-visual task and 'Ball Skills' (r = -0,012, p = 0.960), and auditive-visual divided attention task and 'Dynamic Balance' (r = -0.005, p = 0.984). Meaning that the higher performances on the divided attention task, the lower the scores on the MABC-2 subtests. There was a positive relationship between auditive-auditive divided attention task and 'Dexterity' (*r* = 0.118*, p* = 0.602), auditive-auditive divided attention task and 'Dynamic Balance' (*r* = 0.072*, p* = 0.751), auditive-visual divided attention task and 'Total score' (*r* = 0.042*, p* = 0.865). Meaning that the higher performances the divided attention task, the higher the scores on the MABC-2 subtests.

Table 3

Correlations divided attention and motor performance.

Divided attention task	**Subtest MABC-2**	**Pearson r**	**Significance (2-tailed)**	**n**
Auditive-auditive (SS)	Dexterity (SS)	0.118	0.602	22
Auditive-auditive (SS)	Ball Skills (SS)	-0.305	0.168	22
Auditive-auditive (SS)	Dynamic Balance (SS)	0.072	0.751	22
Auditive-auditive (SS)	Total score (SS)	-0.048	0.833	22
Auditive-visual (SS)	Dexterity (SS)	-0.071	0.772	19
Auditive-visual (SS)	Ball Skills (SS)	-0.012	0.960	19
Auditive-visual (SS)	Dynamic Balance (SS)	-0.005	0.984	19
Auditive-visual (SS)	Total score (SS)	0.042	0.865	19

Note. SS: Standard scores

Cognitive dual tasks and motor dual tasks

The Pearson correlation analysis was used to measure the correlation between the results of children with DCD on the two divided attention tasks and the results on the PER-FIT. There were no significant correlations found between the cognitive dual tasks (auditive-auditive or auditive-visual) and motor dual tasks, including: 'Running in Ladder', 'Stepping in Ladder', 'Side Jump', 'Jumping', and 'Hopping' (table 4). There seemed to be a trend between the variables 'Stepping in Ladder' and the auditive-auditive dual task (*r* = -0.368, *p* =

0.092) (table 4). This trend showed that the better the performances on the audutive-auditive dual task, the faster the children were in the ‘Stepping in Ladder’ task. There is a negative relationship between auditive-auditive divided attention task and ‘Running in Ladder’ (r = -0.310, p = 0.161), the auditive-auditive divided attention task and ‘Hopping Left’ (r = -0.021, p = 0.927), auditive-visual task and ‘Stepping in Ladder’ (r = -0.126, p = 0.607), and auditive-visual task and ‘Hopping Left’ (r = -0.058, p = 0.812). Meaning that the higher the score on the divided attention task, the faster the scores on the PER-FIT subtests. There is a positive relationship between auditive-auditive divided attention task and ‘Side Jump’ (r = 0.337, p = 0.125), auditive-auditive divided attention task and ‘Jumping’ (r = 0.039, p = 0.863), auditive-auditive divided attention task and ‘Hopping Right’ (r = 0.306, p = 0.116), auditive-visual divided attention task and ‘Running in Ladder’ (r = 0.015, p = 0.953), auditive-visual divided attention task and ‘Side Jump’ (r = 0.140, p = 0.568), auditive-visual divided attention task and ‘Jumping’ (r = 0.025, p = 0.918) and auditive-visual divided attention task and ‘Hopping Right’ (r = 0.122, p = 0.618). Meaning that the higher the score on the divided attention task, the higher the scores on the MABC-2 subtests.

Table 4

Correlations cognitive dual task and motor dual-tasks.

Divided attention task	Subtest PER-FIT	Pearson r	Significance (2-tailed)	n
Auditive- auditive (SS)	Running in Ladder (sec)	-0.310	0.161	22
Auditive- auditive (SS)	Stepping in Ladder (sec)	-0.368	0.092	22
Auditive- auditive (SS)	Side Jump (#)	0.337	0.125	22
Auditive- auditive (SS)	Jumping (#)	0.039	0.863	22
Auditive- auditive (SS)	Hopping Right (#)	0.306	0.166	22
Auditive- auditive (SS)	Hopping Left (#)	-0.021	0.927	22
Auditive- visual (SS)	Running in Ladder (sec)	0.015	0.953	19
Auditive- visual (SS)	Stepping in Ladder (sec)	-0.126	0.607	19
Auditive- visual (SS)	Side Jump (#)	0.140	0.568	19
Auditive- visual (SS)	Jumping (#)	0.025	0.918	19
Auditive- visual (SS)	Hopping Right (#)	0.122	0.618	19
Auditive- visual (SS)	Hopping Left (#)	-0.058	0.812	19

Note. The two divided attention tasks were translated into standard scores to measure the correlation (SS). Subtests of the PER-FIT were either measured in time in seconds (sec) or score measured in amount correct (#).

Discussion

A comprehensive exploration of the relationship between divided attention and DCD is crucial to uncover the challenges children with DCD face in multitasking scenarios. This study aimed to examine the relationship between divided attention and motor performance in children with DCD. The research addressed three questions (1) ‘Do children with DCD perform worse on divided attention tasks, differentiating between different resource modalities, compared to typically developing children’, (2) ‘Is there a relationship between motor performance and divided attention in children with DCD?’, and (3) ‘Is there a relationship between motor dual tasks and cognitive dual tasks?'. Our findings indicate that more children with DCD seem to perform worse on the auditive-auditive dual task than on the auditive-visual dual task. Next to this, performance on the two divided attention tasks did not seem to correlate with motor performance measured by the MABC-2. Additionally, there was no significant correlation found between motor dual tasks and cognitive dual tasks, shown by the correlation between the two divided attention tasks and subtests of the PER-FIT. However, a trend was found between 'Stepping in Ladder' and the auditive-auditive dual task.

Divided attention and DCD

Children with DCD performed worse on divided attention compared to norm-scores. This corresponds to previous research, where children with DCD performed worse on divided attention tasks than healthy controls (Jelsma et al., 2021; 2023). Next to this, more children with DCD seemed to have problems with auditive-auditive divided attention tasks than auditive-visual divided attention tasks. These results are in accordance with the multiple resource model (Wickens, 2002), where children with DCD were expected to perform worse on the auditive-auditive tasks, due to shared resource modalities. This results in cognitive overload and thus performance was compromised on one or both tasks of the auditive-auditive divided attention task.

Children with DCD often experience difficulties with divided attention, which might be related to their impaired working memory (Alloway, 2008; 2011). Research identified atypical neural correlates in brain regions associated with working memory, such as the parietal lobe, cerebellum and parts of the frontal lobe (Biotteau et al., 2016; Wilson et al., 2017; Zwicker et al., 2009). This impaired working memory in children with DCD can hinder their ability in processing simultaneously the necessary information to perform dual tasks effectively. Think about counting the scorings sounds and remembering these, while also paying attention to the news report to hear the animal's name. This impaired working memory may result in increased errors, slower processing and cognitive overload, affecting their overall performance on the divided attention tasks. Focusing on both tasks during the dual task, may have increased the cognitive load, which can be overwhelming for children with working memory deficits. During testing, we observed that the cognitive overload caused confusion and stress, likely further impairing their ability to perform tasks effectively.

Another explanation for these results, could be that visual support (in the auditive-visual divided attention task) can aid in attentional control or help children with DCD to better coordinate their responses to auditory stimuli. One possible explanation for the wide range of performance in divided attention tasks among children with DCD, could be that some already have developed skills that enhance their ability to perform these dual tasks more effectively. Another explanation might be the heterogeneity of DCD, where 50% of the children with DCD seem to have attention problems, showed by the overlap with ADHD (Fliers et al., 2010; Kaiser et al., 2015). However, the other 50% of the children do not seem to have ADHD and might not have attentional problems.

Divided attention and motor performance

Performance on the two divided attention tasks showed no correlation with motor skills in children with DCD. This suggests that a child's poorer performance on a divided attention task does not necessarily indicate worse motor skills as measured by the MABC-2. An explanation for these results could be the complexity and multifactorial nature of DCD. It might be possible that where some children exhibit problems with divided attention tasks due to attentional or executive function challenges, their motor skills might not necessarily be affected to the same degree. Another explanation could be the lack of variability in the sample. Children were included in the study only if they scored below the 16^{th} percentile on the MABC-2, indicating that all children have motor difficulties. The likelihood of finding a correlation is reduced when children with better motor performances are excluded from the sample. Therefore, the limited range of motor abilities within the sample may have hindered the detection of significant correlations, suggesting the need for a more diverse sample in future studies. This may enhance the understanding of the complex relationship between divided attention and motor performance in children with DCD

Cognitive dual tasks and motor dual tasks

There is no significant correlation found between cognitive dual tasks and motor dual tasks, suggesting that children with DCD who demonstrate poorer performance on cognitive dual tasks are not necessarily indicative of poorer performance on motor dual tasks as well. The lack of a significant correlation between performance on cognitive dual tasks and motor dual tasks, might be due to the distinct nature of cognitive and motor dual-task performance. Saraiva et al., (2024) showed that performing a cognitive dual task impairs postural control more than performing motor dual tasks. Therefore, the absence of a significant correlation between cognitive and motor dual-task performance in children with DCD could be due to the distinct nature of cognitive and motor processes. This highlights the importance of assessing both cognitive and motor dual-task performance separately to better understand and support the needs of children with DCD. These processes might operate relative independently of each other in dual tasking. Individual variability in children with DCD explains different strengths and weaknesses in either cognitive or motor domains, leading to different results on cognitive dual tasks and motor dual tasks. Another reason might be that tasks may vary in complexity, influencing how children allocate their attention and cognitive resources. Motor dual tasking may require more focus on movement execution and physical coordination, while cognitive dual tasks might need more attentional control and abstract thinking. However, there was a negative trend found between ‘Stepping in Ladder’ and the auditive-auditive dual task. This indicates that children who performed better on the auditive-auditive divided attention task, were faster in the ‘Stepping in Ladder’ task. The ‘Stepping in Ladder’ task is a dual task because it requires to step in the ladder as soon as possible, but also paying attention to the foot placement in the squares.

Clinical applications

Children with DCD seem to have more problems in auditive-auditive divided attention tasks compared to auditive-visual divided attention tasks. This poses challenges, particularly in educational settings such as schools. Given that children with DCD struggle with dual tasking which requires the same modalities, targeted interventions might be beneficial, which aims to enhance this type of divided attention. Specific intervention techniques such as auditory discrimination tasks and auditory sequencing activities might be beneficial. Additionally, using multi-sensory approach in educational settings could be beneficial. Given that children with DCD perform better on auditive-visual divided attention tasks, interventions should use a multi-sensory approach that combines auditory and visual stimuli. For instance, using visual aids like pictures next to an auditory explanation can facilitate comprehension and engagement. Educating parents and teachers about the challenges these children with DCD face with divided attention, can improve the understanding and support. Education should include explaining what DCD is and the impact on divided attention. Discuss how DCD affects a child's ability to divide attention between tasks and highlight that tasks requiring simultaneous processing of more of the same stimuli may be particularly challenging. To benefit the child's overall development, strategies for creating a supportive learning environment and promoting effective communication can be implemented. Some of the practical strategies which can be implemented are, breaking tasks into smaller steps, allow extra time for task completion, minimize distractions in the learning environment and keep the multiple resource model in mind, suggesting using multiple different resources when multi-tasking.

Limitations and recommendations

This study has several strengths, including the clinical relevance of investigating divided attention and motor impairments in children with DCD. Understanding the impairments may enhance interventions to support these children in clinical and educational settings.

The initial objective of this study was to investigate divided attention in children with DCD, both before and after a targeted intervention for motor impairments. However, due to a lack of ethical approval the initial research could not proceed. Consequently, the study was limited to a cross-sectional study design, therefore it was not possible to explain the changes in behavior of skills in children with DCD. This limitation underscored the need for further exploration into the relation between divided attention and DCD.

This study presented some limitations, including the small sample size being utilized. This small sample size may limit the generalizability of the findings to a larger population. Additionally, a non-randomized convenience sample is used from specific schools, which may introduce selection bias, possibly affecting the representativeness of the sample. The sample also consisted of children who were not yet diagnosed with DCD, which may have influenced the results It is important to acknowledge that some children in the study were young and might not have been diagnosed with a comorbidity, despite potential presence of one. This raises the possibility of undiagnosed comorbidities that could influence performance among participants. Another limitation might be the reliability and validity of some measurement tools. The reliability of the TEA-Ch subtests was found to be poor to moderate, and the overall reliability and validity seemed to be insufficient according to the COTAN. Using these tests may raise concerns about the accuracy and consistency of these measurements, which may impact the reliability of the results.

Future research should use a larger and more diverse sample size to enhance the generalizability. To minimize selection bias, it is recommended to use a randomized sampling method and recruit participants from multiple geographical locations. As mentioned above, the TEA-Ch was not a reliable and valid measurement tool. Therefore, researchers should consider using another measurement tool for divided attention, which is not yet developed. Next to this, it might be interesting to explore why more children with DCD are struggling with the auditive-auditive divided attention task compared to the auditive visual divided attention task. This could indicate potential differences in cognitive processing or attentional demands between these tasks for children with DCD. However, future research should consider investigating this finding in typically developing children, because the multiple resource model (Wickens, 2002) may also apply to children without DCD.

The automatization deficit model proposes that motor tasks become automatic for typically developing children but remain effortful for those with DCD (Zwicker et al., 2010). This reduced automatization in children with DCD may lead to increased demand on attentional resources and potential cognitive overload, resulting in attention deficits and difficulties with dual tasks. Initially, we expected this model to explain difficulties observed in children with DCD on the auditive-visual dual task, because this required a motor-component. However, we found that more children with DCD seem to have difficulties with the auditive-auditive dual task. Thus, the multiple resource model appears to better explain divided attention in children with DCD

Additionally, conducting intervention studies to evaluate the effectiveness of targeted interventions, such as motor skills interventions, would have practical implications for clinical practice. These studies would enhance the development of evidence-based interventions for children with DCD. Overall, further analysis and interpretation would be needed to have a comprehensive understanding of divided attention in children with DCD.

Conclusion

This study provides valuable insights into the complex relationship between divided attention and DCD in children, emphasizing the need to understand the challenges they face in multitasking scenarios. Findings showed that children with DCD tend to perform worse on divided attention tasks compared to their typically developing peers, especially on tasks that require the same resource modalities, as the auditive-auditive dual task. This finding aligns with the multiple resource model, which posits that shared resource modalities can lead to cognitive overload and impaired performance. Interestingly, the study found no significant correlations between divided attention and motor performance. This suggests that attentional challenges in children with DCD do not necessarily translate to motor impairments, highlighting the complex nature of the disorder. Moreover, no significant correlations between cognitive dual tasks and motor dual tasks were found, indicating that these processes might operate relatively independently. Individual variability in children with DCD underscores different strengths and weaknesses. This study used a relatively small sample size and therefore possibly introduced biases, there is need for future research with larger and more diverse samples. Clinical implication suggests educating parents and teachers about the challenges children with DCD face with divided attention, and therefore can create supportive learning environments and taking the multi-sensory approach into account. Overall, while this study sheds light on the complex interplay between divided attention and DCD, further research is needed for a comprehensive understanding and developing effective treatment.

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Appendix A

Table A1

Description of the TEA-Ch

Subtest	Attention Type	Description
Sky Search	Selective attention	Child has to find and circle all the pairs of identical spaceships on paper among unpaired spaceship distracters.
Score!	Sustained attention	Child must count the number of “scorings” sounds they hear on a tape.
Creature Counting	Attentional Control/Switching	Child must repeatedly switch between counting upwards and counting downwards. They have to count creatures with periodic arrows informing them of the direction to count.
Sky Search DT	Sustained and Divided attention	Child must repeat the Sky Search subtest under dual task conditions. As they search the pairs of spaceships, they must also count the number of scorings sounds they hear on each trial.
Map mission	Selective attention	Child has a map and must find as many of a particular symbol as possible in 1 minute.
Score! DT	Sustained attention	Child must again count the scoring sounds under dual task conditions, This time with an auditory modality. The goal is to hear an animal name that will occur at some stage during the counting in a spoken news report.
Walk, Don’t Walk	Sustained attention and response inhibition	Here the child learna two tones, one “go” and one “no go.” As the child hears the “go” tone, a mark on the paper can be written but must not mark when hearing the “no go” sound.
Opposite worlds	Attentional control/Switching	This one the child is required to make cognitive reversals. In the ‘Same World’ the child is asked to follow a path naming the digits 1 and 2, which are scattered along it. In the Opposite World the child must do the same task except this time say “one” when seeing a 2 and “two” when seeing a 1.
Code Transmission	Sustained attention	Child must sustain attention on a series of spoken digits, The child must monitor and say the number immediately before the ‘code’. The code is two fives ‘55’.

Table A2

Reliability and Validity of the TEA-Ch According to COTAN

Principles testconstruction	**Quality testmaterial**	**Quality manual**	**Norms**	**Reliability**	**Construct validity**	**Criterium validity**
Excellent	Excellent	Excellent	Insufficient	Insufficient	Insufficient	Insufficient

Appendix B

Table B1

Description of the MABC-2 Age Band 2 (7-10 years)

Area	Item	Description
Manual Dexterity 1	Placing Pegs	Insert small plastic pegs into a board as quickly as possible.
Manual Dexterity 2	Threading a String	Pull a string through the holes of a plastic board.
Manual Dexterity 3	Tracing Path	Trace a route between two lines without exceeding the boundaries.
Ball Skills 1	Catching	Throw a tennis ball against the wall and catch it with both hands.
Ball Skills 2	Throwing	Aim a beanbag into the red circle on a mat.
Balance Skills 1	One-Balance Board	Balance on one foot on the balance board.
Balance Skills 2	Walking Heel-to-Toe Forwards	Walk along the line with the heel of one foot touching the toes of the other foot.
Balance Skills 3	Hopping on mats	Jump forward on one leg from mat to mat in a hopscotch pattern.

Table B2

Description of the MABC-2 Age Band 3 (11-16 years)

Area	Item	Description
Manual Dexterity 1	Turning Plugs	Flip small two-colored plastic plugs to change their facing color.
Manual Dexterity 2	Building a Triangle	Assemble three plastics together with nuts and bolts to create a triangle.
Manual Dexterity 3	Tracing Path	Trace a route between two lines without exceeding the boundaries.
Ball Skills 1	Catching	Throw a tennis ball against the wall and catch it with one hand.
Ball Skills 2	Throwing	Throw the tennis ball into a red circle on the wall.
Balance Skills 1	Two-Board Balance	Balance on the balance board, ensuring that the heel of one foot and the toes of the other foot touch.
Balance Skills 2	Walking Heel-to-Toe Backwards	Walk backward along a line, making sure that the toes of one foot touch the heel of the other.
Balance Skills 3	Zigzag Hopping on Mats	Jump diagonally from one mat to another on one leg.

Appendix C

Table C1

Description of the Items of the Subscale 'Agility and Power' of the PER-FIT

Test Item	Description
Running in Ladder	The child starts with both feet behind the starting line (in front of the first bar of the agility ladder). When signaled, the child runs by placing one foot in each square, then circles around a bottle and returns through the ladder. Timing ends when both feet are over the starting line on the floor.
Stepping in Ladder	The child begins with both feet before the starting line (first bar of the agility ladder). Upon a signal, the child runs by stepping with both feet into each square (no jumping), then circles around a bottle and returns through the ladder. Timing ends when both feet are over the starting line and on the floor.
Side Jump	The child jumps sideways on both feet, landing one foot per square within the same three squares of the agility ladder.
Long Jump	The child stands with their toes just behind a starting line and is instructed to jump as far forward as possible. The child is given no specific instructions on how to jump, except to jump as far as they can without falling. One practice trial with submaximum effort is given to ensure understanding, followed by two test trials with 15-second rest between them.
Throw Sandbag	The child kneels just behind a starting line and is asked to throw a 2kg sandbag as far forward as possible. The bag is held in the middle (not by the corners) and thrown in one motion from a starting position behind the head with flexed elbows. One practice trial with submaximum effort is performed to confirm understanding, followed by two test trials with 15-second rest between them.

Table C2

Description of the Items of the Subscale 'Motor Skill Performance' of the PER-FIT

Test Item	Description
Bouncing and Catching	Children must bounce a tennis ball to the floor and catch. This involves five bouncing and catching items that increase in skill difficulty. All children start at the easiest level. This series is discontinued if the child scores less than 6 out of 10 catches.
Throwing and Catching	Children must throw a tennis ball in the air to at least the height of eye level and catch. It involves five throwing and catching items that increase in skill difficulty. All children start at the easiest level of this series. The series is discontinued if the child scores less than 6 out of 10 catches.
Jumping	Children are asked to jump within an agility ladder. This series involves four jumping items with an increase in difficulty. Two test trials are allowed if maximum score is not obtained.
Hopping	Children are asked to hop within an agility ladder. This series involves four hopping items of increasing difficulty for each leg. Two test trials are allowed if maximum score is not obtained.
Balance	Children are asked to perform two (2) static balance tasks for each leg and three (3) dynamic balance tasks. These tasks involve knee hugging, grasping the foot and picking cans from the floor at close and far distance.