Research in Developmental Disabilities 135 (2023) 104453

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Motor and cognitive dual-task performance under low and high task complexity in children with and without developmental coordination disorder

Hilde Krajenbrink [a,*], Jessica M. Lust [a], Kate Wilmut [b], Bert Steenbergen [a,c]

[a] *Behavioural Science Institute (BSI), Radboud University, Nijmegen, the Netherlands*
[b] *Perception and Motion Analysis Lab, Centre for Psychological Research, Oxford Brookes University, Oxford, United Kingdom*
[c] *School of Behavioural and Health Sciences, Australian Catholic University, Melbourne, VIC, Australia*

ARTICLE INFO

Keywords:
Dual-task
Automatization deficit hypothesis
Developmental coordination disorder
Children

ABSTRACT

Background: In everyday life, tasks are often performed simultaneously, which may be more difficult for children with developmental coordination disorder (DCD) than their peers.
Aims: To examine (1) the effects of task complexity and type of concurrent task on dual-task performance in children with and without DCD; and (2) if the amount of effort that children put into the task performance differs between the groups.
Methods: Participants were 64 children with and without DCD (aged 7–14 years). The dual-task paradigm consisted of a manual dexterity task of relatively low complexity (box and block test) or relatively high complexity (pegboard task), and a concurrent motor task (cycling task) or a concurrent cognitive task (word-listening task). To assess mental effort, children were asked how tired they felt before and after the experiment.
Results: Dual-task interference was highest when the manual dexterity task of relatively high complexity was combined with the concurrent motor task. There were no group differences in dual-task interference, but children with DCD reported a larger increase in the level of tiredness after the experiment indicative of greater mental effort.
Conclusions: Depending on task demands, children with DCD are able to perform dual-tasks at the same level as their peers, but performance may take children with DCD more mental effort.

What this paper adds?

Developmental coordination disorder (DCD) has been linked to poor automatization of motor skills. In behavioral research, the dual-task paradigm has been repeatedly used to assess movement automatization. However, results from studies using this paradigm in children with DCD have been equivocal. This seems to be due to the considerable variability in the experimental design applied across studies, including differences in the type and complexity of the tasks involved. In the present study, children with and without DCD needed to perform two manual dexterity tasks of varying complexity together with a concurrent cognitive or motor task. Results indicated that dual-task interference (i.e., decline from single-task to dual-task) was highest when the primary motor task of relatively high complexity was combined with the concurrent motor task. This was found for both groups of children with no differences in their

* Correspondence to: Thomas van Aquinostraat 4, 6525 GD Nijmegen, the Netherlands.
E-mail address: hilde.krajenbrink@ru.nl (H. Krajenbrink).

https://doi.org/10.1016/j.ridd.2023.104453
Received 20 June 2022; Received in revised form 22 January 2023; Accepted 1 February 2023
Available online 9 February 2023
0891-4222/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Table 1
Overview results previous studies on dual-task performance in children with DCD.

Study	Participants	Primary motor task	Concurrent task	Trial duration dual-task condition	Results dual-task performance
Biotteau et al. (2015)	19 children with DCD, 18 with dyslexia, and 22 with DCD and dyslexia (7–12 years)	Finger tapping sequence task	Cognitive: Picture naming task	Two trials of 30 s	*Primary task*: There was no difference in performance on the finger tapping task in the dual-task condition relative to the single-task condition, and there were no differences in dual-task interference between the groups. *Concurrent task*: All pictures were named correctly by all children in all task conditions.
Chen et al. (2011)	32 children with DCD and 32 TD children (9–10 years)	Bipedal stance	Cognitive: Signal detection task in a low and high difficulty condition	Six trials of 120 s	*Primary task*: While the TD group reduced motion in the high difficulty condition relative to the low difficulty condition, the DCD group increased in motion. *Concurrent task*: There were no group differences in the low difficulty condition, but the DCD group performed worse than the TD group in the high difficulty condition.
Chen et al. (2012)	38 children with DCD and 38 TD children (9–10 years)	Bipedal stance	Cognitive: digit memory test in a low and high difficulty condition	Six trials of 120 s	*Primary task*: While the TD group reduced motion in the high difficulty condition relative to the low difficulty condition, the DCD group did not. *Concurrent task*: Children performed worse in the high difficulty condition relative to the low difficulty condition. There were no group differences.
Chen & Tsai, (2016)	30 children with DCD and 30 TD children (aged 11–12 years)	Bipedal stance (no finger touch condition and light finger touch condition)	Signal detection task	Six trials of 120 s	*Primary task*: Both groups reduced motion in the light finger touch condition relative to the no finger touch condition, but this effect was greater in the TD group compared with the DCD group. *Concurrent task*: Both groups enhanced signal detection performance in the light finger touch condition relative to the no finger touch condition, but this effect was greater in the DCD group compared with the TD group.
Cherng et al. (2009)	14 children with DCD and 28 TD children (4–6 years)	Walking task (dyanmic balance)	Cognitive: Forward repetition of digits (easy) or backward repetition of digits (hard) Motor: Carrying an empty tray (easy) or carrying a tray with marbles (hard)	Twelve trials, no report on task duration (children had to walk 10 m)	*Primary task*: dual-task interference was higher for the DCD group than the TD group for the hard motor task relative to the easy motor task. The cognitive tasks negatively affected walking as well, but the decline in scores did not differ between the difficulty levels of the task or between groups. *Concurrent task*: Reaction times for the cognitive task were longer for the hard task compared with the easy task and longer when the cognitive task was combined with walking than when it was performed alone. But this effect of difficulty level or dual-task interference did not differ between groups.
Jelsma et al. (2021)		Wii Fit ski slalom (dynamic balance)		Six trials of about 60–90 s (trials	*Primary task*: Children improved in scores when the balance task was

(continued on next page)

Table 1 (*continued*)

Study	Participants	Primary motor task	Concurrent task	Trial duration dual-task condition	Results dual-task performance
	24 children with DCD and 36 TD children (7–12 years)		Cognitive: Counting animal sounds Motor: Crossing fingers task	lasted until the Wii task was finished)	combined with the cognitive task. Children decreased in scores when the task was combined with crossing fingers task. The change between dual-task and single-task conditions did not differ between groups. *Concurrent task*: Performance on the cognitive task and motor task was lower when combined with the balance task relative to when performed as a single task, but the decline in scores did not differ between groups.
Kuijpers et al. (2022)	26 children with DCD and 69 TD children (6–12 years)	Walking adaptability task on the C-mill	Cognitive: Sound-listening task Motor: stabilizing a tennis ball on a racket	Two trials of 240 s	*Primary task*: The DCD group performed worse than the TD group. Group differences were increased when the task was combined with the motor task, but not when combined with the cognitive task. *Concurrent task*: There were higher error rates on the cognitive and motor task in the dual-task condition relative to the single-task condition. Furthermore, the DCD group showed larger decrements in performance on the cognitive and motor task compared with the TD group.
Laufer et al. (2008)	26 children with DCD and 25 TD children (4–6 years)	Bipedal stance on a firm or a compliant surface	Cognitive: Object naming task	Four trials of 20 s	*Primary task*: Children in the DCD group demonstrated a higher increase in sway characteristics in the dual-task condition relative to the single-task condition, compared with the TD group. *Concurrent task*: Children in the TD group decreased in their performance on the cognitive task in de dual-task condition relative to the single-task condition, but performance of the DCD group was not affected by dual tasking.
Przysucha et al. (2016)	10 children with DCD and 10 TD children (8–10 years)	Bipedal stance	Cognitive: Numeric classification task	Ten trials of 10 s	*Primary task*: Sway characteristics were increased in the dual-task condition relative to the single-task condition, but the increase in sway characteristics did not differ between groups. *Concurrent task*: No report on performance of the cognitive task.
Schott et al. (2016)	20 children with DCD and 39 TD children (7–10 years)	Trail-tracing task using a pencil or trail-walking task	Cognitive: Following path of increasing numbers (1–2–3, etc.) (low cognitive load) or following path of increasing numbers and letters (1-A-2-B-3-C, etc.) (high cognitive load)	Twelve trials of about 30–150 s (depending on task conditions)	*Primary task*: Higher dual-task interference for task with high cognitive load (numbers and letters) relative to low cognitive load (numbers). For the trial-walking task, this effect was stronger in the DCD group compared with the TD group. For the trail-tracing task, there were no group differences in dual-task interference. *Concurrent task*: Dual-task interference for the cognitive tasks was low in general and there were no group differences
Tsai et al. (2009)		Bipedal stance	Cognitive: Oral counting task, auditory-verbal reaction task,	Five trials of 30 s	*Primary task*: DCD group performed worse than the TD

(*continued on next page*)

Table 1 (*continued*)

Study	Participants	Primary motor task	Concurrent task	Trial duration dual-task condition	Results dual-task performance
	39 children with DCD and 39 TD children (9–10 years)		auditory-choice reaction task, auditory-memory task, and articulation alone		group in three out of five conditions (oral counting task, auditory-verbal reaction task, and auditory-memory task). *Concurrent task*: No group differences in the cognitive task performance in the dual-task condition.

dual-task interference. Furthermore, our study is the first to also focus on changes in children's experienced level of tiredness. We found that children with DCD reported a higher increase in their level of tiredness after the experiment than typically developing (TD) children. This may suggest that it takes children with DCD more mental effort to perform dual-tasks. Our findings seem to indicate that the higher dual-task interference that has been found in previous studies focused on children with DCD is not always apparent. Depending on task demands, children with DCD are able to perform dual-tasks at the same level as their peers, but performance may take children with DCD more mental effort.

1. Introduction

Developmental Coordination Disorder (DCD) is a developmental motor disorder with an estimated prevalence of about 6% (American Psychiatric Association, 2013). The functional presentation of DCD is heterogeneous, with compromised motor coordination of both gross and fine motor skills as common denominators. Children with DCD have been shown to have difficulties with everyday activities such as handwriting, dressing, and tying shoelaces (Summers et al., 2008). As of yet, the exact nature of the motor difficulties in children with DCD is however not fully understood. In an attempt to provide an explanation Visser (2003) proposed the automatization deficit hypothesis, which originated from research in children with dyslexia (Fawcett & Nicolson, 1992). According to this hypothesis, children with DCD have more difficulty with automatizing their movements than their typically developing (TD) peers. Movement automaticity is regarded as the ability to perform a task without significant demands on attention (Stefanidis et al., 2007). In behavioural research, movement automaticity is often assessed with the dual-task paradigm (e.g., Fisk et al., 1986). In children with DCD, results from studies using this paradigm have been equivocal. This seems to be due to the considerable variability in the experimental design applied across studies, including differences in the type and complexity of the tasks involved (Schott, 2019). The present study was designed to follow up on these studies by focusing on the effects of task complexity of the primary manual dexterity task and the type of concurrent task on the dual-task performance of children with and without DCD.

In dual-task paradigms, participants are asked to perform two tasks simultaneously. The use of such paradigms is based on theories that regard attention as having a limited number of resources (Kahneman, 1973). The two tasks compete for these resources and if the available amount is exceeded, this will lead to suboptimal performance in one or both tasks. An adequately learned motor task that is automatized can be performed without significant demands on attentional resources (Fitts & Posner, 1967). Therefore, performing a concurrent task that does require attentional resources will have no or little effect on its performance. However, if a task is not yet fully automatized and requires significant attentional resources, performing a concurrent task that also requires attentional resources will negatively affect the performance of one or both tasks. According to the multiple resource theory of attention of Wickens (1984), attentional resources comprise various 'pools', e.g., tasks that include a manual response use different resources than tasks that include a vocal response. In case two tasks share resources from the same 'pool', like when two tasks require a manual response, performance on the tasks will more likely interfere with each other than if the two tasks require resources from different 'pools'.

In children with DCD, studies that focused on dual-task performance yielded mixed results. An overview of these studies can be found in Table 1. Some studies found that the performance of children with DCD was more affected compared with that of their TD peers under dual-task conditions (e.g., Chen & Tsai, 2016; Chen et al., 2012; Chen et al., 2011; Cherng et al., 2009; Kuijpers et al., 2022; Laufer et al., 2008; Schott et al., 2016; Tsai et al., 2009). Conversely, other studies found no differences between children with DCD and TD children with respect to their performance on dual-tasks (e.g., Biotteau et al., 2015; Jelsma et al., 2021; Przysucha et al., 2016). In these studies, it was typically found that children with DCD perform worse than TD children on the motor task, but that the decline in performance from single-task to dual-task was not different between children with and without DCD. It has been argued that these discrepancies in findings are due to the variability in the type and complexity of the primary motor task as well as the concurrent tasks (Schott, 2019).

Most previous studies included static or dynamic balance tasks, but manual dexterity tasks have also been used in dual-task paradigms. In the study of Schott et al. (2016), the primary motor tasks consisted of both a trail-walking-task (following a path while walking) and a trail-making task (following a path manually with a pencil on paper), which were performed under high and low cognitive load conditions. Results showed that children with DCD had a greater decline in performance in the high cognitive load condition relative to the low cognitive load condition on the trail-walking task, but this was not the case for the manual trail-making-task. In the study of Biotteau et al. (2015) children performed a finger tapping task together with a picture naming task. Similarly, the decline in scores from single-task to dual-task did not differ between the groups. These studies suggest that children with DCD are able to combine manual dexterity movements together with concurrent cognitive tasks at the same level as TD children, suggesting the involvement of different attentional resources. Still, this may be different when a concurrent motor task is introduced, in which similar attentional resources are involved.

There are three studies that evaluated the effects of both a concurrent cognitive and a concurrent motor task (Cherng et al., 2009; Jelsma et al., 2021; Kuijpers et al., 2022). In the study of Jelsma et al. (2021) it was found that children improved on the primary balance task when it was combined with a cognitive task, while children decreased in their performance when it was combined with a motor task. This change from single-task to dual-task performance did not differ between children with and without DCD. Cherng et al. (2009) and Kuijpers et al. (2022) both used a walking task and found that the performance on this task was affected by the concurrent motor task in children with DCD more so than their TD peers. This effect was not found when a concurrent cognitive task was added. It thus appears that completing a concurrent motor task is more difficult than a concurrent cognitive task, which may be especially the case for children with DCD.

Finally, a factor that is generally overlooked in dual-task studies, is the experienced amount of effort that it takes children with DCD to perform the experimental conditions. Two studies that applied a dual-task paradigm in children with DCD also included a measure of the subjective mental workload (Chen et al., 2012, 2011). Both studies found that the experienced level of mental workload was increased for the more difficult task conditions, but no differences between children with and without DCD were found. In these studies, the primary motor task consisted of a postural control task, but results may be different for manual dexterity tasks. This suggestion is based on previous research in which children with DCD were shown to use greater mental effort than TD children to complete manual dexterity tasks (Zwicker et al., 2010).

To sum up, research on the effects of concurrent tasks on the performance of manual dexterity tasks in children with DCD is limited. Yet, children perform many of these tasks in daily life which are usually accompanied by various types of concurrent tasks, both cognitive as well as motor related. This study is the first to use two manual dexterity tasks of varying complexity and to combine them with a concurrent cognitive and motor task. The main aim of the present study was to examine the effect of task complexity and type of concurrent task on dual-task performance in children with and without DCD. Complexity of the primary manual dexterity task was manipulated by the size of the objects that had to be grasped and the precision of the target where the objects had to be placed. Based on the multiple resources theory of attention (Wickens, 2002), we hypothesized that the decline in performance from single-task condition to dual-task condition (i.e., dual-task interference) would be higher for a manual dexterity task of relatively high complexity compared with a task with a relatively low complexity, and for a motor concurrent task compared with a cognitive concurrent task. Based on the automatization deficit hypothesis, we expected that the dual-task interference would be higher for children with DCD compared with TD children, but only for the manual dexterity task of relatively high complexity. Finally, a novel aspect of this study, was to explore to what extent the amount of effort that children put into the performance on the tasks differed for children with and without DCD. The amount of effort was measured as the difference in the self-reported level of tiredness before and after the experiment. It was hypothesized that children with DCD would expend more mental effort and thus report a larger increase in the level of tiredness after the experiment compared with TD children.

2. Method

2.1. Participants

Thirty-six children with DCD participated in the present study. Eighteen of these children were recruited via a local rehabilitation centre. These children were going to participate in an intervention and had an appointment at the centre to complete the necessary pre-test measures. They were invited to participate in the present study on the same day. The other 18 children were recruited via advertisements on websites for parents of children with DCD. In total, 33 of the children had received a formal diagnosis of DCD. All included children met the Diagnostics and Statistical Manual of Mental Disorders 5 (DSM-5; American Psychiatric Association, 2013)

Table 2
Children's characteristics for the DCD group and TD group and test outcomes of differences between groups.

	DCD group *M* (*SD*) min-max	TD group *M* (*SD*) min-max	p-value
Sex (males/females) *n*[1]	26/6	26/6	.625
Dominant hand (left/right) *n*[1]	4/28	4/28	.646
Age in years[2]	10y6m (1y8m) 7y1m-14y1m	10y6m (1y7m) 7y3m-14y1m	.946
MABC-2 manual dexterity score in percentiles[2]	5.37 (8.66) 0.1–37	36.59 (21.59) 5–84	< .001
MABC-2 aiming and catching score in percentiles[2]	6.79 (8.21) 0.1–25	56.69 (24.95) 9–98	< .001
MABC-2 balance score in percentiles[2]	13.12 (21.62) 0.1–75	56.59 (23.49) 16–95	< .001
MABC-2 total score in percentiles[2]	2.22 (3.52) 0.1–16	51.72 (21.52) 25–91	< .001
DCD-Q′07 total score[2]	31.20 (8.22) 16–47	63.68 (8.42) 44–75	< .001
AVL total score[2]	27.41 (11.09) 5–48	13.38 (9.27) 0–39	< .001
VISK total score[2]	29.27 (16.25) 3–66.5	10.43 (9.52) 0–35	< .001

Note. MABC-2, Movement Assessment Battery for Children 2; DCD-Q′07; developmental coordination disorder questionnaire, AVL, attention-deficit/hyperactivity disorder questionnaire; VISK, autism spectrum disorder questionnaire.
[1] Tested with the independent t-test.
[2] Tested with the chi-squared test

criteria for DCD: Movement Assessment Battery for Children 2 (MABC-2; Henderson et al., 2007; Smits-Engelsman, 2010) total score ≤ 16th percentile or any of the three component scores ≤ 5th percentile (criterion A); treated or have been treated for a motor coordination problem by a paediatric physical therapist and the impact of motor issues on daily activities confirmed by parent report on the Developmental Coordination Disorder Questionnaire symptoms (DCD-Q′07, Dutch translation CVO; Schoemaker et al., 2008) with scores in the category "indication for DCD or suspected DCD" (criterion B); early onset of symptoms (criterion C); and parents reported no indication of any cognitive impairment, visual impairment, or neurological deficit which would explain the child's motor difficulties (criterion D). A questionnaire focusing on medical conditions was used to verify this last criterion. Four children were excluded from the data analysis of the present study because the MABC-2 score was above the 16th percentile ($n = 3$) or because the child was not able to complete all experimental conditions ($n = 1$). This resulted in the inclusion of 32 children with DCD.

Forty-seven TD children were recruited. Thirty-two children were selected from this group to match the children with DCD with regard to sex and age (within 6 months, except for 4 children that were matched within 7 months). All TD children had a MABC-2 total score > 16th percentile. Furthermore, for the control group an IQ of > 70 was inferred when attending regular primary or secondary education. Parents of the children indicated no medical or neurological conditions.

In addition to the DCD-Q′07, parents of all children completed the attention deficit hyperactivity disorder (ADHD) questionnaire (AVL; Scholte & van der Ploeg, 2004) and the questionnaire for inventory of social behaviour of children (VISK; Hartman et al., 2014) as a descriptive measure of ADHD and autism spectrum disorder (ASD) symptoms, respectively. For the DCD group, data on the questionnaires was complete. For the TD group, data on the questionnaires was missing for four children. Table 2 represents children's characteristics. Finally, based on parent reports, co-morbid disorders in the DCD group were dyslexia ($n = 5$), ASD ($n = 4$), ADHD ($n = 2$),[1] and Developmental Language Disorder (DLD) ($n = 1$). In the TD group, known neuro-developmental disorders were dyslexia ($n = 2$) and DLD ($n = 1$).

Written informed consent was obtained from the parents. Children themselves gave assent for participation. The study was approved by the ethics committee of the Faculty of Social Sciences at Radboud University (ECSW-2021-071). In addition, the study was considered not to be subject to the Medical Research Involving Human Subjects Act (WMO) by the Committee on Research Involving Human Subject of the region Arnhem-Nijmegen in The Netherlands (protocol number 2021-8298)..

2.2. Materials

2.2.1. Manual dexterity tasks

2.2.1.1. Low complexity. The primary manual dexterity task of relatively low complexity consisted of the box and block test, a test of gross upper limb function (e.g., Mathiowetz et al., 1985). The box and block test is composed of a wooden box that is divided in two compartments by a low partition. The box was placed in front of the children with the compartment holding the blocks oriented towards the dominant hand. Children were required to move as many blocks as possible from one compartment, over the low partition, to the other compartment. Children were instructed to transport one block at a time and their fingertips had to cross the partition while transporting the blocks. The number of blocks transported in 60 s was used as the outcome measure.

2.2.1.2. High complexity. The primary manual dexterity task of relatively high complexity consisted of the pegboard task, a fine manual dexterity task (e.g., Tiffin & Asher, 1948). The pegboard task is composed of a test board with two vertical rows of 25 small holes. Distance between the two rows was 2.5 cm and distance between the holes in each row was 1.8 cm. The board was placed in front of the children and the cup that was oriented towards the dominant hand was filled with pins. Children were required to insert as many small pins as possible starting at the top of the first row. The number of pins inserted in 60 s was used as the outcome measure.

2.2.2. Concurrent tasks

2.2.2.1. Motor. During the cycling task, children were required to cycle on a desk cycle at a comfortable pace. The desk cycle was placed under the table so that children could cycle while sitting on their chair at the table. The size of the desk cycle was the same for all children: 48 cm (L), by 34 cm (W), by 28 cm (H). The number of revolutions in 60 s was used as the outcome measure. The legs of the child were videotaped and the number of revolutions were scored offline. Of all videos, a randomly chosen 10% was scored by two other raters. The inter-rater reliability was excellent, with an average measure ICC of.999, 95% CI [.999, 1.000], calculated based on a mean-rating, absolute agreement, two-way random effects model.

2.2.2.2. Cognitive. During the word-listening task, children needed to listen to a series of Dutch single syllable words (e.g., *kaas* [cheese], *jas* [coat]). These words were presented at random within approximately 2-sec intervals. There was one target word (i.e., *boom* [tree]) that occurred at random (on average every three words). When hearing this word, children were required to repeat the word verbally. There were three different versions of the task, one for each task condition that involved the word-listening task. All versions had 10 instances of *tree*. Errors consisted of missing a *tree*, repeating a *tree* that was not there, or repeating a different word.

[1] All statistical analyses were also conducted without these two children with ADHD. The interpretation of the results did not change and therefore we decided to include the children in the study.

The outcome measure was determined by the following formula: (10 – number of errors) * 100.

2.2.3. Mental effort

As a proxy of mental effort, the experienced level of tiredness was assessed. Previous research has shown a correlation between perceived effort and self-reported fatigue (Goh et al., 2022). Children were asked how tired they felt on a scale from 1 (not tired at all) to 10 (extremely tired). To aid in answering, a number line from 1 to 10 was displayed visually with a smiley next to the 10 that looked extremely tired.

2.2.4. Instruments used for demographics

2.2.4.1. MABC-2. The MABC-2 was used as a measure of motor skill proficiency (Smits-Engelsman, 2010). The MABC-2 consists of eight tasks that focus on three aspects of motor skills (i.e., manual dexterity, aiming and catching, and balance). Internal consistency was found to be good (Cronbach's alpha of.83) (Ghayour Najafabadi et al., 2022).

2.2.4.2. DCD-Q′07. The DCD-Q′07 was used as a measure of DCD symptoms (Schoemaker et al., 2008). The questionnaire consists of 15 items with behavioural descriptions (e.g., "Your child throws a ball in a controlled and accurate fashion"). Items are answered on a five-point scale ranging from 'not at all like your child' (1) to 'extremely like your child' (5). Depending on the age of the children, a total score $\leq$ 46–57 is considered 'an indication for DCD'. Internal consistency was found to be excellent (Cronbach's alpha of.94) (Wilson et al., 2009).

2.2.4.3. AVL. The AVL was used as a measure of ADHD symptoms (Scholte & van der Ploeg, 2004). The questionnaire consists of 18 items with behavioural descriptions (e.g., "Is easily distracted"). Items are answered on a five-point scale ranging from 'never' (0) to 'very often' (4). Depending on the sex and age of the children, a total score of $\geq$ 33–45 is considered clinical (>95th percentile). Internal consistency was found to be excellent (Cronbach's α of.94).

2.2.4.4. VISK. The VISK was used as a measure of ASD symptoms (Hartman et al., 2014). The questionnaire consists of 49 items with behavioural descriptions (e.g., "Does not understand jokes"). Items are answered on a three-point scale ranging from 'never' (0) to 'often' (2). Depending on the sex and age of children, a total score of $\geq$ 26–34 is considered clinical (>95th percentile). Internal consistency was found to be excellent (Cronbach's α of.93).

2.3. Procedure

Children were seated so that they could reach the materials on the table and could comfortably use the desk cycle. Children were first asked to write down their name in order to determine hand preference. Then, the level of tiredness was assessed. Next, the manual dexterity tasks and concurrent tasks were practiced for about 15 s each, first under single-task conditions and then under dual-task conditions. Afterwards, all task conditions were performed for 60 s each in a counterbalanced order. In total, the 8 different task conditions were presented in sixteen different task orders that were randomly divided across children. For the primary manual dexterity tasks, children were instructed to perform the tasks as fast as possible. For the word-listening task and the cycling task, speed or accuracy were not stressed. For the dual-task combinations, children received the instruction to perform both tasks together as well as they could. The attention was not specifically directed to one of the two tasks. When all task conditions were completed, the level of tiredness was assessed again. Finally, the MABC-2 was assessed (If the MABC-2 had already been assessed during the past year, that score was used instead). For most children with DCD, the data collection took place in one session with a short break prior to the MABC-2 assessment to prevent fatigue. For most TD children, data collection took place at school in two sessions. Here the MABC-2 was assessed during the second session. Questionnaires were always completed by the parent(s) of the children, either during the experiment if the parent was present or after the experiment via an online link.

2.4. Data analysis

To examine the effects of performing two tasks simultaneously, dual-task efficiency scores were determined. First, dual-task costs (DTC) were calculated using the formula: ((dual-task performance – single-task performance)/single-task performance)* 100 (Somberg & Salthouse, 1982). This resulted in eight variables: (1) DTC box and block with word-listening (difference between performance on the box and block test while also performing the word-listening task and the performance on the box and block test alone); (2) DTC box and block with cycling (difference between performance on the box and block test while also performing the cycling task and the performance on the box and block test alone); (3) DTC pegboard with word-listening (as described above, but for the pegboard task); (4) DTC pegboard with cycling (as described above, but for the pegboard task); (5) DTC word-listening with box and block (difference between performance on the word-listening task while also performing the box and block test and the performance on the word-listening task alone); (6) DTC word-listening with pegboard (difference between performance on the word-listening task while also performing the pegboard task and the performance on the word-listening task alone); (7) DTC cycling with box and block (as described above, but for the cycling task); (8) DTC cycling with pegboard (as described above, but for the cycling task). Then, dual-task efficiency scores were determined for each combination of tasks by calculating the mean of the DTC scores involved (e.g., the efficiency score of the box and block and cycling condition was determined by calculating the mean of the DTC box and block with cycling and the DTC cycling with box and block). This resulted in four dual-task efficiency scores which represent the mean percentage change from single-task condition to dual-task condition of the two tasks involved. A negative value indicates a relative decline in performance and a positive value indicates a relative improvement in performance in the dual-task condition. The dual-task efficiency scores show the dual-task interference of children irrespective of their individual task priorities (Bock, 2008).

All analyses were performed using SPSS Version 25 (IBM Corp, 2017). There was one child with a missing data point on the cycling task when performed together with the pegboard task. This child was excluded from the analyses that involved this score. First, to examine differences between children with DCD and TD children in the single-task and dual-task conditions, performance on all tasks was compared using independent sample *t*-tests or Mann-Whitney *U* tests. A Bonferroni correction was applied to correct for multiple testing resulting in an alpha level of .004.

Second, to examine whether children with DCD and TD children differed in their performance on the different dual-task conditions, a repeated-measures analysis of variance (ANOVA) was performed. The analyses consisted of a 2x2x2 analyses, with task complexity of the manual dexterity task (low vs high) and type of concurrent task (motor vs cognitive) as within subject variables, group (DCD vs TD) as between-subject variable, and the dual-task efficiency scores as dependent variables. In case of significant interaction terms, post hoc analyses were performed consisting of paired-sample *t*-tests. The dual-task efficiency score of the box and block test and word-listening task did not meet the assumptions of normality and homogeneity of variances. Removing one extreme outlier from the DCD group solved these issues. However, this did not change the interpretation of the results and we therefore decided to include the outlier in the analysis.

Third, to examine differences between the DCD and TD group in their experienced level of tiredness before and after the experiment, two Mann-Whitney *U* tests were performed. Finally, to examine differences in the perceived level of tiredness before and after the experiment, two Wilcoxon signed rank tests were performed for the DCD and TD group separately. For both analyses, a Bonferroni correction was applied which resulted in an alpha level of .025.

3. Results

Table 3 represents the differences between the DCD group and TD group in scores on all tasks in both the single-task condition and dual-task conditions. As expected, the DCD group had a statistically significant lower score on the box and block test and pegboard test compared with the TD group in all task conditions. However, there were no statistically significant differences between the two groups in the word-listening task and cycling task in all task conditions.

3.1. Dual-task efficiency

The dual-task efficiency scores (i.e., mean DTCs of the different task combinations) are represented in Fig. 1. Table 4 shows the results of the Repeated Measures ANOVA. The Repeated Measures ANOVA showed a statistically significant effect of the interaction between task complexity of the primary motor task and type of concurrent task. As expected, follow-up analyses revealed that the dual-task efficiency score was lower for the pegboard task and cycling task than the box and block test and cycling task, $t(62) = 3.84$, $p < .001$. There were no differences in dual-task efficiency scores between the pegboard task and word-listening task and box and block test and word-listening task, $t(63) = -0.84$, $p = .404$. In addition, the dual-task efficiency score of the pegboard task and cycling task was lower than the dual-task efficiency score of the pegboard task and word-listening task, $t(62) = 5.26$, $p < .001$. There were no differences in dual-task efficiency scores between the box and block test and word-listening task and box and block test and cycling task, $t(63) = 1.06$, $p = .293$. Contrary to the expectations, the main effect of group, as well as the interactions between task complexity and

Table 3
Differences between the DCD group and TD group on all tasks in single-task and dual-task conditions.

	DCD group			TD group				
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*	Test value	*p*
Box and block test	51.19	10.58	51.50	58.56	7.65	59.50	$U = 285.50$	**.002**
Pegboard task	21.38	4.82	23.00	26.06	2.83	26.00	$U = 206.00$	**< .001**
Listening task	96.88	7.38	100.00	100.00	0.00	100.00	$U = 416.00$	.011
Cycling task	91.84	17.97	88.00	93.28	16.53	95.00	$t = -0.33$	.740
Box and block while listening	49.31	11.51	52.00	57.72	6.84	58.50	$U = 284.00$	**.002**
Box and block and cycling	48.47	11.16	52.50	56.28	6.82	57.00	$U = 286.50$	**.002**
Pegboard while listening	21.28	4.11	22.50	25.78	2.81	25.00	$U = 181.50$	**< .001**
Pegboard while cycling	19.63	5.00	21.00	24.38	3.70	24.00	$U = 243.50$	**< .001**
Listening while box and block	91.88	13.55	100.00	93.75	12.12	100.00	$U = 480.50$	.627
Listening while pegboard	91.56	12.47	100.00	94.69	8.79	100.00	$U = 451.50$	.352
Cycling while box and block	86.34	19.02	84.50	83.75	15.92	84.50	$t = 0.59$	.556
Cycling while pegboard	80.52	17.53	79.00	80.16	14.23	83.00	$U = 492.00$	.956

Note. Significant results in bold. Significant at the $p < .004$ level. The table shows the task scores (i.e., the number of blocks and pins transported and inserted for the box and block test and pegboard task respectively, the percentage of correct responses for the listening task, and the number of revolutions for the cycling task). For all tasks, a higher score indicates a better performance.

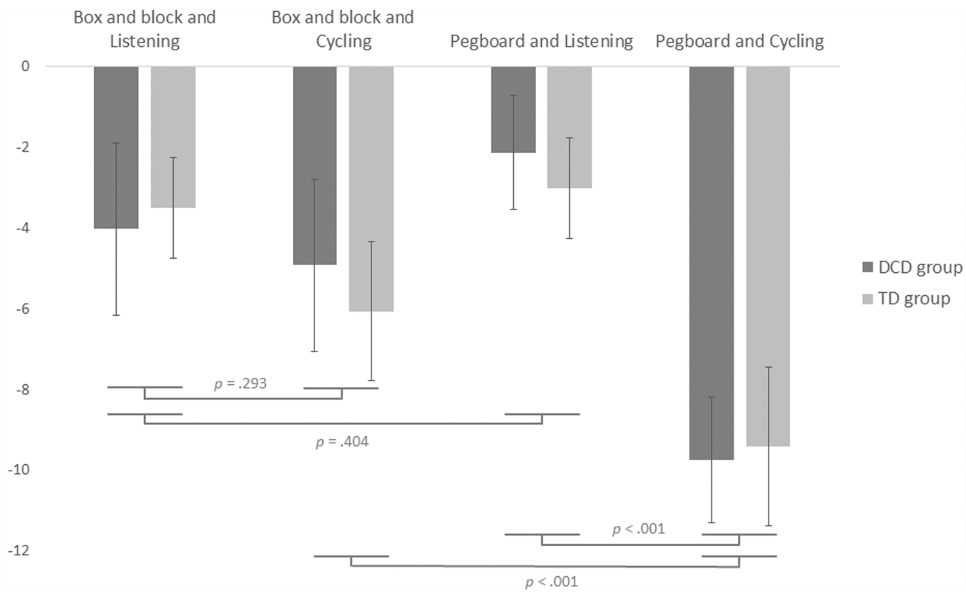

Fig. 1. Dual-task efficiency scores for all task combinations for the DCD group and TD group separately. Error bars represent standard errors. The *p*-values represent the follow-up analyses of the significant interaction effect of task complexity and type of concurrent task.

Table 4
Results of the Repeated Measures Anova including the dual-task efficiency scores.

Independent variable	*F*	*df1*	*df2*	*p*	η^2
Task complexity	2.89	1	61	.094	.05
Type of concurrent task	12.67	1	61	< .001	.17
Group	0.12	1	61	.733	< .01
Task complexity x Type of concurrent task	10.13	1	61	.002	.14
Task complexity x Group	0.04	1	61	.851	< .01
Type of concurrent task x Group	0.04	1	61	.834	< .01
Task complexity x Type of concurrent task x Group	1.14	1	61	.290	.02

group, type of concurrent task and group, and type of concurrent task, task complexity, and group, were not statistically significant. This indicates that the decline in performance from single-task to dual-task was not statistically different between the DCD group and TD group for all task combinations.

The analysis was also performed for the DTC scores of the manual dexterity tasks and concurrent tasks separately (results can be found in the supplementary material). Similarly, here it was found that the DTC of the manual dexterity tasks were lowest for the pegboard task when combined with the cycling task. In addition, DTC of the concurrent tasks were lowest for the cycling task when combined with the pegboard task.

3.2. Mental effort

There were no statistically significant differences in the initial level of tiredness between the DCD group ($Mdn = 3.00$, $M = 2.81$, $SD = 2.28$) and TD group ($Mdn = 2.00$, $M = 2.19$, $SD = 1.42$), $U = 447.00$, $p = .376$. At the end of the experiment, however, the DCD group ($Mdn = 4.50$, $M = 4.59$, $SD = 2.82$) indicated that they felt more tired than the TD group ($Mdn = 3.00$, $M = 2.75$, $SD = 1.88$), $U = 329.50$, $p = .013$. In addition, the difference in the experienced level of tiredness before and after the experiment was statistically significant for the DCD group, $Z = -3.28$, $p = .001$, but not for the TD group, $Z = -2.01$, $p = .045$. In the DCD group, 23 children reported a higher level of tiredness after the experiment, 6 children had equal scores, and 3 children reported a lower level of tiredness. In the TD group, 13 children reported a higher level of tiredness, 14 children had equal scores, and 5 children reported a lower level of tiredness.

4. Discussion

The main aim of the present study was to examine the effects of task complexity and type of concurrent task on dual-task performance in children with and without DCD. In line with the expectations, we found that the dual-task efficiency score was lowest when the primary motor task of relatively high complexity was combined with the concurrent motor task. Contrary to the expectations however, we found no differences between children with DCD and TD children in their dual-task efficiency scores. In addition, although there were no differences in dual-task efficiency scores between children with and without DCD, our findings do suggest that it may have taken children with DCD more mental effort to perform the dual-tasks than TD children. That is, children with DCD reported a higher increase in their experienced level of tiredness compared with their TD peers. Below the results are discussed in more detail and in light of previous studies that focused on dual-tasking in children with DCD.

The dual-task efficiency score in the present study was lowest for the combination of the pegboard task (i.e., relatively high complexity) and the cycling task (i.e., concurrent motor task). This is in line with the multiple resource theory of attention (Wickens, 1984) and previous studies that included both a concurrent cognitive and a concurrent motor task (Cherng et al., 2009; Jelsma et al., 2021; Kuijpers et al., 2022). Our results thus indicate that the previous findings from studies including balance tasks, can also be applied to manual dexterity tasks. According to the multiple resource theory of attention, attentional resources comprise various 'pools' depending on the stage of processing (encoding, central processing, or responding), the processing codes (spatial or verbal), and the modalities of input (auditory or visual) and response (manual or vocal) (Wickens, 2002). The primary motor tasks included in the study (i.e., the box and block test and the pegboard task) involve manual responses that require visual monitoring. The word-listening task is an auditory task which requires a vocal response, and therefore there is little competition for attentional resources. The cycling task, however, likely competes for the same resources within the manual response modality. This explains why the concurrent motor task affected performance on the manual dexterity task more than the concurrent cognitive task. The difference between the concurrent cognitive and motor task was only found for the pegboard task, but not for the box and block test. This suggests that the attentional resources that were necessary to perform these tasks were higher for the pegboard task than the box and block test, which likely due to higher precision requirements. We based our hypothesis on the multiple resource theory of attention, but there are other models to explain the interference that occurs when performing multiple tasks concurrently, such as the bottleneck model (Pashler, 1994). The best theoretical model and related brain mechanisms that may underlie the current findings are yet to be studied.

In addition, the results indicate that the above-mentioned pattern in dual-task efficiency scores did not differ between children with DCD and TD children. In other words, the performance in the dual-task conditions presented a similar decline in both groups of children relative to their single-task performance. This is in contrast with the expectations and does not support the automatization deficit hypothesis (Visser, 2003). Based on this hypothesis, it was assumed that the manual dexterity tasks of relatively high complexity would be less automatized in children with DCD compared with TD children. Therefore, the task was expected to require more attentional resources which would consequently result in a higher decline in performance when executed together with another task that requires conscious monitoring as well. However, although children with DCD had a lower performance on the single-task and dual-task conditions on both manual dexterity tasks, the attentional interference did not impact the DCD group more than their TD peers. Previous studies on dual-task performance in children with DCD found mixed results. Two studies that also included a manual dexterity task found similar results to ours, with no group differences between children with DCD and TD children in dual-task interference (Biotteau et al., 2015; Schott et al., 2016). Also, Przysucha et al. (2016) and Jelsma et al. (2021) did not find group differences in dual-task interference using a static and dynamic balance task, respectively. This indicates that while the majority of studies found that children with DCD had a stronger decline in performance from single-task to dual-task than TD children (Chen et al., 2012, 2011; Cherng et al., 2009; Kuijpers et al., 2022; Laufer et al., 2008; Tsai et al., 2009), it seems that dual-task performance is not necessarily impaired in children with DCD. That is, in line with the multi-component account described in Wilson et al. (2017), dual-task performance seems to be highly dependent on task and environmental constraints.

One task constrain that is important is complexity, and related to this, the level of automatization of the tasks involved. The results of the present study suggest that all tasks were automated in both groups of children. The decline in performance from single-task to dual-task was generally low. For example, on the manual dexterity tasks, the average decline in performance in the dual-task conditions compared with the single-task condition was, two pins or three blocks less, respectively. This suggests that both groups of children were quite able to divide their attention and perform the two tasks simultaneously without large decrements in performance. This is in line with the study of Jelsma et al. (2021) in which the DTC scores of the primary balance task were relatively low as well, indicating that shifting weight while keeping balance is an automated and unconscious task in children. It seems that when primary motor tasks become more demanding, such as when walking with a tray with marbles (Cherng et al., 2009) or walking a zigzag path indicated by increasing numbers and letters (Schott et al., 2016) more distinctive results are found. This raises the question as to whether the tasks included in the present study may have been too easy for the children. However, the fact that children with DCD performed more poorly than the TD children on both manual dexterity tasks in all task conditions shows that the tasks were complex enough to elicit group differences. Yet, an increase in the complexity or novelty of the primary motor tasks or the concurrent tasks would likely result in more pronounced dual-task effects.

Another factor that could potentially explain the lack of group differences in our study and some of the discrepancies in previous research, is the precision of the outcome measures that are used. In the present study, the precision of the outcome measures of the tasks was relatively low. Performance on the manual dexterity tasks and cycling task was based on speed and performance on the word-listening task was based on accuracy. This is in contrast to many previous studies that included balance or walking tasks with precise measures of postural sway or gait parameters (Chen et al., 2012, 2011; Cherng et al., 2009; Kuijpers et al., 2022; Laufer et al., 2008; Przysucha et al., 2016; Tsai et al., 2009). Except for the study of Przysucha et al. (2016), these studies demonstrated higher dual-task interferences in children with DCD compared with TD children. Based on this it may be speculated that more precise measures of, for example, grasping movement patterns in the manual dexterity tasks, or consistency of cycling and reaction time in the word-listening task, may have uncovered greater dual-task interference and differences between children with and without DCD.

With regard to the mental effort that it took children to complete the tasks, we found that children with DCD reported a greater increase in their experienced level of tiredness than TD children. This is in line with the expectations and previous research that found that children with DCD fatigue more easily than TD children (Cairney et al., 2007). It seems to suggest that it takes children with DCD more mental effort to achieve a similar dual-task performance. Results must be interpreted with caution since mental effort was only measured with one question before and after the experiment. Future research should ask children about their experienced level of tiredness multiple times throughout the experiment. Yet, our finding is important to consider when we think about real life dual-tasking. The duration of the experimental trials in the present study (60 s) as well as in all previous studies (varying from 20 to 240 s) is short, while in real life children could dual-task easily for 15 min consecutively or more. Consider for example their bike ride to school during which children cycle, watch the traffic, sign what way they are going, and talk with a friend. It could be that children with DCD are able to perform at the same level as TD children during short experimental trials, but that dual-task interference would increase more quickly if tasks become longer. It would be interesting for future research to study the effects of duration of trials on the dual-task performance in children with and without DCD.

The present study had some limitations resulting in points of attention for future research. First, the difficulty levels of the concurrent cognitive and motor tasks were not measured and matched beforehand. Consequently, it cannot be ruled out that the word-listening task was easier and required less attentional resources than the cycling task. The decision to include the tasks was based on the fact that they both required continuous focus and it was anticipated that both tasks were relatively easy and familiar to the children. The finding that the DTC scores of the word-listening task and cycling task did not differ when they were performed together with the box and block test (see supplementary material) supports our idea that the difficulty levels were indeed comparable. Second, although the primary motor tasks involved standardized tasks with good psychometric properties, we do not know the exact test-retest reliability as we adjusted the protocol of the manual dexterity tasks to make them fit our experiment (e.g., increased the duration of the Purdue Pegboard task from 30 s to 60 s). Finally, although it is easy to think of real life tasks that resemble each of the tasks involved in the present study, the ecological validity of the experimental setup in which all task combinations are performed for 60 s each, can be questioned. For future research, it would be interesting to study more complex and longer dual-task settings, which are more similar to the those children face in their everyday life.

5. Conclusion

Children with DCD and TD children showed the same pattern of results over all task conditions, with the lowest dual-task efficiency score for the combination of a manual dexterity task of relatively high complexity with a concurrent motor task. While children with DCD had lower scores on the primary motor tasks than TD children, performing a concurrent cognitive or motor task did not increase these group differences. The decline in performance from single-task to dual-task was relatively low on all tasks in general. This indicates that both children with and without DCD were able to divide their attention and perform the two tasks simultaneously without a strong decline in performance. Increasing the complexity or duration of the tasks may change these results and provide interesting directions for future research.

CRediT authorship contribution statement

Hilde Krajenbrink: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Jessica Lust:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision. **Kate Wilmut:** Conceptualization, Methodology, Validation, Writing – review & editing. **Bert Steenbergen:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision.

Funding

This work was supported by the Behavioural Science Institute, Radboud University, The Netherlands.

Data Availability

Data will be made available on request.

Acknowledgements

We are thankful for the cooperation of children and their parents, as well as the schools and the rehabilitation center that participated in this research.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2023.104453.

References

American Psychiatric Association. (2013). Diagnostics and statitical manual of mental disorders (5th ed.). American Psychiatric Association.

Biotteau, M., Chaix, Y., & Albaret, J.-M. (2015). Procedural learning and automatization process in children with developmental coordination disorder and/or developmental dyslexia. *Human Movement Science, 43*, 78–89. https://doi.org/10.1016/j.humov.2015.07.005

Bock, O. (2008). Dual-task costs while walking increase in old age for some, but not for other tasks: an experimental study of healthy young and elderly persons. *Journal of NeuroEngineering and Rehabilitation, 5*, 27. https://doi.org/10.1186/1743-0003-5-27

Cairney, J., Hay, J. A., Faught, B. E., Flouris, A., & Klentrou, P. (2007). Developmental coordination disorder and cardiorespiratory fitness in children. *Pediatric Exercise Science, 19*(1), 20–28. https://doi.org/10.1123/pes.19.1.20

Chen, F.-C., & Tsai, C.-L. (2016). Light finger contact concurrently reduces postural sway and enhances signal detection performance in children with developmental coordination disorder. *Gait & Posture, 45*, 193–197. https://doi.org/10.1016/j.gaitpost.2016.01.029

Chen, F. C., Tsai, C. L., Stoffregen, T. A., Chang, C. H., & Wade, M. G. (2012). Postural adaptations to a suprapostural memory task among children with and without developmental coordination disorder. *Developmental Medicine & Child Neurology, 54*(2), 155–159. https://doi.org/10.1111/j.1469-8749.2011.04092.x

Chen, F. C., Tsai, C. L., Stoffregen, T. A., & Wade, M. G. (2011). Postural responses to a suprapostural visual task among children with and without developmental coordination disorder. *Research in Developmental Disabilities, 32*(5), 1948–1956. https://doi.org/10.1016/j.ridd.2011.03.027

Cherng, R.-J., Liang, L.-Y., Chen, Y.-J., & Chen, J.-Y. (2009). The effects of a motor and a cognitive concurrent task on walking in children with developmental coordination disorder. *Gait & Posture, 29*(2), 204–207. https://doi.org/10.1016/j.gaitpost.2008.08.003

Fawcett, A. J., & Nicolson, R. I. (1992). Automatisation deficits in balance for dyslexic children. *Perceptual and Motor Skills, 75*(2), 507–529. https://doi.org/10.2466/pms.1992.75.2.507

Fisk, A. D., Derrick, W. L., & Schneider, W. (1986). A methodological assessment and evaluation of dual-task paradigms. *Current Psychological Research & Reviews, 5*(4), 315–327. https://doi.org/10.1007/BF02686599

Fitts, P., & Posner, M.I. (1967). Human Performance. Brooks/Cole Publishing.

Ghayour Najafabadi, M., Saghaei, B., Shariat, A., Ingle, L., Babazadeh-Zavieh, S. S., Shojaei, M., & Daneshfar, A. (2022). Validity and reliability of the movement assessment battery second edition test in children with and without motor impairment: A prospective cohort study. *Annals of Medicine and Surgery, 77*, Article 103672. https://doi.org/10.1016/j.amsu.2022.103672

Goh, H.-T., Stewart, J. C., Becker, K., & Hung, C.-J. (2022). Perceived effort for reaching is associated with self-reported fatigue. *Journal of Motor Behavior, 54*(1), 14–26. https://doi.org/10.1080/00222895.2021.1871877

Hartman, C., Luteijn, E., Moorlag-Jonger, H., Minderaa, R.B., & De Bildt, A. (2014). VISK: Handleiding [VISK manual]. Boom uitgevers.

Henderson, S.E., Sugden, D.A., & Barnett, A. (2007). Movement Assessment Battery for Children - second edition (Movemetn ABC-2). Pearson Assessment.

I.B.M. Corp. (2017). IBM SPSS Statistics for Windows, Version 25.0. IBM Corp.

Jelsma, L. D., Geuze, R. H., Fuermaier, A. B. M., Tucha, O., & Smits-Engelsman, B. C. M. (2021). Effect of dual tasking on a dynamic balance task in children with and without DCD. *Human Movement Science, 79*, Article 102859. https://doi.org/10.1016/j.humov.2021.102859

Kahneman, D. (1973). Attention and effort. Prentice-Hall International.

Kuijpers, R., Smulders, E., Groen, B. E., Smits-Engelsman, B. C. M., Nijhuis-van der Sanden, M. W. G., & Weerdesteyn, V. (2022). The effects of a visuo-motor and cognitive dual task on walking adaptability in children with and without developmental coordination disorder. *Gait & Posture, 95*, 183–185. https://doi.org/10.1016/j.gaitpost.2022.04.019

Laufer, Y., Ashkenazi, T., & Josman, N. (2008). The effects of a concurrent cognitive task on the postural control of young children with and without developmental coordination disorder. *Gait & Posture, 27*(2), 347–351. https://doi.org/10.1016/j.gaitpost.2007.04.013

Mathiowetz, V., Federman, S., & Wiemer, D. (1985). Box and block test of manual dexterity: Norms for 6–19 year olds. *Canadian Journal of Occupational Therapy, 52*(5), 241–245. https://doi.org/10.1177/000841748505200505

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*, 220–244. https://doi.org/10.1037/0033-2909.116.2.220

Przysucha, E. P., Trap, J., & Zerpa, C. (2016). Low levels of attentional interference have similar effects on static balance control of typically developing children and those with symptoms of developmental coordination disorder (DCD. *Journal of Childhood & Developmental Disorders, 2*(15), 2–15. https://doi.org/10.4172/2472-1786.100023

Schoemaker, M.M., Reinders-Messelink, A.J., & de Kloet, A.J. (2008). Coordinatievragenlijst voor Ouders (CVO) [Coordination Questionnaire for Parents] - translation of DCD-Questionnaire by Wilson (2007).

Scholte, E.M., & van der Ploeg, J.D. (2004). ADHD vragenlijst (AVL) [ADHD questionnaire]. Nippo - Nederlands Instituut voor Pedagogisch en Psychologisch Onderzoek.

Schott, N. (2019). Dual-task performance in developmental coordination disorder (DCD): Understanding trade-offs and their implications for training. *Current Developmental Disorders Reports, 6*(2), 87–101. https://doi.org/10.1007/s40474-019-00163-z

Schott, N., El-Rajab, I., & Klotzbier, T. (2016). Cognitive-motor interference during fine and gross motor tasks in children with developmental coordination disorder (DCD). *Research in Developmental Disabilities, 57*, 136–148. https://doi.org/10.1016/j.ridd.2016.07.003

Smits-Engelsman, B. (2010). Handleiding Movement ABC-2-NL [Instruction Manual Movement ABC-2-NL]. Pearson.

Somberg, B. L., & Salthouse, T. A. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 651–663. https://doi.org/10.1037/0096-1523.8.5.651

Stefanidis, D., Scerbo, M. W., Korndorffer, J. R., & Scott, D. J. (2007). Redefining simulator proficiency using automaticity theory. *The American Journal of Surgery, 193*(4), 502–506. https://doi.org/10.1016/j.amjsurg.2006.11.010

Summers, J., Larkin, D., & Dewey, D. (2008). Activities of daily living in children with developmental coordination disorder: Dressing, personal hygiene, and eating skills. *Human Movement Science, 27*(2), 215–229. https://doi.org/10.1016/j.humov.2008.02.002

Tiffin, J., & Asher, E. J. (1948). The purdue pegboard: Norms and studies of reliability and validity. *Journal of Applied Psychology, 32*(3), 234–247. https://doi.org/10.1037/h0061266

Tsai, C. L., Pan, C. Y., Cherng, R. J., & Wu, S. K. (2009). Dual-task study of cognitive and postural interference: A preliminary investigation of the automatization deficit hypothesis of developmental co-ordination disorder. *Child: Care, Health and Development, 35*(4), 551–560. https://doi.org/10.1111/j.1365-2214.2009.00974.x

Visser, J. (2003). Developmental coordination disorder: A review of research on subtypes and comorbidities. *Human Movement Science, 22*(4), 479–493. https://doi.org/10.1016/j.humov.2003.09.005

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman, & D. R. Davies (Eds.), *Varieties of attention* (pp. 63–102). Academic Press.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159–177. https://doi.org/10.1080/14639220210123806

Wilson, B. N., Crawford, S. G., Green, D., Roberts, G., Aylott, A., & Kaplan, B. J. (2009). Psychometric properties of the revised developmental coordination disorder questionnaire. *Physical & Occupational Therapy In Pediatrics, 29*(2), 182–202. https://doi.org/10.1080/01942630902784761

Wilson, P. H., Smits-Engelsman, B., Caeyenberghs, K., Steenbergen, B., Sugden, D., Clark, J., Mumford, N., & Blank, R. (2017). Cognitive and neuroimaging findings in developmental coordination disorder: New insights from a systematic review of recent research. *Developmental Medicine & Child Neurology, 59*(11), 1117–1129. https://doi.org/10.1111/dmcn.13530

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2010). Brain activation of children with developmental coordination disorder is different than peers. *Pediatrics, 126*(3), e678–e686. https://doi.org/10.1542/peds.2010-0059