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FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN

master in de revalidatiewetenschappen en de kinesitherapie

Masterproef

Underlying processes for problems in manual skills in children with developmental coordination disorder

Promotor :
Prof. dr. Katrijn KLINGELS

Saar Vandepoel
Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

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universiteit hasselt
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Saar Vandepoel, Corneliusstraat 48 3545 Halen, juni 2017 S.V.

Research context

This pilot study, situated within the pediatric rehabilitation, was conducted in the University of Hasselt in association with the Stella Maris Institute of Pisa. The study is part of a research line on manual skills in children with developmental coordination disorder (DCD). Children with DCD have difficulties with coordinating movements and learning new skills, which results in a child being unable to perform common, everyday tasks. Manual skills are crucial in the diagnosis and clinical picture of children with DCD. From this perspective, this study focused on differences in manual skills between children with DCD and typically developing (TD) children. The insights, obtained by this research, are important for optimizing an individual targeted treatment approach in children with DCD.

The research design was drafted last year by two master students of the University of Hasselt and discussed with prof. dr. K. Klingels and dra. E. Bieber. The recruitment of the children and the data acquisition was conducted by prof. dr. K. Klingels and dra. E. Bieber. The data processing was performed independently by the master student. Likewise, the academic writing process was completely and independently performed by the master student, supervised by promotor prof. dr. K. Klingels.

Abstract

Background: Manual skills are crucial in the diagnosis and clinical picture of children with developmental coordination disorder (DCD). Treatments specifically targeting manual skills have not yet been described.

Objectives: The present study investigates the underlying processes for problems in manual skills in children with DCD compared to typically developing (TD) children.

Participants: Eighteen participants between six and 10 years old were recruited, including 10 children with DCD and eight age-and sex matched TD children.

Measurements: Four assessments were performed to examine the different aspects of manual function: the Movement Assessment Battery for Children-Second Edition (MABC-2), the tyneside pegboard test, an experimental action observation test (AOT) and an experimental imitation test.

Results: There were no differences in age, sex and demographic characteristics between children with DCD and TD children. Children with DCD scored significantly lower on the MABC-2 (manual dexterity and aiming & catching) and manual dexterity subtests of the pegboard test. In the dual-task test condition of the pegboard test, children with DCD performed the task, with small pegs, significantly slower in comparison to TD children. Regarding the AOT, children with DCD scored only significantly lower on the quality of imitation. Finally, children with DCD scored significantly lower on the imitation test of static meaningless gestures.

Conclusion: Children with DCD experienced difficulties in all tasks measuring manual function in comparison to TD children. Children with DCD presented with less accurate movements, decreased ability to perform dual tasks and problems with both imitation and action observation.

Introduction

Developmental coordination disorder (DCD) is defined as a 'disorder in which the main feature is a serious impairment in the development of motor coordination that is not solely explicable in terms of general intellectual disability or of any specific congenital or acquired neurological disorder' (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). DCD affects five to six percent of all school-aged children. The ratio of boys to girls varies from 2:1 to 7:1 (Arlington, 2013). Currently, there is no cure for DCD but early intervention and treatment may help reducing the emotional, physical and social consequences often associated with this disorder.

DCD according to DSM-V is defined by the following four criteria: (A) Motor performance is substantially below expected levels given the person's chronologic age and previous opportunities for skill acquisition; difficulties are manifested as clumsiness and as slowness and inaccuracy of performance of motor skills; (B) The motor skills deficit significantly or persistently interferes with activities of daily living appropriate to the chronologic age and impacts academic/school productivity, prevocational and vocational activities, leisure and play; (C) The onset of the symptoms is in the early developmental period; (D) The motor skills deficits cannot be better explained by intellectual disability or visual impairment and are not attributable to a neurologic condition affecting movement (e.g. cerebral palsy, muscular dystrophy, or a degenerative disorder) (Arlington, 2013).

DCD is characterized by problems tapping into various domains of the International Classification of Functioning and Disability-Children Youth Version (ICF-CY) (Bieber et al., 2016). Regarding activity level, children with DCD have difficulties with manual dexterity and fine motor skills such as in-hand manipulation, bimanual coordination and handwriting skills (Feder & Majnemer, 2007; Huau, Velay, & Jover, 2015) (Bieber et al., 2016). Furthermore, children with DCD have less functional strength which contributes to motor difficulties (Haga, 2009) (Farhat et al., 2016). Their motor performance is slower, less accurate, less precise and less consistent compared to their peers (Ferguson, Jelsma, Jelsma, & Smits-Engelsman, 2013) (Farhat et al., 2016). These problems may impact their academic progress, social integration and emotional development (Summers, Larkin, & Dewey, 2008) (Bieber et al., 2016). Poor manual dexterity is a strong discriminator that determines the diagnosis and clinical picture of DCD (Poulsen, Johnson, & Ziviani, 2011).

In addition, the etiology of DCD is still largely unknown (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). Children with DCD are a heterogeneous group which may suggest that several mechanisms can explain why children develop DCD. There are two hypotheses that can explain the underlying processes of problems with manual skills in children with DCD: (1) 'automatization deficit hypothesis' and (2) 'internal modeling deficit hypothesis'.

The 'automatization deficit hypothesis' suggests that a disturbance in the automatization or procedural learning of motor sequences can explain why children with DCD encounter problems with manual dexterity (Biotteau, Chaix, & Albaret, 2015). Procedural learning, or learning a skill through repeated practice is characterized by three stages. In the first stage, the cognitive stage, a child learns a new skill. In the second stage, the associative stage, a child learns how to refine the skill. In the last stage, the autonomous stage, the child can perform the skill without explicit attention. Studies showed that children with DCD can improve a given task with practice, but they do not necessarily reach the automatization stage (Biotteau et al., 2015). This hypothesis can be investigated by the dual-task paradigm in which cognitive and motor tasks are combined. For example, Schott, El-Rajab, and Klotzbier (2016) examined the effect of a concurrent cognitive task on fine and gross motor tasks in children with DCD and found that children with DCD were slower in the dual task conditions. Children with DCD showed a different approach when using cognitive resources and had difficulties making motor skills automatic (Schott et al., 2016).

According to the internal modeling deficit hypothesis, children with DCD have a reduced ability to utilize predictive motor control. (Wilson et al., 2013) (Adams, Lust, Wilson, & Steenbergen, 2014). Internal models provide stability to the motor system by predicting the outcome of movements before slow, sensory-motor feedback becomes available (Wolpert, Miall, & Kawato) (Adams et al., 2014). Children with DCD are, for this reason, very dependent on visual feedback. The internal model is linked to the mirror neuron system (MNS), which is active during both action execution and action observation or imagery. Therefore, the MNS plays an important role in action observation and imitation (Reynolds et al., 2015). To date, no studies have been published about action observation. Concerning imitation, strong support exists for deficits in the imitation of meaningful learned gestures (Reynolds et al., 2015). Imitating novel meaningless gestures has been far less investigated.

To date, very few studies have investigated the various problems regarding manual skills and linked these problems to the two hypotheses. The present study investigates the underlying processes for problems in manual skills in children with DCD compared to TD children, based on the hypotheses. These insights are important for optimizing an individually targeted treatment approach in children with DCD.

Methods

Participants

DCD children were recruited in Flanders in association with 'vzw Dyspraxis' and by contacting local physiotherapists, and in Pisa (Italy) in the 'Stella Maris Institute'. Age and sex matched TD children were recruited from colleagues, friends and families of the investigators both in Flanders and Pisa.

All children with DCD had (1) a score at or below the percentile 16 on the Movement Assessment Battery for Children, second edition (MABC-2) (Smits-Engelsman, Niemeijer, & van Waelvelde, 2011), (2) were between six and 10 years old (3) spoke and understood Dutch or Italian and (4) were sufficiently cooperative when performing the tests. Children were excluded if they had (1) a medical condition that could affect the motor performance (parent questionnaire) or (2) a cognitive or intellectual delay (school performance or in case of doubt intelligence test by psychologist).

Children in the TD group met the following criteria: (1) score above percentile 25 on the MABC-2, (2) spoke and understood Dutch or Italian and (3) were sufficiently cooperative when performing the tests. Children were excluded if they had (1) a medical condition that could affect the motor performance (parent questionnaire) or (2) a cognitive or intellectual delay (school performance or in case of doubt IQ test by psychologist).

The study was approved by the Ethics Committee of UZ KU Leuven/research (3/3/2016, S58819).

Procedure

Children with DCD and TD children were invited to participate in a one-time test situation. The measurements took place at the university sports center (KU Leuven), the Stella Maris institute in Pisa or at the school of the participating children. The tests were conducted by the principal investigators (prof. dr. K. Klingels and dra. E. Bieber) with help of master students in Rehabilitation Sciences from University of Hasselt. The testing lasted up to two hours for the TD children or up to two and half hours for DCD children.

Outcome measurements

(1) *Movement Assessment Battery (second edition)*

The MABC-2 identifies and describes impairments in motor performance of children and adolescents from 3 to 16 years of age divided into three age bands (3-6 years, 7-10 years, 11-16 years). The test consists of eight fine and gross motor tasks distributed over three specific subdomains: manual dexterity (three items), aiming and catching skills (two items) and static and dynamic balance (three items) (Wuang, Su, & Su, 2012). Standard scores and percentile scores are provided for each subdomains, as well as a total standard and percentile score. The MABC-2 is a reliable (intra-class correlation = 0.97) and valid test instrument to measure the motor performance of children with DCD (Wuang et al., 2012). The test administration lasts 30 minutes.

(2) *Tyneside pegboard test*

The tyneside pegboard (figure 1) is an electronic version of the 9-hole pegboard test. This instrument consists of two electronic boards, nine placing pegs, available in small and large sizes and a Perspex screen. The participants were asked to move nine pegs, as fast as possible, from the holes of one board to the other board while the time was recorded. This test was performed unimanually and bimanually.

In the unimanual test condition, the test was performed first with the dominant and then with the non-dominant hand. The pegs were moved from left to right, and then from right to left. The test was performed first with small and then with large pegs.

In the dual task condition, only executed with the dominant hand, the same motor task was performed with small and large pegs in combination with an acoustic task. In this condition the child randomly heard the sound of a helicopter or an airplane. The child was asked to say 'yes' each time they recognized the sound of the helicopter.

In the bimanual test condition, only performed with the large pegs, the participant picked up the peg with one hand, and transferred it to the other hand through a Perspex screen placed at the midline. The test was performed first from left to right, and then from right to left.

Before each new condition, the child had three practice trials. The time from picking up the first peg till the placement of the last peg was recorded. Then, the median time of both directions was calculated. The test administration lasts 20 minutes. This is an experimental task with currently no psychometric characteristics available.

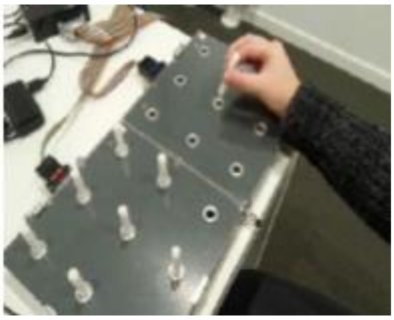

Figure 1: Tyneside pegboard test

(3) *Action observation test (AOT)*

The participants were asked to perform an easy task (screw a bolt on a nut) and a complex task (screw three sticks and three nuts for building a triangle). Children aged six to seven years used wooden material (figure2), children aged eight to 10 years used metallic material (figure 3). First, the child had to perform the task spontaneously and then observe the videos showing two different strategies for the easy task, and one strategy for the complex task. All tasks were video recorded and time-watched. Both the time and quality of imitation were scored. For the quality of imitation, a 4 point ordinal scale was used: Zero point for no movement at all of for a plainly incorrect imitation; one point for an attempt at the correct imitation but poor execution; two points for a correct movement with minor problems in execution and three points for a correct execution of the imitation required (modification of score system used by Watkins, Dronkers, & Vargha-Khadem, 2002).

The test administration lasts 10 minutes. This is an experimental task with currently no psychometric characteristics available.

Figure 2: AOT complex task (6-7 year)

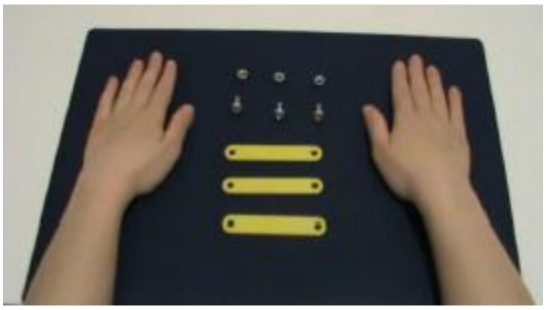

Figure 3: AOT complex task (8-10 years)

(4) *Imitation test*

Meaningless gestures

During the imitation task, 20 static and dynamic meaningless gestures with one or two hands were shown. After the demonstration of the experimenter, the participants imitated the observed gesture. Three different conditions were used: recall, imitation and explanation for the gesture. In the recall or first trial, the examiner showed the gesture and immediately took his hand away. The child was required to reproduce the observed gesture. If the child was able to perform the gesture, the examiner moved on to the next gesture. If the child was unable to reproduce the gesture, a second trial was performed. In this second trial or imitation, the examiner showed the gesture and kept it for 10 seconds. If the child was able to imitate the gesture, the examiner moved on to the next gesture. If the child was unable to imitate the gesture, a third trial was performed. In the third trial or explanation, the examiner showed the gesture in different sequences and explained during the performance orally how to perform it. Then the child was asked to imitate the gesture. The examiner could give other oral advices to the child while he or she was performing the gesture.

The imitation performance of the children was video recorded and then scored according to a three point ordinal scale (modification of Watkins et al., 2002). Zero point for no execution; one point for a correct execution in the explanation condition; two points for a correct execution in the imitation condition and three points for a correct execution in the recall condition. The maximum score was 60. Afterwards, the scores were converted to percentages.

A static gesture had an acceptable quality when: (1) the hand was oriented in the right position, (2) the fingers had a good configuration and (3) the performance was executed within 5 seconds from the target presentation. A dynamic gesture had an acceptable quality when it was done one time without any movement interruption.

The test administration lasts 10 minutes. This is an experimental task with currently no psychometric characteristics available.

Meaningful gestures

Children were asked to perform six uncommon and six common gestures, after the verbal command "Show me how you…" (table 1).

Table 1: Meaningful gestures

Common used gestures	**Unusual used gestures**
1. Brush your teeth with a toothbrush	7. Salute
2. Comb your hair with a comb	8. Pinch your nose
3. Eat ice cream with a spoon	9. Cross your fingers
4. Hit a nail with a hammer	10. Make a fist
5. Cut paper with scissors	11. Wave goodbye
6. Write with a pencil	12. Snap your fingers

A score of zero till three was given according to the criteria of Dewey and Kaplan (Dewey & Kaplan, 1992). Zero point for an incorrect gesture or if the child only indicated where the gesture was to be performed; one point if the child used a body-part as an object or if an orientation, posture of distortion error was made; two points if there were minor inaccuracies in performing the gesture and three points if the action was performed correctly. The maximum score was 36. Afterwards, the scores were converted to percentages.

The test administration lasts 10 minutes. This is an experimental task with currently no psychometric characteristics available.

Data-analysis

Descriptive statistics were used to describe the general and clinical characteristics. Non-parametric statistics were used because of the small sample size.

The Mann-Whitney U test was used to investigate differences between TD children and children with DCD. Wilcoxon Signed Rank tests were used to determine if there was a significant difference between the different task conditions.

The level of significance was set at $p < 0.05$. Statistical analysis was performed using the SPSS software (IBM SPSS Statistics 24).

Results

Subject characteristics

Eighteen participants between six and 10 years old were recruited, including 10 children with DCD (7 boys, 3 girls; 2 Belgian, 8 Italian; median age = 8 years 1 month ± 1 year 3 months) and eight age-and sex matched TD children (5 boys, 3 girls; 3 Belgian, 5 Italian; median age = 8 years 2 months ± 1 year 3 months). There were no statistical differences between both groups regarding age, sex and demographic characteristics (p>0.05). Subject characteristics are displayed in table 2.

Table 2: Subject characteristics

DCD-group			TD-group		
Age	**Gender**	**MABC-2 (pc)**	**Age**	**Gender**	**MABC-2 (pc)**
5y 8m	M	16	6y 0m	M	50
9y 0m	F	16	9y 3m	F	37
8y 11m	M	9	9y 1m	M	63
8y 7m	M	2	8y 5m	M	37
9y 5m	F	0,1	9y 8m	F	75
6y 4m	M	9	7y 6m	F	50
9y 6m	M	2	7y 0m	M	50
7y 11m	F	0,1	8y 9m	M	91
7y 4m	M	0,5			
8y 6m	M	9			

y=year, m= month, M=male, F=female, pc=percentile

Test results

(1) *Movement Assessment Battery (second edition)*

There was a significant difference in the total standard score between the DCD-group and the TD-group (DCD: median = 5 ± 2.3; TD: median=10 ± 3; p<0.0001).

Concerning the subscales on manual skills, significant differences were found in both manual dexterity (p=0.004) and aiming and catching (p=0.003). Results are shown in table 3.

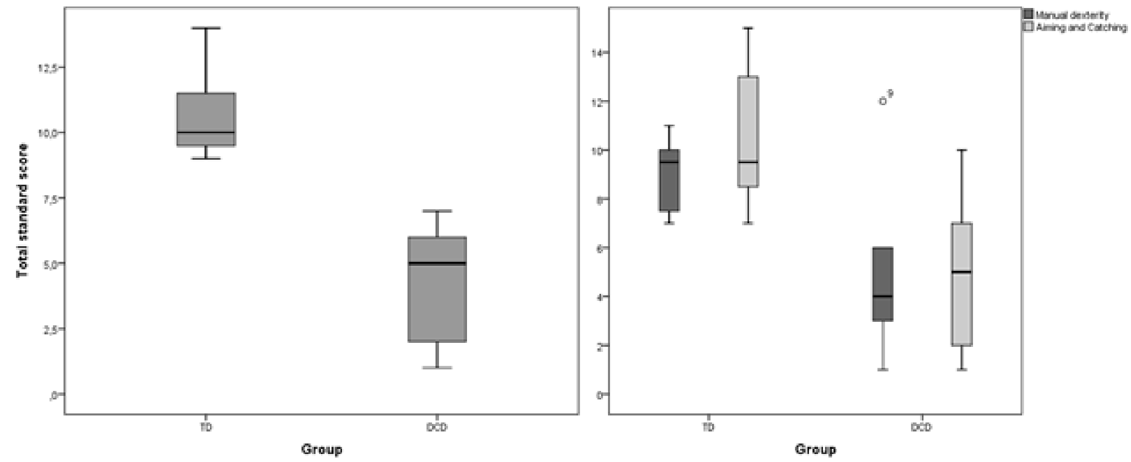

Figure 4: Boxplot of differences in total standard score, and manual dexterity and aiming and catching of the MABC-2 between the TD- and DCD group are displayed.

Boxplot shows: minimum, first quartile, median, third quartile and maximum.

(2) *Tyneside pegboard test*

In the unimanual test condition, children with DCD moved the large pegs significantly slower in comparison with TD children with their dominant (DCD median time: 15.6 ± 4.1; TD median time 12.5 ± 1.6, p=0.026) and non-dominant hand (DCD median time: 16 ± 2.87; TD median time: 14 ± 2.3, p=0.013). Likewise, there was a significant difference in the performance time with the small pegs for both dominant (DCD median time: 17.3 ± 5.9; TD median time 13.2 ± 2.6, p=0.004) and non-dominant hand (DCD median time= 19.5 ± 6.4; TD median time 14.4 ± 3, p=0.009) (Table 3).

Concerning the difference between the dominant and non-dominant hand, children with DCD moved the large pegs significantly faster (p=0.037) with the dominant hand in comparison to the non-dominant hand. No significant difference (p=0.260) was found for the execution with the small pegs. In the TD group there was no significant difference in the time of execution with the dominant and non-dominant hand for the large (p=0.208) and small (p=0.69) pegs (Table 4).

In the dual task test situation, there was no significant difference in performance time with large pegs between children with DCD and TD children (DCD median time= 17.4 ± 8.2; TD median time= 14 ± 4.6; p=0.155). However, children with DCD moved the small pegs significantly slower than TD children (DCD median time= 18 ± 8.1; TD median time= 14.2 ± 4.1; p=0.021) (Table 3).
The speed of execution of the acoustic dual task with the large pegs was significantly slower (p<0.05) than the speed of execution in the single task in both groups. When the acoustic dual task was performed with the small pegs, no significant difference (p>0.05) was found in speed of execution in both groups. (Table 4).

In the bimanual test condition, children with DCD moved the pegs significantly slower than TD children (DCD median time = 21.3 ±6.5; TD median time= 18.4 ± 2.5; p=0.010) (Table 3).

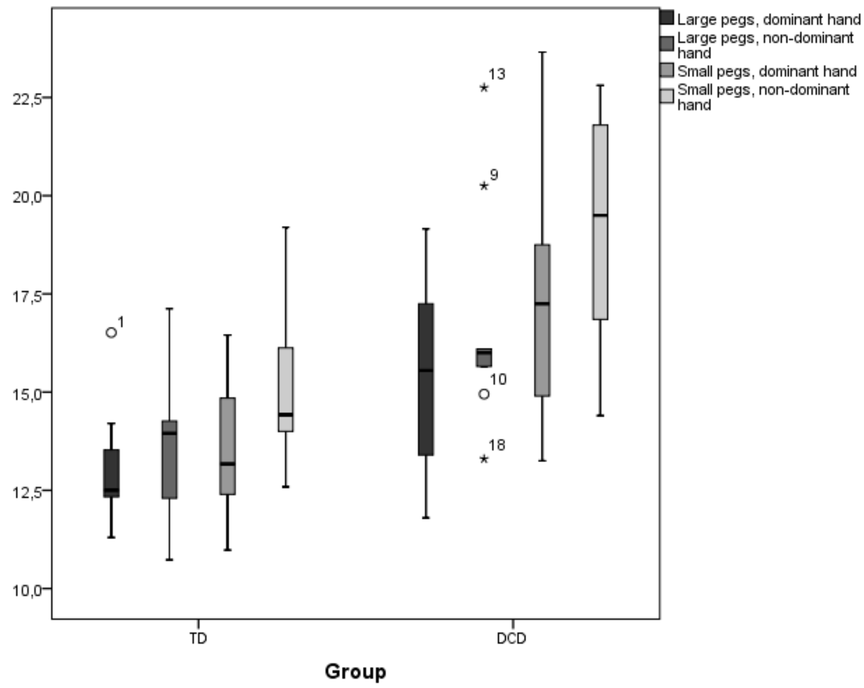

Figure 5a: Boxplots of differences in both hands and for large and small pegs of the tyneside pegboard test between TD- and DCD group are displayed.
Boxplot shows: minimum, first quartile, median, third quartile and maximum.

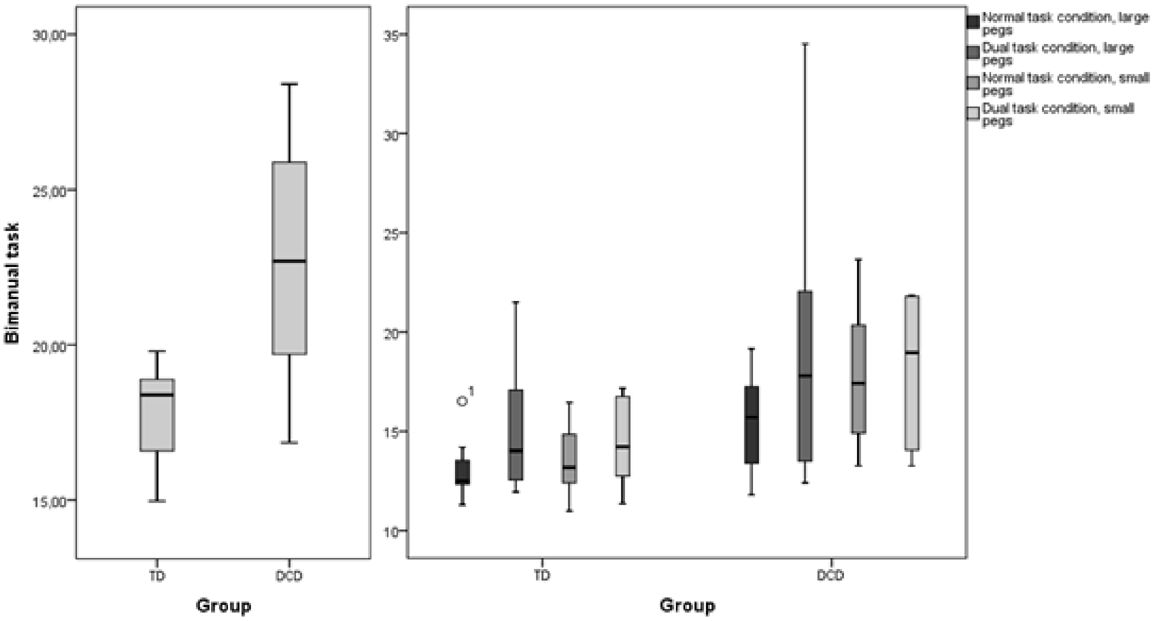

Figure 5b: Boxplot of difference in bimanual test condition and acoustic dual task of the tyneside pegboard test between TD- and DCD group are displayed.
Boxplot shows: minimum, first quartile, median, third quartile and maximum.

(3) *Action observation test*

Only eight children with DCD (median age = 8 years 2 months ± 1 year 3 months) and eight TD children (median age = 8 years 3 months ± 1 year 3 months) performed the action observation test.

First, the time component will be discussed. Analysis revealed no significant difference between the two groups for the spontaneous execution of both the easy (DCD median time=46.4 ± 36; TD median time= 24.2 ± 12.2; p=0.105) and the complex task (DCD median time= 124.1 ± 107.9; TD median time= 113.6 ± 57.1; p=0.935). Also concerning the time of imitation of the first and second strategy, no significant differences were found (p= 0.115, p= 0.529). Finally, for the time of imitation of the complex task, no significant difference was found between children with DCD and TD children (DCD median time= 93.4 ± 12.4; TD median time= 88.4 ± 35.6; p=0.338) (Table 3).

Secondly, the quality of imitation (score) will be discussed. Children with DCD scored significantly lower on the imitation of the first strategy of the easy task compared to TD children (DCD median score = 2 ± 1; TD median score= 3 ± 1; p=0.015). No significant difference was found, between both groups, for the score of the imitation of the second strategy of the easy task (DCD median score 2 ± 2; TD median score 2 ± 3; p=0.824). Finally, the score of imitation of the complex task did not reach significance (DCD median score= 2 ± 2; TD median score= 2 ± 2; p=0.069) (Table 3).

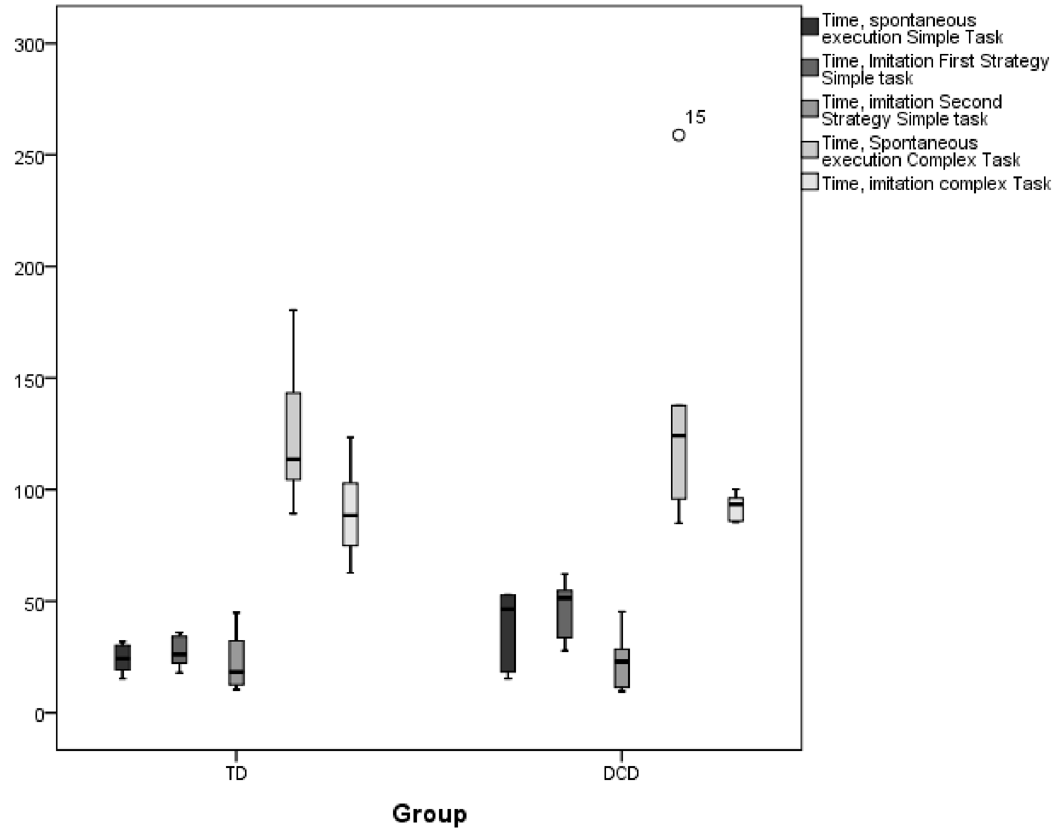

Figure 6: Boxplot of difference in time of the AOT between TD- and DCD group are displayed. Boxplot shows: minimum, first quartile, median, third quartile and maximum.

(4) *Imitation test*

For the total percentage score of the static and dynamic meaningless gestures, children with DCD achieved a significantly lower score compared to TD children (DCD median score= 70.8 ± 15.4; TD median score= 85 ± 12.5; p=0.009). In particular, children with DCD scored significantly lower on the static meaningless gestures compared to TD children (DCD median score 75 ± 24.5; TD median score= 89.6 ± 18.2; p=0.023). For the dynamic gestures, no significant difference was found between the two groups (DCD median score= 58.3 ± 33.3; TD median score= 79.2 ± 14.6, p=0.318). In addition, no significant difference (p=0.514) in both groups was found when the imitation of meaningless static and dynamic gestures was compared (Table 3).

For the meaningful gestures, seven children with DCD (median age= 8 years ± 1 year 4 months) and seven TD children (median age= 8 years 3 months ± 1 year 3 months) completed the test. The percentage of the total score did not reach significance between children with DCD and TD children, although scores in the DCD children were generally lower (DCD median score= 55.6 ± 27.6; TD median score= 74 ± 17.9; p=0.164) (Table 3).

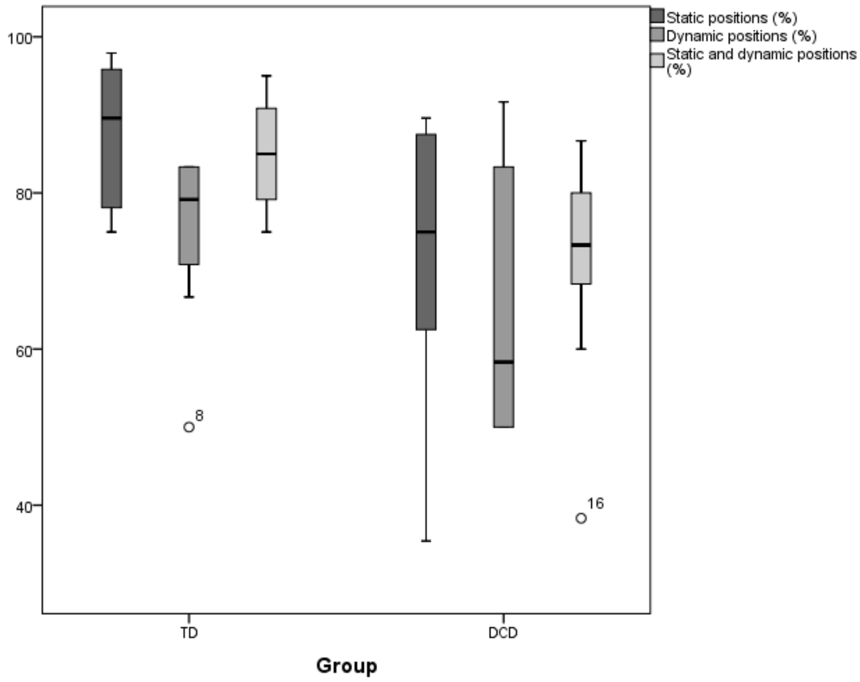

Figure 7a: Boxplot of difference in static, dynamic and meaningless gestures of the imitation test between TD- and DCD group are displayed.

Boxplot shows: minimum, first quartile, median, third quartile and maximum.

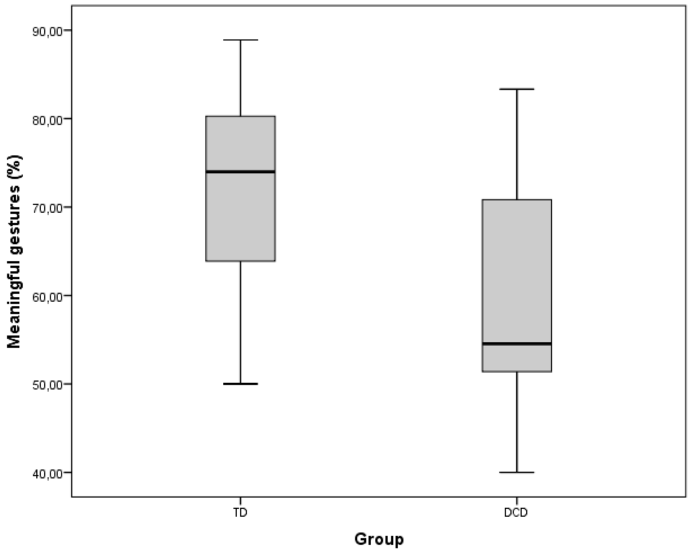

Figure 7b: Boxplot of difference in meaningful gestures of the imitation test between TD- and DCD group are displayed.

Boxplot shows: minimum, first quartile, median, third quartile and maximum.

Table 3: Comparisons of group medians between TD children and children with DCD

	Median (IQR) TD	**Median (IQR) DCD**	**P-value**
MABC-2			
Manual dexterity (SS)	9.5 (3)	4 (3)	0.004*
Aiming and catching (SS)	9.5 (5)	5 (6)	0.003*
Total standard score	10 (3)	5 (2.3)	<0.0001*
TYNESIDE PEGBOARD TEST			
Large pegs, dominant hand	12.5 (1.6)	15.6 (4.1)	0.026*
Large pegs, acoustic dual task	14 (4.6)	17.4 (8.2)	0.155
Large pegs, non-dominant hand	14 (2.6)	16 (2.87)	0.013*
Small pegs, dominant hand	13.2 (2.6)	17.3 (5.9)	0.004*
Small pegs, acoustic dual task	14.2 (4.1)	18 (8.1)	0.021*
Small pegs, non-dominant hand	14.4 (3)	19.5 (6.4)	0.009*
Large pegs, bimanual task	18.4 (2.5)	21.3 (6.5)	0.010*
ACTION OBSERVATION TEST			
EASY			
Spontaneous execution time (seconds)	24.2 (12.2)	46.4 (36)	0.105
Imitation first strategy score	3 (1)	2 (1)	0.015*
Imitation first strategy time (seconds)	26.1 (15.4)	51.3 (27.8)	0.115
Imitation second strategy score	2 (3)	2 (2)	0.824
Imitation second strategy time (seconds)	18.25 (23)	23 (26.3)	0.529
COMPLEX			
Spontaneous execution time (seconds)	113.6 (57.1)	124.1 (107.9)	0.935
Imitation score	2 (2)	2 (2)	0.069
Imitation time (seconds)	88.4 (35.6)	93.4 (12.4)	0.338
IMITATION TEST			
MEANINGLESS:			
Static gestures (%)	89.6 (18.2)	75 (24.5)	0.023*
Dynamic gestures (%)	79.2 (14.6)	58.3(33.3)	0.318
Static and dynamic gestures (%)	85 (12.5)	70.8 (15.4)	0.009*
MEANINGFUL:			
Meaningful gestures (%)	74 (17.9)	55.6 (27.5)	0.164

SS= Standard Score; %= percentage; *p<0.05

Table 4: Descriptive results of differences in task conditions in TD children and children with DCD

	P-value TD	**P-value DCD**
TYNESIDE PEGBOARD TEST		
Dominant VS non dominant		
Large pegs	0.208	0.037*
Small pegs	0.069	0.260
Unimanual VS bimanual		
Large pegs	0.012*	0.005*
Acoustic dual task VS no dual task		
Large pegs	0.05*	0.013*
Small pegs	0.123	0.678
IMITATION TEST		
MEANINGLESS: static VS dynamic gestures	0.063	0.514

*p<0.05

Discussion

This pilot study aimed to investigate the underlying processes for problems in manual skills in children with DCD compared to TD children. Children with DCD face problems with motor planning and execution of motor activities that mainly affect manual activities (Adams et al., 2014) (Bieber et al., 2016). Four assessments were performed to examine the different aspects of manual function: the MABC-2, the tyneside pegboard test, an experimental action observation test and an experimental imitation test. Overall, the included tests seemed to discriminate well between children with DCD and TD children in terms of manual skills.

The subtests 'manual dexterity' and 'aiming and catching' of the MABC-2 and the tyneside pegboard test were used to evaluate motor execution of manual tasks. The MABC-2 is a reliable and valid measure to assess motor competence in children with DCD (Wuang et al., 2012). The tyneside pegboard test is an experimental task with currently no psychometric characteristics available. Results showed that children with DCD scored significantly lower on the subtests 'manual dexterity' and 'aiming and catching' of the MABC-2 compared to TD children. Concerning the tyneside pegboard test, children with DCD moved the pegs significantly slower in all test conditions (unimanual and bimanual, large and small pegs). Literature confirms these findings. Children with DCD have problems with the link between aiming and catching, they move slower and less accurate (Przysucha & Maraj, 2013). Likewise, children with DCD move less accurately and correct their movements more slowly in comparison to TD children while performing a placing task (Fuelscher, Williams, Enticott, & Hyde, 2015).

Two hypotheses can explain the underlying processes of problems with manual skills of children with DCD: (1) 'automatization deficit hypothesis' and (2) 'internal modeling deficit hypothesis'.

According to the 'automatization deficit hypothesis', children with DCD have reduced ability to acquire new skills through repetitive training. They can improve a given task with practice, but they do not necessarily reach automatization (Biotteau et al., 2015). This hypothesis was evaluated by a dual-task paradigm in which a cognitive and a motor task were combined. Data analysis of the tyneside pegboard test showed that children with DCD and TD children needed more time to perform the dual task in comparison to the single task. Only a significant difference was found when the task was performed with large pegs. This could be due to a learning factor, since the task was always first performed with the large pegs. If children with DCD and TD children were compared to each other, children with DCD moved the small pegs significantly slower than TD children. Recent literature showed that children with DCD were generally slower than TD children when performing a complex perceptuomotor adaptation task which suggested that their perceptuomotor procedural learning abilities were preserved (Lejeune, Wansard, Geurten, & Meulemans, 2016).

The 'internal modeling deficit hypothesis' suggests that children with DCD have a deficient internal model that cannot accurately predict the sensory consequences of a motor task (Adams et al., 2014). In addition, a good internal representation of movements is essential for the development of motor imagery and imitation. Children with DCD have a deficit in their MNS, which is active during both action execution and action observation or imagery. These motor imagery deficits may lead to delays in motor development (Reynolds et al., 2015). In this study, two experimental tasks were used to examine the visuo-spatial processing and internal representation of movements.

First, an experimental action observation test was used to evaluate the deficit in the MNS. Concerning the time of the spontaneous execution and the execution time of the first and second strategy of the easy task, no significant differences were found between both groups. Regarding the quality of execution, children with DCD paid significantly less attention to details like 'how to screw a bolt on a nut' or 'were attach the sticks' in the imitation of the first strategy. No significant difference was found for the quality of execution of the second strategy. Finally, the time and quality of execution of the complex task did not reach significance.

Second, an experimental test was used to evaluate the imitation skills of children with DCD in comparison to TD children. Data analyses of the percentage score revealed that children with DCD scored significantly lower on the total score of meaningless gestures, particularly on the static gestures. This finding underlines the imitation difficulties in children with DCD reflecting a probable MNS dysfunction. For the dynamic gestures, no significant difference was found. Imitating dynamic gestures was, for all participants, more difficult than imitating static gestures, because of the complexity of the task. However, this difference did not reach significance. Further, children with DCD performed the task less accurately compared to TD children. For meaningful gestures, no significant difference was found between children with DCD and TD children, although scores in the DCD children were generally lower. The most frequent type of error was the use of a body-part as object (e.g. using their finger as scissors). Evidence has been reported for this deficits in imitation of meaningful gestures. Reynolds et al. (2015) found that children with DCD displays deficits imitating meaningful and novel gestures. Sinani, Sugden, and Hill (2011) found that children with DCD showed an impaired ability to produce familiar gestures, dependent on the type of gesture and presentation modality. Finally, Zoia, Pelamatti, Cuttini, Casotto, and Scabar (2002) found that children with DCD experienced difficulties in using sensory-motor information and integrating it into a motor representation, this suggested a general maturational delay in imitating limb gestural skills.

Further, it is important to acknowledge the limitations of this research. The most important remark was the small sample size. In order to maximize the power of the study, it is advisable to recruit more participants. Another limitation was that both Belgian and Italian children were recruited and compared to each other although the cultural influence is yet unknown. Concerning the experimental tasks, further research into reliability and validity needs to be done. For the tyneside pegboard test, also norm values should still be described. Finally, videos instead of life presentation of the gestures can further standardize the protocol of the imitation test and improve inter-rater reliability. Further longitudinal research to investigate the development of manual skills might be a focus for future research.

In conclusion, children with DCD experienced difficulties in all tasks measuring manual function used in this pilot study in comparison to TD children. These difficulties were less accurate movements, decreased ability to perform dual tasks and problems with both imitation and action observation. These differences could be explained by the two hypotheses that explain the underlying neural processes of problems with manual skills of children with DCD. The present findings warrant further research in children with DCD, to obtain a better understanding of the factors that underlie their (in)ability in manual function. These insights are important for optimizing an individually targeted treatment approach in children with DCD.

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