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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Dual task performance and automatization of movement of manual skills in children with developmental coordination disorder

Lieselotte Holsbeek
Lieselotte Martens

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij kinderen

PROMOTOR :
Prof. dr. Katrijn KLINGELS

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Acknowledgement

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Research context

This master thesis in paediatric rehabilitation forms part of current research about dual task (DT) performance and automatization of movement of manual skills in children with Developmental Coordination Disorder (DCD) compared to typically developing (TD) peers. Previously conducted research was established by Prof. dr. Katrijn Klingels (UHasselt), Prof. H. Feys (KU Leuven) and E. Bieber (Stella Maris Institute in Pisa, Italy). In this study, first, DT performance and the level of automatization of movement of manual skills will be compared between the above-mentioned groups. Second, solely performance within the DCD group will be compared.

Only few studies in current literature, mostly with a small sample size, addressed the previously mentioned topic. Those studies indicated that children with DCD reveal poor DT performance and automatization of movement in comparison to TD children. However, some articles showed inconsistent results (Cherng, Liang, Chen, Y. J., & Chen, J. Y., 2009; Tsai, Pan, Cherng, & Wu, 2009). The latter studies suggested that DT performance depends on primary and secondary task nature, and that these tasks should be difficult enough to interfere with motor performance. The purpose of this study is to gain useful information about the automatization deficit hypothesis in children with DCD compared to TD children regarding manual skills (Fawcett & Nicolson, 1992). This information could be useful to define appropriate treatment plans for this target population.

Prof dr. K. Klingels and E. Bieber developed two slightly different study protocols. In the first study part, participants were recruited and pilot data were collected at the KU Leuven sports centre and the Stella Maris Institute. These data were analysed before in a master thesis by Saar Vandepoel (2017). She compared DT performance and automatization of movement of manual skills in children with DCD to TD children. After finishing the latter study, clinical feasibility of the protocol was discussed by experts based on the results and discussion section. Then, adjustments were made to set up consecutive research. Participant recruitment and data collection following the adapted protocol already started and are still ongoing at the Stella Maris Institute. Thus, only preliminary results were addressed in the second study part. We processed the obtained data, performed statistical analysis of both study protocols and wrote this article under the direction of Prof. dr. K. Klingels.

1. Abstract

Background: Children with Developmental Coordination Disorder (DCD) often experience difficulties with manual skills that interfere with activities of daily living (ADL). One hypothesis that could explain the cause of these difficulties is the automatization deficit hypothesis, which can be explored following the dual task (DT) paradigm.

Objectives: The goals of this study were: (1) to explore the DT paradigm and manual motor task performance in children with DCD compared to age- and sex-matched TD children, (2) to study the impact of manual dexterity and motor task variation on motor performance and (3) to investigate the correlation between manual motor performance and the motor skills level.

Participants: Eighteen participants, whereof 10 children with DCD and eight age- and sex matched TD children, between 6 and 10 years old were enrolled in the first study part. Twelve children with DCD between 5 and 10 years old were included to carry out the adapted protocol.

Measurements: The Movement Assessment Battery for Children, 2nd edition (M-ABC 2) and the Tyneside Pegboard Test (TPT) with and without a concurrent acoustic task were administered.

Results: Outcomes of the TPT were significantly worse for children with DCD relative to TD children, except for the large peg DT condition with the dominant hand and dual task effect (DTE) percentage. Further, the initial protocol showed more significant within-group differences for the DCD- compared to the TD group: for (1) single task (ST) versus DT conditions, (2) small peg versus large peg conditions, (3) dominant versus non-dominant hand conditions and (4) negative correlation between M-ABC 2 percentiles and TPT duration. However, the adapted protocol only showed a significant difference for small peg versus large peg conditions.

Conclusion: Children with DCD revealed poor manual motor performance compared to TD children. Both groups experienced a similar amount of DT cost, meaning that there was a comparable negative impact of the secondary task on TPT duration. This surprisingly contradicts the automatization deficit hypothesis as a possible cause for DCD. Perhaps, the implemented tasks, particularly the acoustic one, were too easy to interfere with motor performance.

Abbreviations used in this study can be retrieved in the Appendix (Table 1).

2. Introduction

Children with developmental disorders, such as Developmental Coordination Disorder (DCD), often experience problems with manual skills. These problems interfere with activities of daily living (ADL) like writing, tying shoelaces, getting dressed or playing sports. Additionally, children with DCD avoid certain activities due to poor ADL performance compared to their peers (Van der Linde, van Netten, Otten, Postema, Geuze, & Schoemaker, 2015; Zwicker, Missiuna, Harris, & Boyd, 2012). The prevalence of DCD is 5 to 6% in school-aged children, with a higher prevalence in boys compared to girls (2:1 to 7:1) (American Psychiatric Association, 2013; Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). Up to 50 to 70% of the children with DCD experience associated problems such as learning and behaviour difficulties that interfere with academic performance and social life in their adolescence (Cantell, Smyth, & Ahonen, 2003). Diagnosis of DCD is based on four criteria of the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-V): (1) motor skill acquisition and execution do not meet the expected chronological age-related levels, (2) motor skill difficulties interfere with ADL (impact on work-, academic- and leisure performance), (3) motor skill difficulties start in the early developmental period, and (4) motor skill difficulties cannot be declared by intellectual disability, visual impairment or a neurological disorder (American Psychiatric Association, 2013).

There is no conclusive evidence about the pathophysiology that causes DCD. Adams, Lust, Wilson, & Steenbergen (2014) stated that DCD is a result of diffuse brain dysfunction, rather than an abnormality in one specific brain area. Up until now, etiology is based upon various theories (Flouris, Fought, Hay, & Cairney, 2005). One of the hypotheses underlying motor skill difficulties in DCD is the automatization deficit hypothesis, founded by Fawcett & Nicolson (1992), which points to an involvement of the cerebellum. The authors stated that there seems to be a deficit in the last stage of motor learning, where automatization of movement occurs. As Biotteau, Chaix, & Albaret (2015) defined, a task is completely automatized when it can be performed "effortlessly even when attention is directed elsewhere and without paying attention to the movements being produced".

The standardized method to verify if a task is automatized is the dual task (DT) paradigm (Passingham, Weinberger, & Petrides, 1996). This paradigm investigates whether or not two tasks can be performed simultaneously with minimal interference. Examples often used in physical therapy are walking while counting (motor-cognitive DT paradigm) or walking while clapping your hands (motor-motor DT paradigm). Only few studies, mostly with small sample sizes, addressed DT performance and automatization of movement in children with DCD. Up until now, most of the existing literature indicated that children with DCD reveal poor DT performance and automatization of movement in comparison to typically developing (TD) children (Biotteau et al., 2015; Chen, Tsai, Stoffregen, Chang, & Wade, 2012; Laufer, Ashkenazi, & Josman, 2008; Lejeune, Wansard, Geurten, & Meulemans, 2016; Schott, El-Rajab, & Klotzbier, 2016). However, other studies with inconclusive results showed that DT performance depends on primary and secondary task nature, and that these tasks should be difficult enough to interfere with motor performance (Cherng et al., 2009; Tsai et al., 2009). Earlier research differed regarding the study type, sample size, inclusion of a control group, M-ABC 2 cut-off values, task choice, usage of the DT paradigm and outcome measures (Biotteau et al., 2015; Biotteau et al., 2017, Chen et al., 2012; Cherng et al., 2009; Laufer et al. 2008; Lejeune et al., 2016; Schott et al., 2016, Tsai et al., 2009). For this reason, it is hard to make an overall conclusion about the study results. In the future, studies following a similar design need to be conducted to assure generalisability of results about DT performance and automatization of movement in children with DCD compared to TD age-related children.

Therefore, the first research aim was to explore the DT paradigm and manual motor task performance in children with DCD compared to age- and sex-matched TD children. The second research aim was to study the impact of manual dexterity and motor task variation on motor performance. Third, the correlation between manual motor performance and the motor skills level, as measured by the Movement Assessment Battery for Children, 2nd edition (M-ABC 2), was considered. This research could contribute to the current understanding of motor learning in children with DCD and may optimize an individualized treatment approach.

3. Methods

This two-part observational cross-sectional study was carried out in collaboration with KU Leuven and the Stella Maris Institute in Pisa (Italy). In the first study part, pilot data collected following an initial protocol, analysed before in a master thesis by Saar Vandepoel (2017), were addressed. The initial protocol can be retrieved in the Appendix (Document 1). After finishing the pilot study, clinical feasibility of the protocol was discussed by experts based on the results and discussion section. Then, adjustments were made to set up consecutive research. The adapted protocol can be retrieved in the Appendix (Document 2). Participant recruitment and data collection following the latter protocol already started and are still ongoing at the Stella Maris Institute. Thus, only preliminary results were addressed in the second study part.

Study approval was given by the ethical committee of UZ KU Leuven/research (3/3/2016, S58819).

3.1 Participant recruitment

In the first study part, children with DCD were recruited at the Stella Maris Institute in Pisa and 'vzw Dyspraxis' in Flanders. A control group of TD children was recruited through colleagues, friends and family of the Belgian and Italian researchers. In the second study part, solely a sample of children with DCD was recruited at the Stella Maris Institute.

Children with DCD were diagnosed according to the DSM-V criteria (American Psychiatric Association, 2013). Inclusion criteria were: (1) M-ABC 2 score ≤ 16^{th} percentile, (2) age of 5 to 10 years old, (3) comprehending and speaking Italian or Dutch and (4) cooperation during test procedure.

Typically developing children were matched for sex and age. Inclusion criteria were: (1) M-ABC 2 score > 16^{th} percentile, (2) age of 5 to 10 years old, (3) comprehending and speaking Italian or Dutch and (4) cooperation during test procedure.

Exclusion criteria for both groups were: (1) a visual impairment or neurological condition that could interfere with motor performance, measured by a parental questionnaire, and (2) a cognitive delay or intellectual disability, measured in case of doubt with an intelligence test performed by a psychologist.

3.2 Outcome measures

First, the M-ABC 2 was completed. Thereafter, children performed a set of consecutive TPT trials during one and the same appointment at the KU Leuven sports centre or the Stella Maris Institute.

3.2.1 Movement Assessment Battery for Children, 2nd edition

The M-ABC 2 is a tool to identify a motor function impairment in 3- to 16-year-old children. It contains a checklist and an assessment battery. The latter incorporates eight tasks for each of three age ranges (3-6 years, 7-10 years, 11-16 years), which are divided into three domains: manual dexterity, aiming and catching, and static and dynamic balance (Wuang, Su J.H., & Su C.Y., 2012). Standard scores and percentiles are available for each domain and the total test score. The M-ABC 2 is considered to be reliable and valid for both TD children and children with DCD (Blank et al., 2012; Ellinoudis, Evaggelinou, Kourtessis, Konstantinidou, Venetsanou, & Kambas, 2011; Psotta, & Abdollahipour, 2017; Wagner, Kastner, Petermann, & Bos, 2011; Wuang et al., 2012).

Test administration lasts 20 up to 30 minutes.

3.2.2 Tyneside Pegboard Test

The Tyneside Pegboard Test (TPT) is a modified version of the Nine-Hole Peg Test (9-HPT). It includes two electronic pegboards with nine holes each, nine small pegs, nine large pegs and a Perspex screen (Figure 1). Psychometric characteristics for the DCD population have not been published yet. Basu, Kirkpatrick, Wright, Pearse, Best, & Eyre (2018) provided TD norm values and validation of the test for children with unilateral cerebral palsy. Children were asked to transfer nine pegs from one pegboard to the other as quickly as possible. The time from picking up the first peg until inserting the last peg was registered for each trial by the electronic pegboard. Two different unimanual motor single task (ST) conditions (one with large and one with small pegs) were executed with both the dominant and non-dominant hand. In the bimanual condition, which was only completed with large pegs, participants were asked to pick up a peg with the dominant or non-dominant hand leading, transfer it through a Perspex screen to the other hand and put it in the other pegboard. In the DT condition, children performed the unimanual motor task while performing a concurrent acoustic task. Children heard the sound of a helicopter or an airplane in random order and were asked to say ‘yes’ each time they recognized the indicated sound. In the second study part, additionally, video recordings were made to count the percentage of correct answers on the acoustic task. At the beginning of each new test condition, a practice trial with three pegs was given to gain task confidence. Breaks were included during the procedure to avoid fatigue.

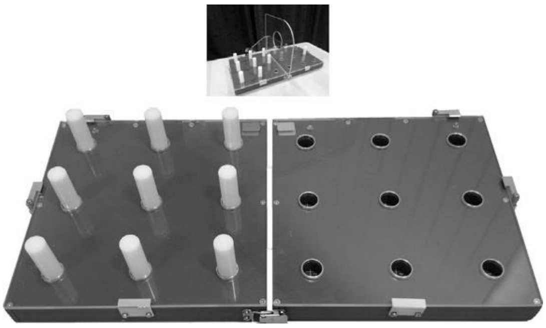


Figure 1. The Tyneside Pegboard Test (TPT) (Basu et al., 2018)

Furthermore, the motor dual task effect (DTE) was calculated to compare TPT duration of the ST and DT condition according to the formula described by Plummer & Eskes (2015):

$$DTE\ (\%) = \frac{-(DT\ performance - ST\ performance)}{ST\ performance} \times 100\ \%$$

The negative sign in the formula signifies that a longer TPT duration suggests a worse task performance. For that reason, a negative DTE means that the motor performance was not as good in the DT condition as in the ST condition due to the impact of a secondary task. This can be described as the DT cost. A positive DTE means that children performed better in the DT condition compared to the ST condition due to the impact of a secondary task. This represents the DT benefit.

Total test administration lasts 20 minutes.

3.3 Test procedure

Regarding the test procedure, there were some differences between both protocols. For example, the starting position of participants was based on hand preference in the initial protocol. Right handed children started consistently at the left pegboard, while left handed children commenced right. In the unimanual motor ST and DT condition, every child performed the test from left to right and vice versa. Each trial was performed once. The mean value of both directions was calculated to implement in data analysis. In the adapted protocol however, children started always at the left side of the pegboard regardless of hand preference. They only completed the experimental conditions from left to right. Each trial was performed twice. The best performance was used in data analysis. Secondly, in the initial protocol, the DT was performed with both small and large pegs, while in the adapted protocol solely small pegs were used. Moreover, initially, the experimental conditions were completed following one and the same order. In the adapted protocol, these were administered in blocks of random according to one out of six different test procedure sheets (Appendix: Document 3). Finally, children listened to both the sound of the helicopter and airplane before testing in the initial protocol. They were asked to choose at which sound they wanted to say ‘yes’. In the adapted protocol, each and every child had to say ‘yes’ at the sound of the helicopter.

3.4 Data analysis

The IBM SPSS statistics 25 software was used to perform data analysis. Probability level (p-value) <0.05 was considered statistically significant. Baseline between-group differences for participant characteristics were assessed following descriptive statistics in the initial protocol. In addition, nonparametric statistics were used due to small sample sizes: the Mann-Whitney U test to compare between-group differences and the Wilcoxon Signed Rank test to investigate within-group differences.

A Spearman's rank-order correlation coefficient was used to examine the correlation between TPT performance and M-ABC 2 percentiles. Schober, Boer & Schwarte (2018) presented the correlation coefficient interpretation as negligible ($\rho = 0.00 – 0.10$), weak ($\rho = 0.10 – 0.39$), moderate ($\rho = 0.40 – 0.69$), strong ($\rho = 0.70 – 0.89$) and very strong ($\rho = 0.90 – 1.00$). Solely in the adapted protocol, a Spearman's rank-order correlation coefficient was applied to compare the motor DTE and the percentage of correct answers on the acoustic task.

4. Results

An overview table of data used in statistical analysis per participant can be retrieved in the Appendix (Table 2 and 3).

4.1 Initial study protocol

In this study part, both children with DCD and TD children were included. Table 4 shows the characteristics of all 18 participants. No significant between-group differences were found regarding age (p=0.859), gender (p=1.000) and country (p=0.608).

Table 4
Initial protocol: participant characteristics of the DCD and TD group, with mean values and M-ABC 2 percentiles (± standard deviations).

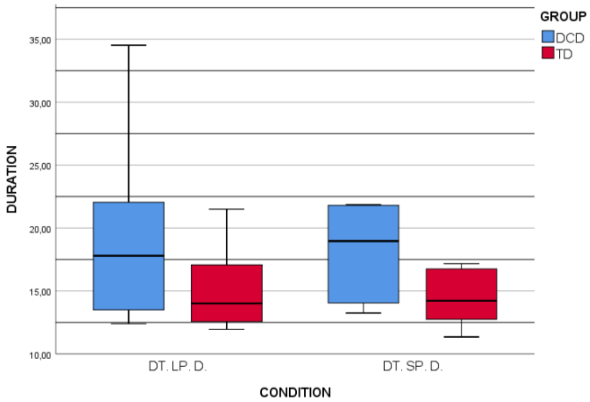
	DCD (n = 10)	TD (n = 8)	SIGNIFICANCE LEVEL (p)
Participant characteristics			
Age (years.months)	8.1 ± 1.3	8.2 ± 1.3	p = 0.859
Gender (boys:girls)	7:3	5:3	p = 1.000
Country (Italy:Belgium)	8:2	5:3	p = 0.608
M-ABC 2 percentiles			
Total test score	6.37 ± 6.30	56.63 ± 18.75	p < 0.001*
Manual dexterity	10.51 ± 22.90	38.38 ± 17.70	p = 0.004*
Aiming and catching	11.57 ± 15.63	53.25 ± 30.16	p = 0.003*
Balance	24.91 ± 30.56	66.50 ± 20.25	p = 0.010*

*M-ABC 2= Movement Assessment Battery for Children, 2nd edition; DCD= Developmental Coordination Disorder; TD= typically developing; *= statistically significant p<0.05*

4.1.1 Dual task paradigm and manual motor task performance

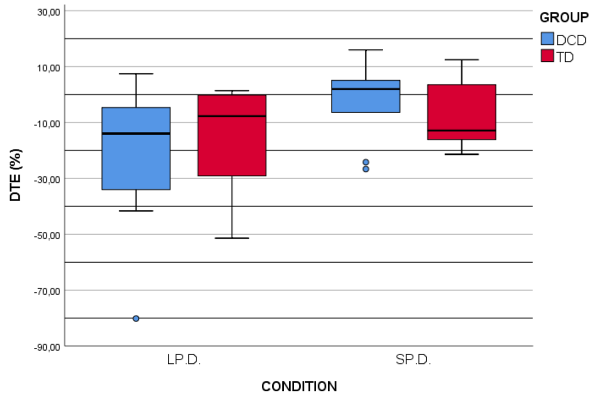
4.1.1.1 Between-group differences

Children with DCD performed the small peg DT condition significantly slower than the TD children (p=0.021). However, no statistically significant difference between groups was found for the large peg DT condition (p=0.155) (Figure 2). Further, there were no significant differences in motor DTE between groups for the large (p=0.477, DCD; mean DTE (%)= -21,12 ± 25,41, TD; mean DTE (%)= -15,51 ± 20,63) and small peg condition (p=0.424, DCD; mean DTE (%)= -2,39 ± 13,82, TD; mean DTE (%)= -7,48 ± 12,56) (Figure 3). This means that, although there were significant between-group differences in time to perform the dual task with the small pegs, the effect of the secondary task on TPT duration in the DT condition was similar for children with DCD and TD children.



DCD= Developmental Coordination Disorder; TD= Typically developing; DT= dual task; LP= large pegs; SP= small pegs; D= dominant hand

***Figure 2**: TPT duration in function of the DT condition with the dominant hand regarding the DCD and TD group.*

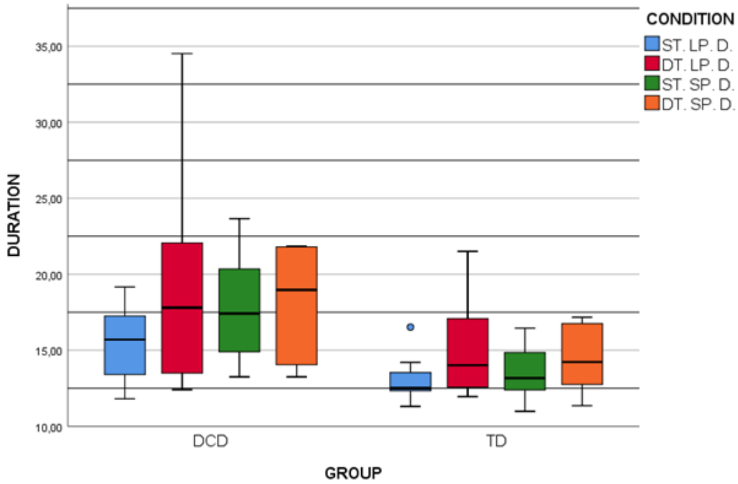


DCD= Developmental Coordination Disorder; TD= Typically developing; DTE= Dual task effect; LP= large pegs; SP= small pegs; D= dominant hand

***Figure 3**: Motor DTE (%) in function of the small peg and large peg condition with the dominant hand regarding the DCD and TD group.*

4.1.1.2 Within-group differences

There were no statistically significant within-group differences for TPT duration in the small peg ST condition compared to the DT condition (DCD; p=0.678, TD; p=0.123). The timespan to complete the test with the small pegs was similar in both conditions, which means children did not slow down while executing the concurrent task. However, the DCD group performed the large peg DT significantly slower compared to the ST (DCD; p=0.013). The TD group revealed a similar trend, although this was not significant (TD; p=0.050) (Figure 4).



DCD= Developmental Coordination Disorder; TD= Typically developing; DT= dual task; ST= single task; LP= large pegs; SP= small pegs; D= dominant hand

***Figure 4**: TPT duration in function of the research group regarding ST and DT conditions with the dominant hand.*

4.1.2 Impact of manual dexterity and motor task variation on motor performance

4.1.2.1 Between-group differences

TPT duration was significantly longer in children with DCD compared to TD children for the dominant and non-dominant hand in both the small peg ST condition (dominant; p=0.004, non-dominant; p=0.009) and in the large peg ST condition (dominant; p=0.026, non-dominant; p=0.013). Furthermore, the DCD group performed the bimanual task significantly slower than the TD group (p=0.010).

4.1.2.2 Within-group differences

Performance with the dominant and the non-dominant hand were comparable within groups for the small peg ST condition (DCD; p=0.260, TD; p=0.069). Nevertheless, children with DCD moved the large pegs significantly slower with the non-dominant hand compared to the dominant hand (p=0.037). This was not the case for TD children (p=0.208). In both groups, increasing task duration was observed in the small peg ST condition compared to the large peg ST condition with the non-dominant hand (DCD; p=0.028, TD; p=0.025), and in the DCD group also with the dominant hand (DCD; p=0.022, TD; p=0.484). However, no statistical differences were found between small and large pegs in the DT condition (DCD; p=0.445, TD; p=0.674).

4.1.3 Correlation between manual motor performance and the motor skills level

The correlation between the duration of the TPT conditions with the dominant hand and the M-ABC 2 score percentile for the participants altogether was calculated. Because the TPT predominantly requires the application of fine motor skills, only the percentiles of subdomain manual dexterity and the total score were used. An overview of the correlations can be retrieved in Table 5.

The M-ABC 2 total score percentile and TPT duration were moderately negatively correlated in all conditions (ST.SP.D.; ρ=-0.627, DT.SP.D.; ρ=-0.500, ST.LP.D.; ρ=-0.500, DT.LP.D.; ρ=-0.414, BT.LP.; ρ=-0.668). This means that a lower motor skills level corresponded in a moderate manner with a higher TPT duration and thus a minor performance. Manual dexterity on its own showed moderate (BT.LP.; ρ=-0.415) and weak (ST.SP.D.; ρ=-0.330, DT.SP.D.; ρ=-0.299, ST.LP.D.; ρ=0.268, DT.LP.D.; ρ=-0.173, BT.LP.; p=0.087) negative correlations with the TPT duration.

Table 5
Initial protocol: M-ABC 2 and TPT duration correlation

M-ABC 2 DOMAIN	TEST CONDITION	CORRELATION COEFFICIENT (ρ)	CORRELATION SIGNIFICANCE LEVEL (p)
Total test score	ST. SP. D.	ρ = - 0.627	p = 0.005*
	DT. SP. D.	ρ = - 0.500	p = 0.035*
	ST. LP. D.	ρ = - 0.500	p = 0.035*
	DT. LP. D.	ρ = - 0.414	p = 0.087
	BT. LP.	ρ = - 0.668	p = 0.002*
Manual dexterity	ST. SP. D.	ρ = - 0.330	p = 0.181
	DT. SP. D.	ρ = - 0.299	p = 0.229
	ST. LP. D.	ρ = - 0.268	p = 0.281
	DT. LP. D.	ρ = - 0.173	p = 0.492
	BT. LP.	ρ = - 0.415	p = 0.087

*M-ABC 2= Movement Assessment Battery for Children, 2nd edition; TPT= Tyneside Pegboard Test; ST= single task; DT= dual task; BT= bimanual task; SP= small pegs; LP= large pegs; D= dominant hand; *= statistically significant p<0.05*

4.2 Adapted protocol

In this study part, solely a sample of children with DCD was recruited. Three out of 15 participants were excluded due to excessive missing data. Characteristics of the 12 remaining participants can be retrieved in Table 6.

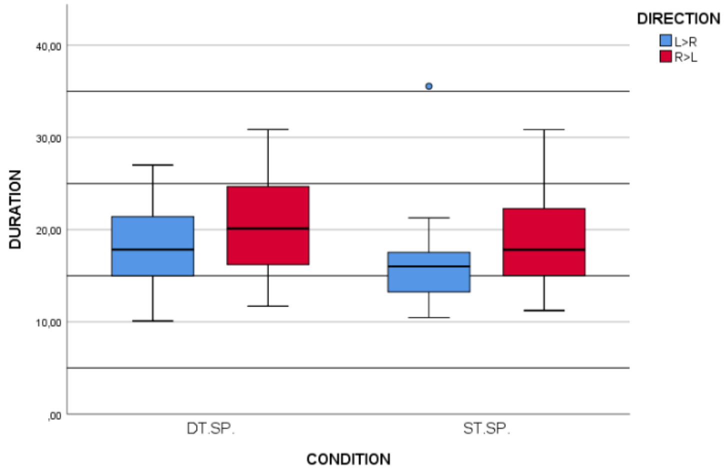
Table 6
Adapted protocol: participant characteristics of the DCD group, with mean values and M-ABC 2 percentiles (± standard deviations).

	DCD (n = 12)
Participant characteristics	
Age (years.months)	7.8 ± 1.8
Gender (boys:girls)	8:4
M-ABC 2 percentiles	
Total test score	2.35 ± 2.90
Manual dexterity	5.67 ± 10.22
Aiming and catching	11.76 ± 10.67
Balance	5.55 ± 7.70

M-ABC 2= Movement Assessment Battery for Children, 2nd edition; DCD= Developmental Coordination Disorder

4.2.1 Dual task paradigm and manual motor task performance

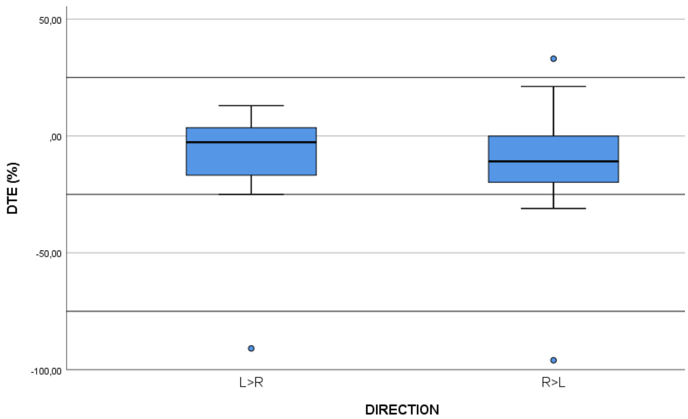
The TPT duration did not differ between the small peg ST and DT condition (dominant direction (L>R); p=0.169, non-dominant direction (R>L); p=0.239). This means motor performance did not deteriorate meanwhile executing the secondary task (Figure 5).



DT= dual task; SP= small pegs; L>R= transfer from left to right; R>L= transfer from right to left

***Figure 5**: TPT duration in function of the test condition regarding the transfer direction.*

Additionally, the motor DTE and the percentage of correct answers on the acoustic task in DT condition were calculated for both the dominant (L>R) (mean DTE (%) = -17,51 ± 36,70; mean correct answers (%) =90,74 ± 22,22) and non-dominant direction (R>L) (mean DTE (%) =-12,83 ± 31,74; mean correct answers (%) =82,61 ± 18,38). The impact of a secondary task on TPT duration resulted in a larger execution time compared to the ST condition. For that reason, there was a DT cost in both directions (Figure 6). The Spearman's rank-order test showed a positive moderate and a weak correlation coefficient between the motor DTE and percentage of correct answers on the acoustic task, from L>R (ρ=0.525; p=0.147) and R>L (ρ=0.124; p=0.702), respectively. The positive correlation means that a smaller DT cost, and thus a less negative DTE, is correlated with a higher percentage of correct answers on the acoustic task while performing the TPT. Hence, the less impact the secondary task had on the TPT duration, the more correct answers were given on the acoustic task.



DTE= dual task effect; L>R= transfer from left to right; R>L= transfer from right to left

***Figure 6**: Motor DTE (%) in function of the transfer direction.*

4.2.2 Impact of manual dexterity and motor task variation on motor performance

Children performed the large peg ST condition from L>R faster compared to R>L (p=0.008). However, they translocated pegs equally as fast with both hands in the small peg ST (p=0.050), bimanual (p=0.878) and DT condition (p=0.050). Similarly, no statistically significant differences according to peg size were found (L>R; p=0.657, R>L; p=0.937).

4.2.3 Correlation between manual motor performance and the motor skills level

Moderate correlations between TPT duration and M-ABC 2 scores, although not significant, were found for both manual dexterity (ST.SP. (L>R); ρ=-0.458, BT.LP. (L>R); ρ=-0.479) and total score percentiles (ST.SP. (L>R); ρ=-0.408). This means that a lower motor skills level intended to correspond moderately with a higher TPT duration and thus a slower motor performance, for these conditions. However, the TPT duration in DT condition and M-ABC 2 only showed weak correlations (total test score versus DT. SP. (L>R); ρ=0.325, manual dexterity versus DT. SP. (L>R); ρ=-0.254). Results can be retrieved in Table 7.

Table 7

Adapted protocol: M-ABC 2 and TPT duration correlation

M-ABC 2 DOMAIN	TEST CONDITION	CORRELATION COEFFICENT (ρ)	CORRELATION SIGNIFICANCE LEVEL (p)
Total test score	ST. SP. (L>R)	ρ = - 0.408	p = 0.213
	DT. SP. (L>R)	ρ = 0.325	p = 0.330
	BT. LP. (L>R)	ρ = - 0.005	p = 0.989
Manual dexterity	ST. SP. (L>R)	ρ = - 0.458	p = 0.156
	DT. SP. (L>R)	ρ = - 0.254	p = 0.452
	BT. LP. (L>R)	ρ = - 0.479	p = 0.136

*M-ABC 2= Movement Assessment Battery for Children, 2nd edition; TPT= Tyneside Pegboard Test; ST= single task; DT= dual task; BT= bimanual task; SP= small pegs; LP= large pegs; (L>R) = transfer from left to right; *= statistically significant p<0.05*

5. Discussion

This two-part observational study aimed to explore the automatization deficit hypothesis as a possible cause of DCD based on the dual task paradigm (Fawcett & Nicolson, 1992). The results could contribute to the current understanding of motor learning in children with DCD and may optimize an individualized treatment approach.

5.1 Results section

The main goal of this study was to investigate the level of automatization of movement in children with DCD compared to age- and sex-matched TD children, by performing a manual motor task along with an acoustic task. Children with DCD completed the TPT significantly slower in most of the DT conditions, as was expected following earlier research (Biotteau et al., 2015; Chen et al., 2012; Laufer et al. 2008; Lejeune et al., 2016; Schott et al., 2016). However, in the initial protocol, no significant between-group differences were found in the large peg DT condition with the dominant hand. Previous studies mentioned that the incorporated primary and secondary tasks should be difficult enough to interfere with motor performance (Cherng et al., 2009; Tsai et al., 2009). Thus a possible reason could be that, in comparison with the small pegs, the condition with large pegs was not challenging enough to affect TPT duration while dual tasking.

Within groups, TPT duration increased from the large peg ST onto the DT condition, relative to the TPT duration from the small peg ST onto the DT condition. Solely in the DCD group a significant discrepancy was found. Possibly, the large peg DT condition was indeed more difficult than its ST condition in children with DCD. However, no differences were found between the small peg ST and DT condition. Perhaps both tasks were equally as demanding to perform, whereby it was more difficult to identify significant differences. Nonetheless, TD children did not show differences between both the small and large peg ST and DT condition. An explanation could be that the TPT was equally as easy in the latter test conditions. Further, it is important to mention that conditions with large pegs were consistently examined before conditions with small pegs. Subsequently, a potential learning effect in the DCD and TD group could influence TPT duration, but also the percentage of correct answers on the acoustic concurrent task in the small peg DT condition. However, this was not the case in the adapted protocol, in which only the small pegs were used in the DT condition. Hence, participants performed the acoustic task concurrently with the TPT for the first time.

Results of both study protocols showed an overall negative DTE, and thus a DT cost as was expected. Still some children showed a positive DTE effect, and thus a DT benefit. Possible reasons for the DT benefit are: (1) a learning effect on the TPT due to former execution in ST condition, (2) a secondary task that was not difficult enough to interfere with the primary task or (3) a primary task that was too easy or not interesting enough, whereby children were not focused or motivated to accomplish the TPT as quickly as possible in ST condition. Consequently, children could have been more challenged and more focused to achieve their best performance in the DT condition. Previous literature stated that executive functions, which include attention, are impaired in children with DCD. Their relative grey matter volume is not only reduced in motor, but also in attentional regions of the brain (Reynolds, Licari, Reid, Elliot, Bynevelt, & Billington, 2017). Additionally, Fong et al. (2016) revealed poor motor performance and more inattentiveness in children with DCD than in TD children. Moreover, the motor DTE did not differ between children with DCD compared to their TD peers. Both groups experienced a similar amount of DT cost, meaning that there was a comparable negative impact of the secondary task on TPT duration. This important finding contradicts the automatization deficit hypothesis, which was described by Fawcett & Nicolson (1992). In addition, results revealed a positive correlation between the motor DTE percentage and the amount of correct answers on the acoustic task. Thus, the better the motor performance while dual tasking, the higher was the percentage of correct answers on the acoustic task. This is contradictory to what was expected. One supposed a negative correlation following the DT paradigm, which means that children would focus more on one out of two tasks and the performance on the other task would decline. It is hard to justify these conflicting results. A feasible explanation could be that the primary task was too easy or not interesting enough. Motor performance then got better while executing a secondary task because children were more focused. In the other direction, the poorer the motor performance while dual tasking, the lower was the percentage of correct answers. This could mean that children with DCD cannot distinguish between several tasks when executing them concurrently. If so, they would not be able to answer correctly to the acoustic task meanwhile translocating the pegs even slower or taking breaks in motor execution to distinguish the sounds. Another reason could be the difficulty level of the secondary self-invented acoustic task. Up until now, few research about the impact of a concurrent acoustic task on motor performance was carried out. Solely Tsai et al. (2009) included an auditory-verbal task in addition to bipedal quiet stance, which is a gross motor ST. Here, a significant variation in sway area was exclusively observed in the DCD group in DT condition. Within groups, no significant differences in sway area in the DT condition compared to the ST condition were revealed for this task. Nonetheless, earlier research that examined the DT paradigm on a primary fine motor task in children with DCD compared to their peers, additionally revealed significant differences while dual tasking. The more complex secondary tasks performed in these studies were: (1) the picture naming task and (2) the Trail-Making-Test, where children had to trace over a dotted line to connect circles on a piece of paper (Biotteau et al., 2015, Biotteau et al., 2017, & Schott et al., 2016). Thus, perhaps the implemented acoustic-verbal task in the present study was too easy to interfere with fine motor performance.

Secondary, the impact of unimanual dexterity, bimanual dexterity and motor task difficulty on motor performance was examined. First of all, longer TPT durations were observed within the DCD group compared to the TD group for the unimanual and bimanual ST conditions. These findings confirm previous research, assuming that children with DCD perform fine motor skills more poorly compared to their peers (Wang, Tseng, Wilson, & Hu, 2009). It also supports the first DSM-V criterium to diagnose children with DCD, which states that motor skill acquisition and execution do not meet expected chronological age-related levels (American Psychiatric Association, 2013). Unimanual and bimanual tasks such as writing, using a cell phone or playing videogames are now more than ever embedded in children's daily life. Assuming that all participants already had experience with fine motor tasks, although not the TPT itself, these findings may declare the impact of DCD on manual skills in ADL.

In the initial study protocol, outcomes show that children performed the TPT significantly faster with the dominant hand compared to the non-dominant hand in the large peg condition, but not in the small peg condition. Perhaps, a learning effect exists due to the fact that dominant hand conditions were consistently examined before non-dominant hand conditions. Furthermore, it could be stated that small peg conditions with the dominant and non-dominant hand were both difficult for the DCD group, which would make it harder to detect differences between the two. Typically developing children show the same trend in outcomes. Only the small peg condition with the non-dominant hand was statistically significant. Thus, maybe the large peg dominant, large peg non-dominant and small peg dominant conditions were considerably easier compared to the small peg non-dominant condition. In the adapted study protocol, almost the same conditions were compared. Important to note is that here, the direction of peg translocation was examined instead of hand preference. Performing the TPT in the dominant direction means that pegs were transferred from left to right, which matches the writing direction in our Western culture (Waterman, Giles, Havelka, Culmer, Wilkie, & Mon-Williams, 2017). In short, this direction was assigned to be the most functional one in terms of ADL activities. And indeed, results showed better performance in the dominant direction compared to the non-dominant direction. However, differences seem harder to detect in the small peg and DT conditions. Again, this could possibly be declared by the fact that children with DCD already found it more difficult to perform the task following the dominant direction.

Basu et al. (2018) found that TD children completed the large peg conditions faster in comparison to the small peg conditions. Therefore, the large peg conditions were assumed to be easier compared to the small peg conditions. Results of the initial protocol confirmed this hypothesis. Nonetheless, outcomes of the adapted protocol did not reveal statistically significant differences between the two peg sizes. This inconsistency could possibly be explained due to the difference in study protocols. The initial protocol included more task conditions compared to the adapted protocol, which could have led to fatigue at the end of the testing procedure. This might have influenced actual task performance. For this reason, the hypothesis that tasks with the small peg size are indeed harder than tasks with the large peg size must be interpreted with caution.

Finally, the correlation between motor performance and the M-ABC 2 percentile was researched. Mainly, negative correlations were found. This means that the lower the TPT duration, the lower the M-ABC 2 percentiles were. Surprisingly, only in the initial protocol statistically significant correlations were found. Perhaps a stronger correlation in the latter protocol could be explained by the fact that here, the scores of the DCD as well as the TD group were implemented increasing the interindividual variability in both TPT durations and M-ABC 2 percentiles. Also, more participants were included in the data analysis. Notably, M-ABC 2 total test score percentiles showed stronger correlations compared to the manual dexterity percentiles. These findings were to our surprise because especially the subdomain manual dexterity is applicable for the TPT.

5.2 Study strengths and limitations

A small amount of participants were recruited, which led to a low statistical power. Furthermore, within-group comparability remains questionable because of the small sample size of children from different age categories (five years and 10 months up to 10 years and 10 months). Children step-by-step become more cooperative and establish a more stable motor- and ADL performance as they grow older, which means it would be hard to compare motor performance of younger with older children (Blank et al., 2012). However, each participant with DCD was diagnosed following the DSM-V criteria, with clear cut-off values for the Dutch version of the M-ABC 2. A TD control group was additionally recruited following the initial protocol. Thereby, motor performance in children with DCD could be compared to age- and sex-matched TD peers. Nonetheless, both Italian and

Belgian participants were enrolled. Niemeijer, van Waelvelde, & Smits-Engelsman (2015) revealed that M-ABC 2 norm values for children across countries are not always identical. Thus, a possible lack of comparability between Italian and Flemish children should be kept in mind. Due to unforeseen circumstances, only a small sample of children with DCD was included in the second study part. The timespan for data collection was too short to gather more DCD participants or a control group with TD peers. However, these are only preliminary results. Participant recruitment and data collection are still ongoing.

Another strength of this research was the implementation of the DT paradigm, because this is the standardized method to verify if a task is automated or not (Passingham et al., 1996). Basu et al. (2018) developed the TPT, which is an adapted version of the 9-HPT. It incorporates an asymmetrical bimanual task, is accessible to those with a disability affecting the hand function (distance between pegs was increased from 3.2 to 7.7cm, adding supplementary space for hand movements), and is suitable for use in a clinical setting. By modifying the 9-HPT, it allows us to compare unimanual and bimanual function, but also to research the effect of peg size on motor performance. For these reasons, the TPT was chosen instead of the 9-HPT to be included in this study. However, up until now the same authors only validated the test for children with unilateral cerebral palsy. Therefore it is unknown to which degree the TPT measures what it is supposed to measure in children with DCD. Furthermore, in the initial protocol, the percentage of correct answers could not be retrieved considering no video recordings were made. Therefore, the correlation between the motor DTE and percentage of correct answers was not calculated. Nonetheless, video recordings were made following the adapted protocol.

Although the primary and secondary task answered the criteria to investigate the study aims, their difficulty level was perhaps too low to make a statement about the level of automatization of movement in children with DCD compared to TD children. Unfortunately, no differentiation in secondary task difficulty was made. Moreover, the TPT is no functional task that can be used in ADL.

To end with, another advantage of this study was that data collection and analysis was independently performed by different investigators.

5.3 Future directions

First of all, more participants should be recruited in future research to assure higher power and thus generalizability of results. Further, a group of TD children should always be included to correlate primary and secondary task performance of children with DCD with reference values, otherwise motor performance in children with DCD cannot be compared to chronological age-related TD levels. Functional primary and secondary tasks executed in an ecological environment should be included to reflect ADL performance. Moreover, the difficulty level of the different tasks needs to be high enough to interfere with one another. Various primary and secondary tasks of a different difficulty level should be included. Further research should also consider the influence of confounding factors. Bernardi, Leonard, Hill, Botting, & Henry (2017) revealed that children with DCD and motor difficulties demonstrated executive function deficits, which may affect ADL and academic achievement, in addition to their motor deficits. Finally, longitudinal studies need to be carried out, to describe automatization of movement and its development over time more accurately.

6. Conclusion

Children with DCD revealed poor manual motor performance compared to TD children aged 5 to 10 years old. Motor execution of children with DCD and their peers in the DT condition was slower as in the ST condition due to the impact of the secondary task. However, the negative effect of the secondary task was similar between groups. This surprisingly contradicts the automatization deficit hypothesis as a possible cause for DCD. Furthermore, motor skills level (the M-ABC 2 percentile) was negatively correlated with manual motor performance. Results should be interpreted with caution, because of the small sample size. Possibly, the primary and secondary task implemented in this study were too easy to interfere with motor performance. The impact of attentional problems in children with DCD should also be taken into consideration. Therefore, further research is needed to make more well-founded statements about DT performance and automatization of movement in children with DCD compared to TD age-related children.

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8. Appendices

Table 1
Abbreviations

ABBREVIATION	MEANING
DCD	Developmental Coordination Disorder
TD	Typically developing
DSM-V	Diagnostic and Statistical Manual of Mental Disorders, fifth edition
ADL	Activities of daily living
M-ABC 2	Movement Assessment Battery for Children, 2nd edition
TPT	Tyneside Pegboard Test
ST	Single task
DT	Dual task
BT	Bimanual task
LP	Large pegs
SP	Small pegs
D	Dominant hand
L>R	Dominant direction: transfer from left to right
R>L	Non-dominant direction: transfer from right to left
DTE	Dual task effect
9-HPT	Nine-Hole Peg Test

Document 1
The initial study protocol

TYNESIDE PEGBOARD INSTRUCTIONS and SCORING SHEET

Setting: comfortable sitting position

Video recording: yes

Time: in the software

Experimental conditions:

1. UNIMANUAL TASK (BIG PEGS) DOMINANT HAND.

Starting position: comfortable direction, i.e:

- Right handed: left side
- Left handed: right side

The child is asked to pick and replace the pegs using onehand from one board to the other.

2. DUAL TASK

The child is required to perform the first task with his/her dominant hand meanwhile is has to pay attention to acoustic stimuli.

- Before the starting make the child listen the sounds.
- The task need to be repeated twice

4. UNIMANUAL TASK (BIG PEGS) NON-DOMINANT-HAND.

Starting position: right side for right-handed

Left side for left-handed

5. UNIMANUAL TASK (small pegs) DOMINANT-HAND.

6. UNIMANUAL TASK (small pegs) NON-DOMINANT HAND.

7. BIMANUAL TASK.

The child has to pick the pegs, one by one, as fast as possible, put them in the hole of the plastic screen, hold them with the other hand and replace them in the contralateral board.

Starting position:

- Right handed: right side
- Left handed: left side

PEGBOARD CHECKLIST

ID - Name	Date of birth	Date	Name tester

Begin with large board overlays and **large pegs** placed in right board				Time	Comment
Practice	LARGE	3 pegs	Dominant hand		
1	LARGE	L > R	Dominant hand		
2	LARGE	R >L	Dominant hand		
Give instruction on **acoustic dual task**					
5	LARGE	L > R	Dominant hand		
6	LARGE	R >L	Dominant hand		
Ask person to swap hands					
7	LARGE	L > R	Non dominant hand		
8	LARGE	R >L	Non dominant hand		
Change to small board overlays and **small pegs** placed in right board					
9	SMALL	L>R	Dominant hand		
10	SMALL	R>L	Dominant hand		
Give instructions on **acoustic dual task**					
13	SMALL	L>R	Dominant hand		
14	SMALL	R>L	Dominant hand		
Ask person to swap hands					
15	SMALL	L>R	Non dominant hand		
16	SMALL	R>L	Non dominant hand		
Change to large board overlays, place large pegs in left board, give person **bimanual** instructions					
Practice	LARGE	L>R	3 pegs		
17	LARGE	L > R	left hand leading		
18	LARGE	R > L	right hand leading		

Document 2
The adapted study protocol

TYNESIDE PEGBOARD INSTRUCTIONS

Setting: comfortable sitting position.

Video recording: yes (it's fundamental for the counting of answer during the dual task).

Time: in the software.

Procedure order: follow the different sheets (A,B,C,D,E,F) organized in a random order for dominant and non dominant hand. Prepare the condition in the software before the beginning of the task.

The dual task performance will be recored in a different file.

Experimental conditions:

UNIMANUAL TASK (BIG and SMALL PEGS) DOMINANT HAND and NON DOMINANT HAND

Starting position: left side.

The child is asked to pick and replace the pegs using one hand from one board to the other two times with the dominant hand and two times with the non-dominant hand, respctively with large and small pegs.

The displacement of three pegs is used at the beginning of each condition (large and small pegs) as an example to get the child confident with the task.

A randomized order for starting the task with dominant or non-dominant hand is reported in the sheets.

BIMANUAL TASK.

The child has to pick the large pegs first and the small ones afterwards, one by one, as fast as possible, put them in the hole of the plastic screen, hold them with the other hand and replace them in the controlateral board.

Starting position: left-side.

DUAL TASK

The child is required to perform the first task with his/her dominant and non-dominant hand meanwhile is has to pay attention to acoustic stimuli.

- Before the starting make the child listen the sounds and he/she is asked to choose the acoustic stimuli he/she likes most.
- The task is performed with small pegs.

Document 3

Experimental condition order following the adapted protocol

PEGBOARD CHECKLIST: score sheet A

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Dominant hand			
2	LARGE	R > L	Dominant hand			
3	LARGE	L > R	Dominant hand			
4	LARGE	R > L	Dominant hand			
5	LARGE	L > R	Non dominant hand			
6	LARGE	R > L	Non dominant hand			
7	LARGE	L > R	Non dominant hand			
8	LARGE	R > L	Non dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Dominant hand			
6	SMALL	R > L	Dominant hand			
7	SMALL	L > R	Dominant hand			
8	SMALL	R > L	Dominant hand			
9	SMALL	L > R	Non dominant hand			
10	SMALL	R > L	Non dominant hand			
11	SMALL	L > R	Non dominant hand			
12	SMALL	R > L	Non dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Dominant hand			
14	SMALL	L > R	Dominant hand			
15	SMALL	L > R	Non dominant hand			
16	SMALL	L > R	Non dominant hand			

PEGBOARD CHECKLIST: score sheet B

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Non dominant hand			
2	LARGE	R > L	Non dominant hand			
3	LARGE	L > R	Non dominant hand			
4	LARGE	R > L	Non dominant hand			
5	LARGE	L > R	Dominant hand			
6	LARGE	R > L	Dominant hand			
7	LARGE	L > R	Dominant hand			
8	LARGE	R > L	Dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Non dominant hand			
6	SMALL	R > L	Non dominant hand			
7	SMALL	L > R	Non dominant hand			
8	SMALL	R > L	Non dominant hand			
9	SMALL	L > R	Dominant hand			
10	SMALL	R > L	Dominant hand			
11	SMALL	L > R	Dominant hand			
12	SMALL	R > L	Dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Non dominant hand			
14	SMALL	L > R	Non dominant hand			
15	SMALL	L > R	Dominant hand			
16	SMALL	L > R	Dominant hand			

PEGBOARD CHECKLIST: score sheet C

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Dominant hand			
2	LARGE	R > L	Dominant hand			
3	LARGE	L > R	Dominant hand			
4	LARGE	R > L	Dominant hand			
5	LARGE	L > R	Non dominant hand			
6	LARGE	R > L	Non dominant hand			
7	LARGE	L > R	Non dominant hand			
8	LARGE	R > L	Non dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Non dominant hand			
6	SMALL	R > L	Non dominant hand			
7	SMALL	L > R	Non dominant hand			
8	SMALL	R > L	Non dominant hand			
9	SMALL	L > R	Dominant hand			
10	SMALL	R > L	Dominant hand			
11	SMALL	L > R	Dominant hand			
12	SMALL	R > L	Dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Dominant hand			
14	SMALL	L > R	Dominant hand			
15	SMALL	L > R	Non dominant hand			
16	SMALL	L > R	Non dominant hand			

PEGBOARD CHECKLIST: score sheet D

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Dominant hand			
2	LARGE	R > L	Dominant hand			
3	LARGE	L > R	Dominant hand			
4	LARGE	R > L	Dominant hand			
5	LARGE	L > R	Non dominant hand			
6	LARGE	R > L	Non dominant hand			
7	LARGE	L > R	Non dominant hand			
8	LARGE	R > L	Non dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Non dominant hand			
6	SMALL	R > L	Non dominant hand			
7	SMALL	L > R	Non dominant hand			
8	SMALL	R > L	Non dominant hand			
9	SMALL	L > R	Dominant hand			
10	SMALL	R > L	Dominant hand			
11	SMALL	L > R	Dominant hand			
12	SMALL	R > L	Dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Non dominant hand			
14	SMALL	L > R	Non dominant hand			
15	SMALL	L > R	Dominant hand			
16	SMALL	L > R	Dominant hand			

PEGBOARD CHECKLIST: score sheet E

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Non dominant hand			
2	LARGE	R > L	Non dominant hand			
3	LARGE	L > R	Non dominant hand			
4	LARGE	R > L	Non dominant hand			
5	LARGE	L > R	Dominant hand			
6	LARGE	R > L	Dominant hand			
7	LARGE	L > R	Dominant hand			
8	LARGE	R > L	Dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Dominant hand			
6	SMALL	R > L	Dominant hand			
7	SMALL	L > R	Dominant hand			
8	SMALL	R > L	Dominant hand			
9	SMALL	L > R	Non dominant hand			
10	SMALL	R > L	Non dominant hand			
11	SMALL	L > R	Non dominant hand			
12	SMALL	R > L	Non dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Dominant hand			
14	SMALL	L > R	Dominant hand			
15	SMALL	L > R	Non dominant hand			
16	SMALL	L > R	Non dominant hand			

PEGBOARD CHECKLIST: score sheet F

ID - Name	Date of birth	Date	Name tester

A. Begin with large board overlays and **large pegs** placed in right board				Time	Comment	Acoustic stimuli/correct answers
Practice	LARGE	3 pegs	Dominant hand			
1	LARGE	L > R	Non dominant hand			
2	LARGE	R > L	Non dominant hand			
3	LARGE	L > R	Non dominant hand			
4	LARGE	R > L	Non dominant hand			
5	LARGE	L > R	Dominant hand			
6	LARGE	R > L	Dominant hand			
7	LARGE	L > R	Dominant hand			
8	LARGE	R > L	Dominant hand			
B. Change to large board overlays, place **large pegs** in left board, give person **bimanual** instructions						
Practice	LARGE	L>R	3 pegs			
9	LARGE	L > R	left hand leading			
10	LARGE	R > L	right hand leading			
C. Change to small board overlays and **small pegs** placed in right board						
5	SMALL	L > R	Dominant hand			
6	SMALL	R > L	Dominant hand			
7	SMALL	L > R	Dominant hand			
8	SMALL	R > L	Dominant hand			
9	SMALL	L > R	Non dominant hand			
10	SMALL	R > L	Non dominant hand			
11	SMALL	L > R	Non dominant hand			
12	SMALL	R > L	Non dominant hand			
D. Give instructions on **acoustic dual task**						
13	SMALL	L > R	Non dominant hand			
14	SMALL	L > R	Non dominant hand			
15	SMALL	L > R	Dominant hand			
16	SMALL	L > R	Dominant hand			

Table 2

Overview table per participant of the initial protocol (mean TPT scores and DTE %)

PARTICIPANT	ST.LP.D.	ST.LP.ND.	DT.LP.D.	BT.LP.	ST.SP.D.	ST.SP.ND.	DT.SP.D.	DTE % LP.D.	DTE % SP.D.
TD01	*16.52*	*17.13*	*16.50*	*18.76*	*14.99*	*19.20*	*17.17*	*0.12*	*-14.54*
TD02	*11.30*	*11.25*	*11.95*	*16.35*	*12.45*	*14.35*	*11.35*	*-5.75*	*8.84*
TD03	*12.40*	*13.45*	*13.60*	*18.65*	*13.80*	*14.25*	*16.75*	*-9.68*	*-21.38*
TD04	*12.61*	*13.99*	*14.43*	*19.01*	*14.71*	*17.53*	*12.88*	*-14.43*	*12.44*
TD05	*12.86*	*14.08*	*12.68*	*14.97*	*12.34*	*13.75*	*13.73*	*1.40*	*-11.17*
TD06	*12.27*	*13.92*	*17.65*	*18.13*	*12.54*	*14.72*	*14.71*	*-43.84*	*-17.30*
TD07	*14.20*	*14.45*	*21.50*	*19.80*	*16.45*	*14.50*	*16.75*	*-51.41*	*-1.82*
TD08	*12.40*	*10.73*	*12.46*	*16.82*	*10.98*	*12.59*	*12.62*	*-0.48*	*-14.94*
TD MEAN ± SD	*13.07 ± 1.61*	*13.61 ± 1.98*	*15.09 ± 3.27*	*17.81 ± 1.62*	*13.53 ± 1.78*	*15.11 ± 2.16*	*14.49 ± 2.20*	*-15.51 ± 20.63*	*-7.48 ± 12.56*
DCD01	*17.25*	*20.25*	*20.50*	*24.15*	*22.70*	*22.60*	*21.80*	*-18.84*	*3.96*
DCD02	*15.55*	*14.95*	*18.15*	*21.10*	*17.10*	*14.40*	*18.05*	*-16.72*	*-5.56*
DCD03	*14.70*	*16.10*	*16.35*	*19.70*	*18.75*	*19.50*	*17.90*	*-11.22*	*4.53*
DCD04	*12.90*	*16.10*	*13.50*	*21.25*	*13.25*	*16.85*	*13.25*	*-4.65*	*0.00*
DCD05	*19.16*	*22.75*	*34.52*	*25.88*	*17.59*	*21.80*	*21.85*	*-80.17*	*-24.22*
DCD06	*17.30*	*15.66*	*17.44*	*26.19*	*23.66*	*22.81*	*19.88*	*-0.81*	*15.98*
DCD07	*13.40*	*15.85*	*12.40*	*16.85*	*14.90*	*20.20*	*13.50*	*7.46*	*9.40*
DCD08	*16.45*	*28.80*	*22.05*	*28.40*	*20.35*	***M.D.***	*21.65*	*-34.04*	*-6.39*
DCD09	*15.85*	*16.00*	*22.45*	*24.25*	*17.25*	*18.20*	*21.85*	*-41.64*	*-26.67*
DCD10	*11.80*	*13.30*	*13.05*	*17.45*	*14.80*	*14.75*	*14.05*	*-10.59*	*5.07*
DCD MEAN ± SD	*15.44 ± 2.26*	*17.98 ± 4.68*	*19.04 ± 6.53*	*22.52 ± 3.86*	*18.03 ± 3.40*	*19.01 ± 3.19*	*18.38 ± 3.62*	*-21.12 ± 25.41*	*-2.39 ± 13.82*

TD0X= participant X of the typically developing group; DCD0X= = participant X of the Developmental Coordination Disorder group; SD= standard deviation; ST= single task; DT= dual task; BT= bimanual task; SP= small pegs; LP= large pegs; D= dominant hand; ND= non-dominant hand; DTE= dual task effect; M.D.= missing data

Table 3

Overview table per participant of the adapted protocol (best TPT scores, DTE % and % correct AT answers)

PARTICIPANT	ST.LP. (L>R)	ST.LP. (R>L)	ST.SP. (L>R)	ST.SP. (R>L)	DT.SP. (L>R)	DT.SP. (R>L)	BT.LP. (L>R)	BT.LP. (R>L)	DTE % SP. (L>R)	DTE % SP. (R>L)	% CORRECT AT ANSWERS SP. (L>R)	% CORRECT AT ANSWERS SP. (R>L)
DCD01	*19.73*	*23.67*	***35.55****	*30.84*	***M.D.***	*20.64*	*32.09*	***M.D.***	***M.D.***	*+33.07*	***M.D.***	*71.43*
DCD02	*16.97*	*15.21*	***16.03****	*24.51*	*16.31*	*19.32*	***25.20****	*25.59*	*-1.75*	*+21.18*	*100.00*	*100.00*
DCD03	*15.27*	*20.28*	*17.23*	*14.14*	*17.84*	*16.32*	*23.25*	*24.75*	*-3.54*	*-15.42*	*100.00*	*100.00*
DCD04	*15.16*	*17.40*	*12.44*	*14.95*	*23.75*	*30.86*	***31.47****	*23.26*	*-90.92*	*-96.00*	*100.00*	*90.00*
DCD05	*16.81*	*22.32*	*16.01*	*22.04*	*18.70*	*26.57*	***M.D.***	*35.66*	*-16.80*	*-20.55*	*83.33*	*55.56*
DCD06	*13.51*	*15.78*	*13.83*	*22.52*	***27.01****	*26.82*	***27.07****	*25.69*	*-95.30*	*-19.09*	***M.D.***	*57.14*
DCD07	*15.41*	*19.13*	***M.D.***	*15.90*	*19.08*	*20.83*	*30.14*	*31.96*	***M.D.***	*-31.01*	***M.D.***	*100.00*
DCD08	*17.08*	*17.67*	*17.83*	*20.20*	*15.52*	*19.59*	*19.56*	*19.98*	*+12.96*	*+3.02*	*100.00*	*71.43*
DCD09	*13.27*	*15.52*	*12.64*	*15.09*	*11.78*	*15.56*	*19.51*	*18.39*	*+6.80*	*-3.12*	*100.00*	*100.00*
DCD10	*21.32*	*21.70*	*21.28*	*19.76*	*26.59*	*22.78*	*25.70*	*38.83*	*-24.95*	*-15.28*	*33.33*	*85.71*
DCD11	*15.01*	*15.90*	*14.45*	*15.12*	*14.48*	*16.09*	*22.26*	*20.30*	*-0.21*	*-6.42*	*100.00*	*60.00*
DCD12	*11.10*	*11.71*	*10.46*	*11.22*	*10.09*	*11.70*	*13.51*	*13.01*	*+3.54*	*-4.28*	*100.00*	*100.00*
MEAN ± SD	*15.89 ± 2.78*	*18.02 ± 3.49*	*16.41 ± 4.95*	*18.86 ± 5.51*	*18.29 ± 5.58*	*20.59 ± 5.48*	*24.52 ± 5.68*	*25.22 ± 7.69*	*-17,51 ± 36,70*	*-12,83 ± 31,74*	*90,74 ± 22,22*	*82,61 ± 18,38*

*DCD0X= = participant X of the Developmental Coordination Disorder group; SD= standard deviation; ST= single task; DT= dual task; BT= bimanual task; SP= small pegs; LP= large pegs; L>R= transfer from left to right; R>L= transfer from right to left; DTE= dual task effect; AT= acoustic task; M.D.= missing data; *= Error in TPT performance*

Document 4

Inventory form master thesis

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UHASSELT

INVENTARISATIEFORMULIER WETENSCHAPPELIJKE STAGE DEEL 2

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
06/12/2018	verslag MP2	Promotor: Copromotor/Begeleider: Student(e): Student(e):
12/02/2019	data collectie	Promotor: Copromotor/Begeleider: Student(e): Student(e):
13/04/2019	bespreken verschil in protocol + data collectie → skype gesprek	Promotor: Copromotor/Begeleider: Student(e): Student(e):
23/04/2019	begin statistische analyse	Promotor: Copromotor/Begeleider: Student(e): Student(e):
29/04/2019	statistische analyse	Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):

In te vullen door de promotor(en) en eventuele copromotor aan het einde van MP2:

Naam Student(e): Liselotte Holsbeek **Datum:** 26.05.2019

Titel Masterproef: Dual task performance and automatization of acquirement of manual skills in children with DCD

1) Geef aan in hoeverre de student(e) onderstaande competenties zelfstandig uitvoerde:
   - NVT: De student(e) leverde hierin geen bijdrage, aangezien hij/zij in een reeds lopende studie meewerkte.
   - 1: De student(e) was niet zelfstandig en sterk afhankelijk van medestudent(e) of promotor en teamleden bij de uitwerking en uitvoering.
   - 2: De student(e) had veel hulp en ondersteuning nodig bij de uitwerking en uitvoering.
   - 3: De student(e) was redelijk zelfstandig bij de uitwerking en uitvoering
   - 4: De student(e) had weinig tot geringe hulp nodig bij de uitwerking en uitvoering.
   - 5: De student(e) werkte zeer zelfstandig en had slechts zeer sporadisch hulp en bijsturing nodig van de promotor of zijn team bij de uitwerking en uitvoering.

Competenties	NVT	1	2	3	4	5
Opstelling onderzoeksvraag	X	O	O	O	O	O
Methodologische uitwerking	X	O	O	O	O	O
Data acquisitie	X	O	O	O	O	O
Data management	O	O	O	O	O	X
Dataverwerking/Statistiek	O	O	O	O	O	X
Rapportage	O	O	O	O	X	O

2) Niet-bindend advies: Student(e) krijgt toelating/geen toelating (schrappen wat niet past) om bovenvermelde Wetenschappelijke stage/masterproef deel 2 te verdedigen in bovenvermelde periode. Deze eventuele toelating houdt geen garantie in dat de student geslaagd is voor dit opleidingsonderdeel.

3) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) openbaar verdedigd worden.

4) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) opgenomen worden in de bibliotheek en docserver van de UHasselt.

Datum en handtekening Student(e)	Datum en handtekening promotor(en)	Datum en handtekening Co-promotor(en)
26/05/2019	26/5/2019	

In te vullen door de promotor(en) en eventuele copromotor aan het einde van MP2:

Naam Student(e): MARTENS LIESELOTTE .... **Datum:** 26/05/2019

Titel Masterproef: Dual task performance and automatization of movement of manual skills in children with DCD.

1) Geef aan in hoeverre de student(e) onderstaande competenties zelfstandig uitvoerde:
   - NVT: De student(e) leverde hierin geen bijdrage, aangezien hij/zij in een reeds lopende studie meewerkte.
   - 1: De student(e) was niet zelfstandig en sterk afhankelijk van medestudent(e) of promotor en teamleden bij de uitwerking en uitvoering.
   - 2: De student(e) had veel hulp en ondersteuning nodig bij de uitwerking en uitvoering.
   - 3: De student(e) was redelijk zelfstandig bij de uitwerking en uitvoering
   - 4: De student(e) had weinig tot geringe hulp nodig bij de uitwerking en uitvoering.
   - 5: De student(e) werkte zeer zelfstandig en had slechts zeer sporadisch hulp en bijsturing nodig van de promotor of zijn team bij de uitwerking en uitvoering.

Competenties	NVT	1	2	3	4	5
Opstelling onderzoeksvraag	X	0	0	0	0	0
Methodologische uitwerking	X	0	0	0	0	0
Data acquisitie	X	0	0	0	0	0
Data management	0	0	0	0	0	X
Dataverwerking/Statistiek	0	0	0	0	0	X
Rapportage	0	0	0	0	X	0

2) Niet-bindend advies: Student(e) krijgt toelating/geen toelating (schrappen wat niet past) om bovenvermelde Wetenschappelijke stage/masterproef deel 2 te verdedigen in bovenvermelde periode. Deze eventuele toelating houdt geen garantie in dat de student geslaagd is voor dit opleidingsonderdeel.

3) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) openbaar verdedigd worden.

4) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) opgenomen worden in de bibliotheek en docserver van de UHasselt.

Datum en handtekening Student(e)	Datum en handtekening promotor(en)	Datum en handtekening Co-promotor(en)
26/05/2019	26/5/2019	