Article

Children With Developmental Coordination Disorder: Can Underlying Perceptual Disability be Remediated Through Specific Training?

Psychological Reports
0(0) 1–13

DOI: 10.1177/0033294116687761
journals.sagepub.com/home/prx

J. M. Loftesnes
Department of Sport Science, University College of Sogn og Fjordane, Norway

R. P. Ingvaldsen
Nord University, Levanger, Norway

Hermundur Sigmundsson
Department of Psychology, Norwegian University of Science and Technology and Reykjavik University, Norway

Abstract
This study tested the effect of task-specific training of a perceptual ability for children with Developmental Coordination Disorder (DCD) compared to control children. A manual matching task (target location and pointing task) was used, which required the children to locate target pins either visually (seen target) or proprioceptively (felt target), while matching to the located target was always carried out without vision. Thirty-one children (11–12 years) were selected based on teacher statements regarding everyday motor skill performance, the DSM-IV criteria, and the Movement ABC test. Based on this, 10 children with obvious motor problems were placed in the DCD group (Trg-DCD), 9 children with no identified motor problems were placed in a training group (Trg-N), and 12 children also with no identified motor problems were placed in a control group. All the children were tested pre and post to training on a manual matching task. In the pretest, the children in the DCD group were significantly inferior to the control groups in the proprioceptive condition with both the preferred and nonpreferred hands. In the posttest, after the training periode was completed, the DCD subjects showed significant improvement in the proprioceptive condition for both preferred and nonpreferred hands. For the other groups, no significant training effects were observed across the training period.

Corresponding Author:
Hermundur Sigmundsson, Department of Psychology, Norwegian University of Science and Technology, 7491 Trondheim, Norway.
Email: hermundurs@svt.ntnu.no

It is concluded that children in the DCD group may benefit from specific training of perceptual abilities, because they have motor control resources not exploited due to a lack of relevant experience.

Keywords
Developmental Coordination Disorder, perceptual abilities, intervention, manual matching

Introduction

Children with Developmental Coordination Disorder (DCD) have reduced sensitivity to perceptual and proprioceptive information compared to their peers (Laszlo & Bairstow, 1985; Sigmundsson & Whiting, 2002; Sigmundsson,Whiting, & Ingvaldsen, 1997a, 1997b). Proprioceptive information, such as that related to hand positions, is a prerequisite for sucessful performance in the reaching and grasping of objects. This proprioceptive information is reportedly absent or degraded in children with motor problems, which may be an underlying cause of clumsy behavior (Laszlo & Bairstow, 1985).

Inter- and intrasensory modalilty matching tests (manual matching tests) have been developed to examine the use of visual and proprioceptive[1] cues in children, in which participants are required to locate target pins under one of two conditions, visually (seen target) or proprioceptively (felt target), and match the target position using proprioceptive cues only[2] (von Hofsten & Rösblad, 1988).

Using this methodology, Sigmundsson et al. (1997a) have shown that children with Hand-Eye Coordination Problems (HECP) show better results in the visual condition (mean 20.81 mm) than the proprioceptive condition (mean 30.76 mm) on a manual matching task. A follow-up study demonstrated that children at eight years of age with HECP problems had scores lower than their control children matched for age. The scores of the eight years old HECP children were actually worse to those of five-year-old children in the visual condition (mean 20.81 mm vs. 14.19 mm) and equivalent in the proprioceptive condition (mean 30.76 mm vs. 29.20 mm). These results were explained by delays in maturation of the corpus callosum or an interruption of transcallosal interhemispheric communication (Sigmundsson et al., 1997a, 1997b).

Prior research seems to support that manual matching may be regarded as a perceptual ability (Fleishman, 1966; von Hofsten & Rösblad, 1988). This is further supported by the observation that absolute scores across studies using the same test procedures for the normal children seem remarkably stable (Loftesnes & Ingvaldsen, 2003). The range in mean scores across four studies, both hands counting, is only 1.6 mm (from 22.9 mm to 24.5 mm) (Sigmundsson et al., 1997a, 1997b; von Hofsten & Rösblad, 1988). It is further suggested from these studies that children with developmental coordination disorder may have a disadvantage using their nonpreferred hand compared to their peers on a manual matching task (Sigmundsson & Whiting, 2002; Smyth & Mason, 1998); data from this hand were less reliable for and more prone to errors than equivalent measures for control children. Children with DCD in addition have performance levels that are lower than control children when measures of movement time and trajectory length are used in pointing tasks without the use of visual cues (i.e., proprioception) (Ameratunga, Johnston, & Burns, 2004). This also applies to spatial and temporal aspects of grasping a ball (Estil, Ingvaldsen, & Whiting, 2002)

Problems in motor skills appear to impact almost all kinds of motor behavior children with DCD engage in. Therefore, it comes as no surprise that children with motor problems tend to compensate for their motor difficulties by avoiding situations where their relative weaknesses in motor skills are exposed (Henderson, 1993, Zwicker et al., 2012). The paradox now is that the way the children cope with their own motor problems might add to and prolong the very same problems. The adaptation of alternative strategies exclude this children from the relevant experience that might be exactly what is needed to mend the problem, i.e., more motor experience and training (Revie & Larkin, 1993). But on the other hand, this relatively long-term lack of relevant stimulation might also provide children with a "developmental reservoir." As Clark and Clark (1976) point out, this might be the explanation of why many deprived children might recover at a remarkable speed. Given the appropriate experience, this may enable quick changes in practical skills (Whiting, 1984).

Many studies have examined whether training interventions improves the movement skill for children with clumsiness (see for overview Polatajko & Cantin, 2006; Zwicker et al., 2012). Conflicting results and insufficient data in this field are still present (Zwicker et al., 2012). Nevertheless, it should be possible to let children with DCD undergo interventions focusing on their problem areas by providing relevant practice and training in tasks that may give effect on their underlying perceptual (dis)abilities (Fleishman, 1966). Such relevant training is acknowledged by various researchers to comprise task-specific training and interventions (Ayyash & Preece, 2003; Haga, Pedersen, & Sigmundsson, 2008; Pless & Carlsson 2000; Stöckel & Hughes, 2016). Observations of task-specificity of motor skills were reported by Larkin and coworkers (Larkin & Hoare, 1992; Larkin & Parker, 2002; Revie & Larkin, 1993). They found that children with motor problems made specific improvements only to the task actually trained. This is supported by Smits-Engelsman et al. (2013). In their systematic review and meta-analysis, they found out that task-orientated approach was most effective for intervention for DCD children. Pless and Carlsson (2000) also claimed that the frequency of intervention is crucial for the outcome. Only interventions repeated three to five days a week seem to be effective. They also claim that whether the interventions lasted for more or less than three months did not matter for the outcome.

Based upon the research evidence of the effect of task-specific training, the study aims to evaluate specific training effects on a manual matching task of children with DCD.

Method

Participants

The participants in this study were selected using a two-stage process. In the first stage, teachers randomly selected 68 of 171 children at the age 11 to 12 years from two schools. These 68 children completed the Movement ABC (MABC; Henderson & Sugden, 1992). Consent to participate in the study was obtained from both the children and their parents. Participation was voluntary and a child could withdraw from the study at any time, without giving any reason. An interscorer test of 20 children showed a correlation between two independent testers of $r = .90$ for the total MABC score. Children with known medical symptoms and low cognitive ability were left out in stage one (two children).

In the second stage, 31 children ($M = 11.91$ years, $SD = 0.514$) were selected based on their performance on the MABC and they were invited to the intervention based upon the criteria in the DSM-IV (American Psychiatric Association [APA], 1994). Ten children were identified who scored 13.5 points or more (equivalent to the fifth percentile) on this measure; these were designated to the DCD group (Trg-DCD, N = 10). The classification of these children was confirmed by their teachers and their parents as those who demonstrated weaknesses in play activities and sports and academic achievement. Ten children who scored less than 7.5 points on the MABC test were assigned to a typical developing training group (Trg-N). One of these children subsequently dropped out of the experiment, so that the training group (Trg-N) did involve only nine children. Twelve other children, who also scored less than 7.5 points on the MABC test, were selected for the control group (C) based on their MABC score. An overview of the 31 children participating in the study is presented in Table 1. To classifiy handendess, the Edinburgh handedness inventory (from Oldfield, 1971) was used.

Materials

MABC test. The MABC test (Henderson & Sugden,1992) was designed to identify motor coordination problems in children between the ages of 4 and 12 years. In this study, we used the MABC to identify children with and without motor difficulties and to assign the children to the DCD and control groups. The subtests used in this study were taken from the quantitative measures from age band 4 (11–12 years). This consists of eight subtests in three categories: manual dexterity (turning pegs, cutting out an elephant, and flower trail); ball

Table 1. Age, MABC scores, and gender for the three groups ($N = 31$).

	Trg-DCD $N = 10$		Trg-N $N = 9$		Control $N = 12$	
Value	Mean score	*SD*	Mean score	*SD*	Mean score	*SD*
Age (y)	11.55	0.28	11.55	0.31	12.45	0.26
MABC	19.96	4.51	5.83	1.27	4.5	3.27
Gender, boys/girls	5/5		5/4		6/6	

Note. The subjects were selected on the basis of their MABC score. MABC: Movement ABC.

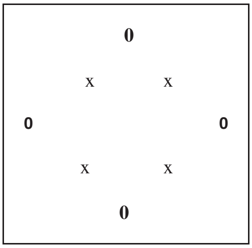

Figure 1. Plan view of the tabletop used in the experiment. *x*: targets in position 1; 0: targets in position 2.

skill (one-hand catch and throwing at a target), and balance (two-board balance, jump clap, and walking backwards).

The manual matching task. This test was based upon that developed by von Hofsten and Rösblad (1988) with modifications made by Sigmundsson et al. (1997a). A tabletop measuring 60 × 80 cm and standing 63 cm above the floor was used to support the targets. On the tabletop, two squares measuring 12 × 12 cm were placed, each of which had four pins, one in each corner (8 targets in all). At the center of each target pin on the tabletop, a narrow hole was made through the table so that the true position of the targets could be detected on both sides. The targets could thereby be presented in different positions rather than in a constant position (see Sigmundsson et al., 1997a). The distance from the side of the table where the child was seated to the closest target pin (position 1) was 16 cm and the distance between the targets was 12 cm. A transparent sheet measuring 30 × 42 cm (A3) was attached underneath the table and was used as a measuring frame for the placement of the pins. The subjects used a drawing pin (thumb tack) to indicate the locations of the actual target as seen in Figure 1.

Design

This study was conducted as an intervention within a pre–post design. The three groups of children were tested on a manual matching task before and after the intervention period. Two of the groups, one group of children with DCD (Trg-DCD) and another group of typical developing children (Trg-N), received specific training on the test itself during the intervention. The third group of typical developing children (Control) participated in a children's game of flipping coins, which served as a control condition. The intervention period lasted for three weeks. Five days a week they carried out their training under supervision of their teacher. Each training session took about 30 minutes per day for all 31 subjects.

In the manual matching task, the children in both training groups were exposed to two different conditions which were defined by the perceptual system(s) used to locate the target: vision (*V*) and proprioception (*P*) (von Hofsten & Rösblad, 1988). Because the matching position was always on the underside of the table, attempts to match the target position were all carried out without visual guidance of the hand.

1. *V* (vision): the children had to *locate* the target on the table top visually (ca. 5 s) and then try to locate/point its position on the underside of the table with a pin held between the thumb and the index finger with the designated hand.
2. *P* (proprioception): the children were blindfolded. The experimenter moved the child's locating arm to the target position. The children could feel but not see the target position (ca. 5 s). An attempt was then made to match the target position with the other hand, on the underside of the table.

Procedure

The study was carried out in accordance with the Declaration of Helsinki. The children were tested at their school in a quiet room where they were alone with the experimenter, using child-sized furniture. The children were seated at the table, facing the experimenter throughout the test. The procedure corresponded with that of Sigmundsson et al. (1997a, 1997b). In brief, the child was given a drawing pin and was told to hold it between the thumb and the index finger of the hand to be tested, then to reach beneath the table and to stick the pin in a position that coincided with the target. Testing was carried out with both the preferred and the nonpreferred hand; the order of which was randomly allocated across subjects. Each condition required the location of each of the four target positions. Both the order of conditions and the locations of the target positions was randomized across subjects. Opaque, liquid-crystal glasses were used in the proprioception (*P*) condition in order to obscure the vision of the target.

After the completion of each trial, the experimenter turned over the tabletop in such a way as to conceal the placement of the pin from the subject. After removing the pin, the experimenter marked the position on the transparent sheet with a unique code and returned the tabletop to its original position, after which the next trial commenced. Altogether, four targets in two conditions (*V* and *P*) for two hands (preferred and nonpreferred) were completed for each child.

The intervention

The intervention for training groups Trg-DCD and Trg-N was to practice the manual matching task under the supervision from their teacher every day and the researcher and teacher two times a week. During the training, however, a thinner pin board was used to replace the thicker tabletop. The children could therefore see and feel or only feel the pin sticking through the board by a little less than ½ mm when they pointed to the pin from underneath the tabletop. Therefore, they obtained direct feedback on their performance (Schmidt, 1991) both in visual and the proprioceptive conditions. Children worked together in pairs. During each training session, the children performed four repetitions in each condition (visual and proprioception) with each hand, with their eyes open and blindfolded and with the preferred and nonpreferred hand. The time taken to carry out 16 repetitions was approximately 1 minute, and each child carried out 240 repetitions during each 30-minute session. The training took place in the middle of the day, after lunch followed by a 30-minute break.

The control group practiced a game of throwing a coin as close as possible to a line drawn on the ground in pair or in groups of three. The control children used both preferred and nonpreferred hands. This also took place during a period of 30 minutes each day, in connection with a longer break.

Measurements and statistics

The scores from the manual matching task (von Hofsten & Rösblad, 1988) are determined by the distance between the true target and the pointing of each individual, measured in millimeters. The results are presented as the means of four trials in each subtasks for each training group. The results from the manual matching task were compared using one-way analysis of variance (ANOVA). The results for the effect of intervention were analyzed by paired samples *t* test. Significant level was set at .05. All analyses were carried out using SPSS.

Table 2. Means and *SD*s of the distance target-pin (t-p; millimeters) scores for the two conditions of the experiment for the three groups for both the preferred and nonpreferred hand ($N = 31$).

	Trg-DCD				Trg-N				Control			
	Preferred hand		Nonpreferred hand		Preferred hand		Nonpreferred hand		Preferred hand		Nonpreferred hand	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Pretest												
V	18.60	4.76	20.12	7.78	15.75	9.63	16.36	9.62	13.96	4.97	14.29	5.30
P	33.50	13.67	37.94	15.18	18.78	6.82	23.41	5.97	21.14	9.14	23.31	4.64
Posttest												
V	17.35	6.45	20.57	8.13	16.89	5.35	17.06	7.19	11.54	3.65	16.27	7.19
P	20.95	5.64	21.50	6.24	21.80	5.86	25.16	6.81	24.65	9.14	24.63	8.85

Note. *V*: vision; *P*: proprioception; DCD: Developmental Coordination Disorder.

Results

Distance target-pin (t-p) score was defined as the shortest distance, in millimeters, between the position of the the target marked by the subject and is true position. The mean distance t-p scores and SDs for the two conditions for the three groups, pre- and posttest, are reported in Table 2.

Pre-test—Intergroup differences: Vision (V) and proprioception (P), preferred and nonpreferred hand

The descriptive statistics (Table 2) show that the subjects perform better with preferred hand than nonpreferred hand but not significantly for neither groups.

For the *V* condition while using the preferred hand and nonpreferred hand, no significant differences were found between the groups in the pretest. For the proprioceptive condition, when using the preferred hand the difference between Trg-DCD and Trg-N was significant (one-way ANOVA) (mean 33.5 mm vs. 18.78 mm; $F(1,17) = 8.495$, $p = 0.01$), and for Trg-DCD and the Control group, it was also significant (one-way ANOVA) (mean 33.5 mm vs. 21.14; $F(1,20) = 6.408$, $p = 0.02$). When using the nonpreferred hand, the between-group comparisons were along the same line Trg-DCD vs. Trg-N (mean 37.94 mm vs. 23.41 mm; $F(1,17) = 7.207$, $p = 0.01$) and Trg DCD vs. Control (37.94 mm vs. 23.31 mm; $F(1,20) = 10.105$, $p = 0.005$). The Trg-N and Control group difference were not significant with either hand.

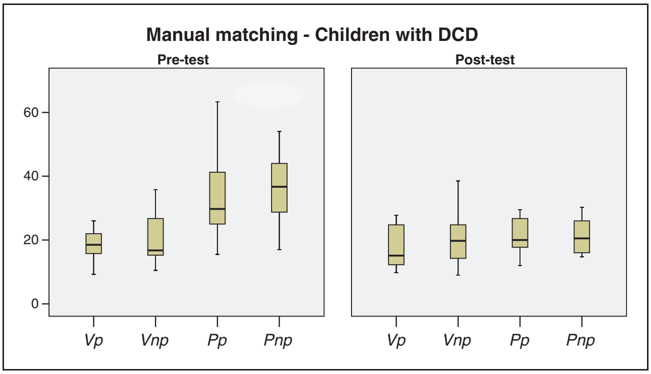

Figure 2. Manual matching task; mean score for the Trg-DCD in the two conditions, preferred and nonpreferred hand for pretest and posttest ($N = 10$).

Posttest—Intergroup posttest differences: Vision and proprioception, preferred and nonpreferred hand

No significant differences between the three groups were detected for the *V* condition in the posttest except in the *V* condition preferred hand between Trg-DCD and Control (one-way ANOVA) ($F(1,20) = 7.069$, $p = 0.015$). There were also no significant differences in the posttest between groups on the proprioceptive condition with neither the preferred nor nonpreferred hand.

Intervention effects

The results indicate a marked difference in the Trg-DCD group between pre- and posttest in the Proprioceptive condition, but no such difference for the other groups. This difference was significant for the preferred hand (33.50 mm vs. 20.95 mm) (paired samples *t* test, $t(18) = 2.68$, $p = 0.015$) and nonpreferred hand (37.94 mm vs. 21.50 mm) (paired samples *t* test, $t(18) = 3.16$, $p = 0.005$) (see Table 2 and Figure 2). There was no intervention effect for the *V* condition for any of the groups.

Discussion

Based upon the research evidence of the effect of task-specific training, we aimed to evaluate specific training effects on a manual matching task of children with DCD.

The present study focused on the effect of task-specific training on manual matching task for children with DCD (Sigmundsson et al., 1997a, 1997b; von Hofsten & Rösblad, 1988). The manual matching requires participants to locate targets, either seen or unseen with one hand while matching to the located target with the other hand without vision.

The results of pretest indicated a difference between Trg-DCD and typical developing children in the proprioceptive condition. The results also indicated a training effect only for the Trg-DCD in that condition. No such effect could be observed for the visual condition.

For the typical developing children (Trg-N), no training effects could be observed from the pretest to the posttest. The same applies for the control group, who received the same teacher attention during the intervention period while spending as much time as the intervention groups doing a different kind of training (flipping coins).

Previously, it has been pointed out that children with DCD are inferior in proprioceptive manual matching compared to their typical developing peers (Sigmundsson et al., 1997a, 1997b). This, however, is probably the first time that it has been shown that their disadvantage in the proprioceptive condition; considered as underlying perceptual ability (see Laszlo & Bairstow, 1985 for overview); can be remedied quite effectively through specific training. The outcome of our study is in agreement with what Pless and Carlsson (2000) conclude in their meta-analysis, that a frequency of five times a week during three weeks is effective. It seems that it does not matter whether interventions for training children with DCD last less than three months or more than three months in regard to the outcome of the training as long as the training is specific.

It is also noteworthy that the improvement in the manual matching task appeared in the two conditions (preferred and nonpreferred) where the children with DCD initially (in the pretest) exhibited their worst scores in relation to their peers (see Table 2). It might well be argued that this is quite natural, as in these conditions there was still room for improvement within the limits of this training period. This is a very reasonable argument, which implies that the other "good" scores were close to some kind of functional or natural limit for the precision of manual matching, i.e., a kind of biological boundary of performance (Loftesnes & Ingvaldsen, 2003). This must not, however, be interpreted as ceiling effect due to the measuring instrument itself, as this present experimental setup can register accuracy down to less than a millimeter.

It is, however, important to note that our intervention, which was in accordance with recommendations from Pless and Carlsson (2000), was effective only for those children that beforehand had been identified having a perceptual motor ability problem. They improved their mean absolute scores in the proprioceptive condition from 33.5 mm to 20.95 mm (preferred hand) and 37.94 mm to 21.50 mm (nonpreferred hand). The same intervention did not have an effect for typical developing children. In other words, it seems that our intervention brought the children with DCD up to the same average level of performance that has been repeatedly demonstrated as "normal" in several other studies. As it seems difficult to improve the typical developing children's scores beyond this level through specific training, and that the best five-year-old children scores are at the same level as adults, it is tempting to regard this as a kind of biological boundary for this task, already for some children attained at five years of age (Sigmundsson et al. 1997b). So our training seems only to be effective in bridging the gap between this boundary and the poor performance of the children with DCD.

What is left to investigate is whether the performance of the children with DCD on the manual matching test can be influenced from more general motor training programs and whether the DCD children's improvement in the manual matching test, generalize to other tasks depending upon this ability. We also have to ask what the effective factors are when the scores from the children with DCD improve as a result of an intervention. Is it the specific practice as such, or do also the improvements depend on intrinsic and/or extrinsic feedback?

Key messages

- DCD group may benefit from specific training of perceptual abilities
- DCD group may have motor control resources not exploited due to a lack of relevant experience

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Notes

1. "The precision in matching in this condition reflects the congruency between the proprioceptive space of the left hand and the proprioceptive space of the right hand" (von Hofsten & Rösblad, 1988, p. 807).
2. In this task, the subjects moved slowly with the unseen hand and really tries to "feel" the correct position before placing the pin (a bulletin board pin was used by subjects to indicate the locations) (Sigmundsson & Whiting, 2002).

References

Ameratunga, D., Johnston, L., & Burns, Y. (2004). Goal directed upper limb movements by children with and without DCD: A window into perceptuo-motor dysfunction? *Physiotherapy Research International*, *9*, 1–12.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorder* (4th ed, Text Revision). Washington, DC: APA.

Ayyash, H. F., & Preece, P. M. (2003). Evidence-based treatment of motor co-ordination disorder. *Current Paediatrics*, *13*, 360–364.

Clark, A. M., & Clark, A. D. B. (1976). *Early experience, myth and evidence*. London: Open Books.

Estil, L. B., Ingvaldsen, R. P., & Whiting, H. T. A. (2002). Spatial and temporal on performance in children with movement co-ordination problem. *Experimental Brain Research*, *147*, 153–161.

Fleishman, E. A. (1966). Human abilities and the acquisition of skill. In E. A. Bilodeau (Ed.), *Acquisition of skill* (pp. 147–167). New York, NY: Academic Press.

Haga, M., Pedersen, A. V., & Sigmundsson, H. (2008). Interrelationship among selected measures of motor skills. *Child: Care, Health and Development*, *34*(2), , 245–248.

Henderson, S. E. (1993). Motor development and minor handicap. In A. F. Kalverboer, B. Hopkins & R. H. Geuze (Eds.), *Motor development in early and later childhood: Longitudinal approaches. European Network on Longitudinal Studies on Individual development (ENLS)* (pp. 286–306). New York, NY: Cambridge University Press.

Henderson, S., & Sudgen, D. (1992). *The movement assessment battery for children*. Kent: Thepsychological corporation.

Larkin, D., & Hoare, D. (1992). The movement approach: A window to understanding the clumsy child. In J. Summers (Ed.), *Approaches to the study of motor control and learning* (pp. 413–439). Amsterdam, the Netherlands: North Holland Publishing Company.

Larkin, D., & Parker, H. E. (2002). Task-specific intervention for children with developmental coordination disorder: A systems view. In S.A. Cermak, & D. Larkin (Eds.), *Developmental coordination disorder*. Albany, NY: Delmar.

Laszlo, J. I., & Bairstow, P. J. (1985). *Perceptual motor behaviour: Developmental assessment and therapy*. London, England: Holt, Rinehart and Wilson.

Loftesnes, J. M., & Ingvaldsen, R. P. (2003). DCD and the learning of Manual Matching. N*ordic Conference in Human Movement Science* (NKB 2003), 14–20.

Pless, M., & Carlsson, M. (2000). Effects of motor skill intervention on developmental coordination disorder: A meta-analysis. *Adapted Physical Activity Quarterly*, *17*, 381–401.

Polatajko, H. J., & Cantin, N. (2006). Developmental Coordination Disorder (dyspraxia): An overview of the state of the art. *Seminars in Pediatric Neurology*, *13*, 250–258.

Revie, G., & Larkin, D. (1993). Task-specific intervention with children reduces movement problems. *Adapted Physical Activity Quarterly*, *10*, 29–41.

Schmidt, R. A. (1991). *Motor learning and performance: From principles to practice*. Champaign, IL: Human Kinetics Books.

Sigmundsson, H., & Whiting, H. T. A. (2002). Hand preference in children with developmental coordination disorders: Cause and effect? *Brain and Cognition*, *49*, 45–53.

Sigmundsson, H., Whiting, H. T. A., & Ingvaldsen, R. P. (1997a). Inter- and intrahemispheric competence in children with hand-eye coordination problems. *Experimental Brain Research*, *14*, 492–499.

Sigmundsson, H., Whiting, H. T. A., & Ingvaldsen, R. P. (1997b). Inter-and-Intra sensory modality matching in children with hand-eye coordination problems: Exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, *12*, 790–796.

Smits-Engelsman, B. C. M., Blank, R., van der Kaay, A. -. C., Mosterd-van der Meijs, R., Vlugt-van den Brand, E., Polatajko, H. J., & Wilson, P. H. (2013). Efficacy of interventions to improve motor performance in children with developmental coordination disorder: A combined systematic review and meta-analysis. *Developmental Medicine & Child Neurology*, *55*, 229–237. doi:10.1111/dmcn.12008

Smyth, M. M., & Mason, U. S. (1998). Direction of response in aiming to visual and proprioceptive targets in Children with and with out DCD. *Human Movement Science*, *17*, 515–539.

Stöckel, T., & Hughes, C. M. L. (2016). The relation between measures of cognitive and motor functioning in 5- to 6- year-old children. *Psychological Research*, DOI 10.1007/s00426-015-0662-0.

von Hofsten, C., & Rösblad, B. (1988). The integration of sensory information in the development of precise manual pointing. *Neuropsychologia*, *26*, 805–821.

Whiting, H. T. A. (1984). The concepts of 'adaptation' and 'attunement' in skill learning. In O. G. Selfridge, E. L. Risland & M. A. Arbib (Eds.), *Adaptive control of Ill-defined systems* (pp. 187–205). New York, NY: Plenum.

Zwicker, J. G., Missiuno, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordonation disorder: A review and update. *European Journal of Paediatric Neurology*, *16*, 573–581.

Author Biographies

J. M. Loftesnes is Assistant Professor at the Department of Sport Science, University College of Sogn og Fjordane. His main research field is motor behaviour.

R. P. Ingvaldsen is Professor at Department of Sport Science at the Nord University. His main field of research is Human Movement Science.

Hermundur Sigmundsson is Professor at Department of Psychology, Norwegian University of Science and Technology. His main field of research is learning and skill development.