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The Roles of Declarative Knowledge and Working Memory in Explicit Motor Learning and Practice Among Children With Low Motor Abilities

Femke van Abswoude
Radboud University

John van der Kamp
VU University Amsterdam and The University of Hong Kong

Bert Steenbergen
Radboud University and Australian Catholic University

Effective learning methods are essential for motor skill development and participation in children with low motor abilities. Current learning methods predominantly aim to increase declarative knowledge through explicit instructions that necessitate sufficient working memory capacity. This study investigated the roles of declarative knowledge and working memory capacity in explicit motor learning of children with low motor abilities. We studied both acquisition performance (i.e., performance during practice) and learning (i.e., the improvement in performance from pretest to posttest). After practice with explicit instructions, children with low motor abilities showed significant learning, albeit that improvement was relatively small. However, working memory capacity and declarative knowledge did not predict learning. By contrast, working memory capacity and declarative knowledge did predict performance during practice. These findings suggest that explicit instructions enhance motor performance during practice, but that motor learning per se is largely implicit in children with low motor abilities.

Keywords: explicit learning, motor difficulties, motor skill, instructions, skill acquisition

van Abswoude and Steenbergen are with Behavioural Science Institute, Radboud University, Nijmegen, The Netherlands. van der Kamp is with the Dept. of Human Movement Sciences, Faculty of Behavioural and Movement Sciences, Research Institute MOVE, VU University Amsterdam, Amsterdam, The Netherlands; and Institute of Human Performance, The University of Hong Kong, Hong Kong SAR, China. Steenbergen is with the School of Psychology, Australian Catholic University, Melbourne, Victoria, Australia. Address author correspondence to Femke van Abswoude at f.vanabswoude@pwo.ru.nl.

Childhood is one of the most important phases for acquiring and refining motor skills. Children start with learning the most fundamental motor skills, such as running, jumping, and throwing. These lay the foundation for further development of more complex skills that are required in sports and physical activity (Gallahue & Ozmun, 2006). However, this development and refinement of motor skills is not self-evident for all children. For example, approximately 5–6% of all school-aged children experience difficulties with, or delay in, motor skill learning and control, and are formally diagnosed with developmental coordination disorder (DCD; *The Diagnostic and Statistical Manual of Mental Disorders*, DSM-V; American Psychiatric Association, 2013). Improving the motor skills of children with low motor abilities, including, but not limited to children with DCD, is important to enable participation in sports, physical activity, and activities of daily living. In this respect, it is increasingly recognized that motor learning interventions should be tailored to the children's individual motor and cognitive abilities and constraints (Chow, Davids, Button, & Renshaw, 2015). At present, explicit instructions are the most common intervention to promote motor learning in physical education and therapy (e.g., Johnson, Burridge, & Demain, 2013), but the degree to which this is suitable for children with low motor abilities has not been studied as of yet. The present study aims to examine the effectiveness of explicit instructions in motor learning in children with low motor abilities. Children with low motor abilities are less proficient in motor skills compared with their peers, but are not formally diagnosed with DCD. In the nonclinical research literature, children with low motor abilities are often referred to as "at risk" or "probable" DCD because of the large similarity in motor difficulties to children with DCD (Geuze, Schoemaker, & Smits-Engelsman, 2015).

Although we target children with low motor abilities, it is informative to provide some background on the motor problems that characterize children with DCD. Children with DCD often show more effortful, erratic movements than typically developing peers. These movements also show large variability from trial-to-trial (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). Moreover, children with DCD have problems attending to the relevant task aspects. This not only hinders movement planning, but has also been argued to hamper identification of, and learning from, errors (Adams, Lust, Wilson, & Steenbergen, 2015; Smits-Engelsman et al., 2013). It is likely that (parts of) these problems are also present among the larger group of children with low motor abilities. A recent meta-analysis showed that effective motor interventions in children with DCD included task-specific practice with an emphasis on enhancing children's problem-solving ability and the provision of feedback (Smits-Engelsman et al., 2013; see also Schoemaker & Smits-Engelsman, 2015). Interestingly, these are constituents of explicit learning, but the benefits of these interventions were found to be dependent on children's verbal abilities (Green, Chambers, & Sugden, 2008). Hence, weaknesses in using, manipulating, and/or retaining verbal, explicit information may be an important constraint on motor learning in children with DCD and possibly other children with low motor abilities. In other words, these children can benefit from explicit motor learning, but they may be poorly equipped to do so.

Explicit motor learning has traditionally been conceived as motor skills that progress through distinct stages, during which control is initially explicit or conscious but eventually becomes implicit or automatized (Adams, 1971; Anderson, 1983; Fitts & Posner, 1967). Consequently, learners must first become consciously aware of rules and facts on how to move. They have to accumulate declarative knowledge for learning to proceed. Declarative knowledge refers to rules that learners can verbalize and consciously apply to try to control and improve the execution of the movement. This knowledge typically originates from the instructions, feedback, and other cues provided by coaches, teachers, therapists, or other movement experts (see Magill & Anderson, 2014, for an overview). Verbal recall protocols, which require participants to verbalize any rules or facts about the movement they have learned, are used to tap into this pool of declarative knowledge. Indeed, studies using these protocols have shown that adults build up a fairly extensive pool of declarative knowledge following explicit motor learning interventions (i.e., Masters, 1992; Maxwell, Masters, & Eves, 2000; Maxwell, Masters, Kerr, & Weedon, 2001).

It has been argued that a learner's attentional and cognitive capacities are an important prerequisite for the accumulation and application of declarative knowledge, and hence, also for explicit motor learning (Buszard, Farrow, et al., 2017; Buszard, Masters, & Farrow, 2017; Halsband & Lange, 2006; Maxwell, Masters, & Eves, 2003). In particular, the conscious memorizing and manipulation of information relies on working memory. Consequently, working memory capacity may affect explicit learning, especially in the initial stage of learning. That is, with practice, the need for conscious control and attention is thought to gradually decrease until the movement is fully automated. Although it has been argued that motor learning can proceed without the learner becoming consciously aware of rules and facts on how to move (i.e., implicit motor learning; see Masters, 1992; Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010), most coaches, teachers, and therapists do predominantly stimulate the accumulation of declarative knowledge early in learning (Johnson et al., 2013; Kal et al., 2017), also for children with low motor abilities (Smits-Engelsman et al., 2013). As working memory capacity is developing during childhood (Gathercole, Pickering, Ambridge, & Wearing, 2004) and may relate to motor abilities (Piek, Dawson, Smith, & Gasson, 2008; Wilson et al., 2013), we are interested in how the accumulation of declarative knowledge and working memory capacity relate to motor performance and learning in children with low motor abilities.

A series of studies have provided evidence that explicit motor learning depends on working memory functioning (see Masters & Poolton, 2012, for a review). The majority of this evidence is indirect. For example, adults were shown to improve motor skills when working memory is loaded with a cognitively demanding secondary task (Masters, 1992). The dual-task practice, however, led to a reduction in the number of movement-related rules that learners reported compared with participants who practiced without this secondary task. On the one hand, this shows that motor learning can proceed implicitly (i.e., without or with reduced accumulation of declarative knowledge). On the other hand, this also shows that normally (i.e., without the dual-task), practice entails the use of working memory to apply and/or accrue declarative knowledge. This was the case irrespective of the learners receiving instructions about the to-be-learned skill (Masters, 1992). More recently, Buszard, Farrow, Zhu, and Masters (2013) have shown that working memory capacity was related to initial performance on a novel motor task. This highlights the role of working memory in the performance (and perhaps practice) of a novel skill. Yet, it remains elusive over its contribution to more permanent, long-term motor learning effects (also see Buszard, Masters, & Farrow, 2017 for a discussion). Recently, Buszard, Farrow, et al. (2017) presented more direct evidence regarding the role of working memory capacity in explicit motor learning in children. Children with high working memory capacity showed improved performance after having received explicit instructions during practice, both immediately and after a 1-week retention period. Children with low working memory capacity did not show learning. In contrast, two other recent studies involving children, both typically developing children and children with severe motor difficulties, did not find support for the conjecture that working memory capacity is associated with learning (Brocken, Kal, & van der Kamp, 2016; Jongbloed-Pereboom, Peeters, Overvelde, Nijhuis-van der Sanden, & Steenbergen, 2015). The relationship between working memory capacity and performance during practice (or acquisition performance) was not assessed in these studies. More recently, Jongbloed-Pereboom, Janssen, Steiner, Steenbergen, and Nijhuis-van der Sanden (2017) found an effect of visuospatial working memory capacity on performance during acquisition in implicit and explicit practice conditions in children born very preterm, but again, no effect on learning (i.e., performance improvements after practice) was found.

The above observations do not unambiguously support the conventional view regarding the roles of declarative knowledge and working memory in motor learning. However, they may be consistent with a subtly different perspective on the role of working memory and declarative knowledge in (early) motor learning. Instead of working memory supporting the accumulation of declarative knowledge and bringing about long-term learning, working memory and declarative knowledge may facilitate conscious control and monitoring of movement execution promoting short-term performance during practice. In this scenario, working memory would not primarily function to accumulate declarative knowledge but to support the application of declarative knowledge during practice (see e.g., Bernstein, 1996; Dreyfus, 2004). It would be this acquisition performance during practice that grants learning, instead of learning being a direct consequence of the buildup of declarative knowledge. If true, the roles of working memory and declarative knowledge might be more predictive for acquisition performance than for the long-term changes underlying learning (see also Schmidt & Bjork, 1992, for the distinction between acquisition performance and learning). We evaluate this alternative hypothesis by examining the roles of working memory capacity and declarative knowledge not only for learning, but also for acquisition performance.

In sum, the aim of the current study was to examine the roles of declarative knowledge and working memory capacity in motor learning and practice among children with low motor abilities. The children practiced a far-aiming task and received a series of explicit instructions on how to perform the task. Working memory capacity (using the *Automated Working Memory Assessment*, AWMA; Alloway, 2007) and the amount of declarative knowledge (using verbal recall protocols) were assessed. Our primary hypothesis was that the amount of accumulated declarative knowledge and working memory capacity would be related to learning, that is, the performance improvement from pretest to posttest—as is anticipated by the more traditional conceptions of explicit motor learning.

However, as an alternative, more exploratory hypothesis, we also tested if working memory capacity and the amount of declarative knowledge related to acquisition performance, that is, the performance during practice.

Methods

Participants

For this study, initially 69 children (35 girls) aged 6–11 years ($M = 9.4$, $SD = 1.5$) were recruited at a mainstream primary school. Parents completed a health questionnaire to ensure that the children had no known neurological or psychological disorders. All parents gave written informed consent. The procedures of the study were approved by the ethics committee of the Faculty of Social Sciences of the Radboud University (ECSW2013-1811-147). Children received a small gift for their participation.

All children completed the second version of Dutch version of the *Movement Assessment Battery for Children* (M-ABC2; Henderson, Sugden, Barnett, & Smits-Engelsman, 2010). Based on the Dutch interpretation of the DSM-V criteria for DCD (American Psychiatric Association, 2013), children who had a total score on this test at or below the 16th percentile, or who scored at or below the 5th percentile on any of the subscales, are referred to as probable DCD, and formed the low motor abilities group. This procedure yielded 20 children with low motor abilities, or probable DCD (six girls, age $M = 9.1$, $SD = 1.6$). The results of children that were not referred to as probable DCD are not reported here.[1]

Material and Tasks

Aiming task. The aiming task was adapted from boccia. In this sport, originally designed for people with motor disabilities, players roll balls as close as possible to a target ball. Although the game of boccia is new to most children, the participants often did have some experience with rolling balls, as rolling is considered a fundamental motor skill.

Learning: Pretest and posttest improvement in performance. During the pretest and posttest, children aimed official boccia balls at a target ball (as in the official sport of boccia) placed 600 cm in front of them, while sitting on a stool. The target ball was placed on a lane with a total length of 650 cm and a width of 80 cm. Children performed 25 trials in both the pretest and posttest. They were instructed and encouraged to roll the balls as close as possible to the target ball, but received no further instructions on how to achieve this. All trials were recorded on video camera (Sony Handycam HDR-CX220E, full HD, 1080p; Sony Electronics Inc., San Diego, CA) and scored afterward using Dartfish® software (version 6; Dartfish SA, Fribourg, Switzerland). The change in performance from pretest to posttest served as the measure for learning, which is to be distinguished from acquisition performance during the practice blocks (see below). The task contexts in the practice and test sessions were not identical. This was done in order to more clearly distinguish the acquisition performance during practice from the relatively more permanent learning observed after practice (see Schmidt & Bjork, 1992).

Acquisition performance: Performance during the practice blocks. During practice, the children tried to score as many points as possible by rolling the ball into the middle of a round target, each consisting of three concentric circles (Figure 1). These targets were drawn onto similar lanes as used in the pretest and posttest, but the targets were drawn at three different distances (500, 350, and 250 cm; see Figure 1) creating three different task difficulties. Practice was divided in sets of three blocks of 15 trials. In each block, a different target distance was used. To create an environment that promotes explicit learning, the order of the blocks was randomized within a set of three blocks. That is, the difficulty of the task was varied by using different target distances to create an environment in which errors are likely to occur frequently. Frequent errors have been shown to promote conscious hypothesis testing and the accumulation of declarative knowledge (Maxwell et al., 2001). Also, changes in task difficulty keep the children more engaged and motivated during practice. The target itself consisted of three concentric circles. The inner circle of the target had a radius of 15 cm, and the surrounding two circles had radii of 45 and 75 cm, respectively (Figure 1). A strip was drawn on the lanes with a width of 15 cm on the longest lane, 20 cm on the middle lane, and 60 cm on the shortest lane. The children were encouraged to score as many points as possible and try to aim across the strip. Five points were scored when the ball stopped in the inner circle, three points when it stopped in the second

Figure 1 — Design of the three targets used during practice. The order of the target distances was manipulated in order to create a more explicit practice environment.

circle, and one point when it ended in the outer circle. The number of target hits (i.e., balls stopping within the outer circle) was used as a measure of acquisition performance during practice. Next to the series of instructions on movement execution, no feedback on movement execution was provided. The children were encouraged—at various moments during practice—to perform to the best of their abilities.

Motor ability. Children completed the M-ABC2 (Henderson et al., 2010) to assess their motor skill ability. This test is divided in three subscales: manual ability, aiming and catching, and balance consisting of three, two, and three items, respectively. The items of the test differ based on which age band is used (i.e., either 4–6, 7–10, or 11–16 years). Standard and percentile scores were calculated for each of the subscales, and for the tests as a whole, based on age.

Working memory capacity. To assess working memory capacity, children performed the short version of the Dutch AWMA (Alloway, 2007). Two subtests were used: listening recall and spatial recall. These subtests measure verbal working memory capacity and visuospatial working memory capacity. The used subtests both show good test–retest reliability with correlation coefficients above .75, and an average of .85. For the current purpose, raw scores were used in the analyses as a measure of absolute working memory capacity.

Declarative knowledge. To determine the amount of declarative knowledge about rules and facts of the rolling task that children had accrued, a verbal recall protocol was used. We asked children in an open question to verbally report any rules or facts that they had used or paid attention to in order to perform the aiming task. Responses were verbally reported to the experimenter, who wrote them down. Afterward, the first author and a research assistant independently categorized the responses. Both rules and facts related to the movement execution (e.g., "I tried to make a straight swing with my arm") and rules related to the task performance (e.g., "I focused on the red dot") were scored. Responses that did not describe actual movement execution or task performance (e.g., "it is difficult to score 5 points") were not used for further analyses. The interrater agreement was 97%. Items on which the raters disagreed were discussed until consensus was reached.

Procedure

The experiment was conducted across 3 days within 1 week (Figure 2). Most children participated for 3 consecutive days, except for three children who had one extra day between the first and second practice day because of logistic reasons. On Day 1, children first performed the pretest and then underwent the first three practice blocks. At the start of the practice sessions, the children received a set of seven explicit instructions about how to perform the rolling task (see Table 1). These instructions, which were developed together with the coach of the Dutch boccia team, described the sequence of movements that the children had to perform for adequate motor execution (see Maxwell et al., 2001, for similar practice protocols using explicit instructions). The experimenter ensured that the children understood the instructions by giving additional explanations or providing a visual

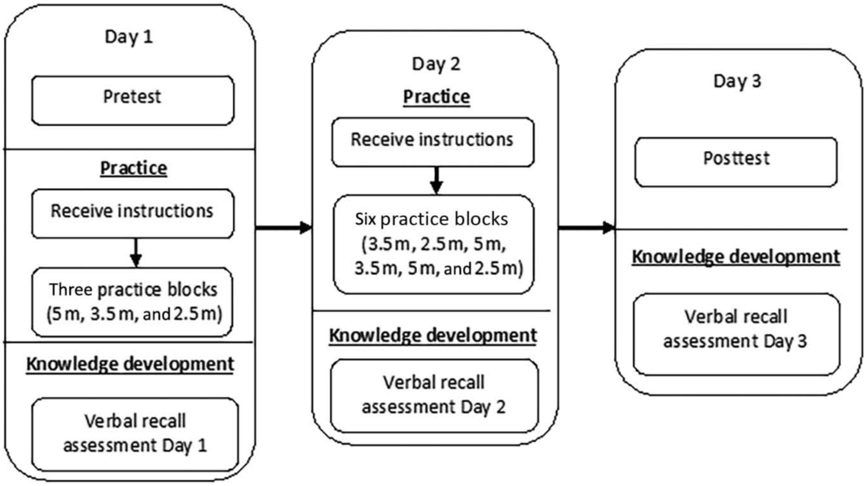

Figure 2 — Schematic representation of experimental procedures.

Table 1 Stepwise Rules About the Performance of the Task

1. Look at where you want to aim the ball
2. Make sure that your body is in a straight line with the target
3. Swing your arm backward to create speed for the ball
4. Let the ball go at its lowest point
5. Continue the swing with your arm after releasing the ball
6. Follow through in the direction of the target
7. Keep your body stable, so do not sway left or right

demonstration if necessary. They then practiced 45 trials (see Figure 2). On Day 2, children performed the next six practice blocks. The same procedure was followed as in the first practice block. That is, practice started with a repetition of the set of instructions, followed by 90 trials. On Day 3, the posttest was performed. The instructions used during practice were no longer provided. To determine the amount of accumulated declarative knowledge, a verbal recall protocol was used at the end of each experimental day (i.e., after the third and ninth practice block, and after the posttest). The verbal protocol gauged the children's use of rules and facts to perform the rolling task.[2] The M-ABC2 and the AWMA were administered on separate days within 3 weeks before or after the main experiment.

Data Analysis

Learning across tests. To describe performance on the pretest and posttest, the score was defined as the distance between the end point of the rolled ball and the target ball in centimeters.[3] Hence, higher values represent worse performance.

Learning was calculated by subtracting the mean accuracy on the posttest from the mean accuracy of the pretest. A positive score corresponds to an improvement in performance and indicates that learning had taken place. Data were checked for outliers in this outcome. One outlier of $\pm{>}2 \times SD$ was removed from analysis.[4] To assess if children showed learning, a one-sample t test was performed (against zero), with learning score as dependent variable.

Acquisition performance during practice. To describe acquisition performance and compare the number of target hits (i.e., the number of balls landing within the outer circle) in the three sets of three practice blocks, a repeated-measures analysis of variance with sets as within-factor was performed. We also compared the number of rules and facts reported during and after practice using the Friedman test. This test was used because of the low variance in the number of rules at Day 1.

Relationships with working memory capacity and declarative knowledge. Finally, the primary and secondary hypotheses were tested using stepwise linear regressions. The order of entering the independent variables is based on the presumption that explicit learning depends on the amount of declarative knowledge, and that this amount is restricted by working memory capacity. First, we tested the relation to learning (i.e., the performance change from pretest to posttest). To this end, a stepwise multiple linear regression analysis was performed to examine if the number of rules and facts reported after the posttest and/or verbal and visuospatial working memory capacity were related to learning. Second, we tested the relation to acquisition performance (i.e., the total number of target hits). To this end, the number of rules and facts reported during practice (i.e., the number reported at the end of Day 2), and verbal and visuospatial working memory capacity were entered into a stepwise multiple linear regression analysis with the total number of target hits as the dependent variable. Finally, we explored the correlations between verbal and visuospatial working memory capacity and the number of rules and facts reported during practice and after the posttest.

All analyses were performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, version 19.0; IBM Corp., Armonk, NY), and statistical significance was set at $p < .05$.

Results

Learning Across Tests

Most children improved their aiming performance, with increases ranging between 3.8 and 33.9 cm. Nevertheless, five children showed decreases ranging between 3.0 and 27.5 cm. On average, the children improved their aiming performance from the pretest ($M = 104.94$, $SD = 13.74$) to the posttest ($M = 99.34$, $SD = 14.58$). The one-sample t test showed that this learning was significant with a medium effect size, $t(18) = 2.19$, $p = .042$, Cohen's $d = 0.51$.

Acquisition Performance During the Practice Blocks

It was first assessed whether children's acquisition performance changed across the practice blocks. There were only small differences in the number of target hits

Table 2 Hierarchical Linear Regression Model of Performance During Practice

	B	*p*	R^2	ΔR^2
Step 1			.154 ($p = .049$*)	
Constant	43.55	<.001*		
Rules	2.91	.049*		
Step 2			.339 ($p = .022$*)	.245 ($p = .045$**)
Constant	37.85	.005*		
Rules	2.47	.073**		
Verbal WM	0.62	.202		
Visuospatial WM	0.631	.059**		

Note. WM = working memory.
*Significant value ($p < .05$). **Near-significant value ($p < .10$).

between the three sets of practice blocks, with most hits in the final three blocks ($M = 17.05$, $SD = 4.12$), followed by the first three blocks on Day 1 ($M = 16.05$, $SD = 3.99$) and the first three blocks on Day 2 ($M = 15.25$, $SD = 3.92$). The repeated-measures analysis of variance did not reveal an effect of set, $F(2, 38) = 1.44$, $p = .249$, indicating that acquisition performance did not significantly improve across the sets of practice blocks.

A Friedman test was performed to determine if there were differences in the number of rules and facts reported between the 3 days (see Table 2). This showed a significant difference, $\chi^2(2) = 7.32$, $p = .026$. The number of facts and rules measured just after the first three practice blocks at the end of Day 1 ($M = 1.55$, $SD = 1.05$) had slightly increased after the final practice block at Day 2 ($M = 1.65$, $SD = 1.35$), and more so after the posttest at Day 3 ($M = 2.10$, $SD = 1.45$). However, follow-up analysis with Wilcoxon signed-rank tests with Bonferroni correction did not confirm significant differences.

Relationships With Working Memory Capacity and Declarative Knowledge

The first stepwise linear regression, with the change in performance from pretest to posttest as dependent variable, did not return any significant models. This indicated that neither the number of rules and facts reported after the posttest nor verbal or visuospatial working memory capacity significantly related to motor learning. By contrast, the second stepwise linear regression model with the total number of hits during practice resulted in a significant model, with the number of rules and facts reported during practice entered in the first step and both verbal and visuospatial working memory capacity in the second step. The model summary can be found in Table 3. The analysis revealed that the model was already significant in the first step, with a significant effect of the number of rules ($B = 2.91$, $p = .049$). The second step led to a significant improvement in the model fit, with both the number of rules and facts ($B = 2.47$, $p = .073$) and visuospatial working memory capacity

Table 3 Frequencies of the Number of Rules Reported After Each Day

No. of Rules	Start of Practice, Day 1 (*N*)	During Practice, Day 2 (*N*)	After Learning, Day 3 (*N*)
0	4	6	4
1	4	2	3
2	10	7	4
3	1	3	5
4	1	2	4

($B = 0.63$, $p = .059$) showing near-significantly relations to acquisition performance. This model met the assumptions for linear regression and did not include influential cases (Field, 2009).

Finally, no significant correlations were found between the number of rules reported at each of the 3 days and either verbal or visuospatial working memory capacity.

Discussion

The aim of this study was to investigate the role of declarative knowledge and working memory in explicit practice and motor learning in children with low motor abilities. The primary hypothesis was that motor learning would be dependent on the amount of accumulated declarative knowledge and working memory capacity. We found that children showed a moderate, significant improvement in aiming performance from pretest to posttest, even with the current relatively brief practice period (cf. Buszard, Farrow, et al., 2017; Capio, Poolton, Sit, Holmstrom, & Masters, 2013). In contrast to arguments from traditional views of explicit learning, we did not find the predicted relation between motor learning and working memory capacity and/or the amount of accumulated declarative knowledge after practice. As a secondary aim, we also explored to what degree declarative knowledge and working memory capacity affect acquisition performance during practice. This revealed that acquisition performance in practice was related to the amount of declarative knowledge reported during practice and visuospatial working memory capacity. These findings suggest that declarative knowledge and working memory capacity may have distinct roles in obtaining improvements in motor performance observed after practice (i.e., learning) and in controlling performance during practice (i.e., acquisition performance). Below, we will elaborate on these new findings.

The Roles of Working Memory Capacity and Declarative Knowledge in Learning

The current study demonstrates that children with low motor abilities are able to learn the aiming task following practice with explicit instructions. Here, motor learning is understood as relatively permanent improvements over a period practice (i.e., indicated by the performance change from the pretest to posttest). Even though the average improvement is small, the medium effect size suggests that this improvement is meaningful. This finding lends positive support for the explicit interventions that are typically used to promote motor functioning in children with low motor abilities, such as DCD (Smits-Engelsman et al., 2013), but the large variability in learning improvement among children also underlines that not all children benefit equally (Green et al., 2008). Intriguingly, and as an extension of the current literature, we did not find support for the conjecture that the amount of declarative knowledge and working memory capacity predict these learning improvements. Hence, we cannot corroborate that the learning process as such was explicit, despite the fact that practice took place with explicit instructions. Rather than the accumulation of declarative knowledge, it may have been the accumulation of experience during practice that induces motor learning (Bernstein, 1996; Dreyfus, 2004). As Dreyfus argued, explicit instructions may promote the quality of practice, and in doing so, allow learning to occur, rather than causing learning directly through the buildup of declarative knowledge. If correct, then learning might largely have been implicit, despite the explicit prescriptive instructions (see Masters, van der Kamp, & Capio, 2013, for an overview of implicit learning in children). Implicit learning would also be consistent with the relatively low number of explicit rules and facts that children reported after practice. Indeed, in a recent study by Capio, Poolton, Sit, Holmstrom, and Masters (2013), children with low motor abilities equally improved their overhand aiming performance following explicit and implicit practice protocols. This demonstrated that children with low motor abilities can indeed learn implicitly and do not necessarily need to learn explicitly via the provision of explicit instructions to stimulate the accumulation of declarative knowledge. Effective implicit motor learning has also been reported for children born preterm (Jongbloed-Pereboom et al., 2017), children with unilateral cerebral palsy (van der Kamp, Steenbergen, & Masters, 2017), children with multiple disabilities (Jongbloed-Pereboom et al., 2015), and children with intellectual disabilities (Capio, Poolton, Sit, Eguia, & Masters, 2013).

There may be alternative reasons why children did not learn explicitly. An obvious one is the nature and content of the instructions. For example, Brocken et al. (2016) recently showed that children benefit more from instructions that direct attention toward the effects of the movement, rather than toward the execution of the movement as in the present study. In addition, not all instructions are equally meaningful for facilitating learning in novices; we developed the instructions in collaboration with an expert boccia coach. Perhaps, the instructions were directed too much toward an ideal movement pattern, while more skill-level appropriate instructions might have been more effective for learning.

It should also be noted that the number of reported rules was low. One reason might be that verbal protocol used to gauge declarative knowledge required not only working memory capacity, but also adequate verbal abilities and communication skills (Rieber, 1969). Hence, we cannot conclude with certainty that children did not accumulate more declarative knowledge than they reported. Accordingly, identifying the purported relationship between declarative knowledge and learning may await further methodological advances, such as the measurement of electroencephalography coactivation between verbal-cognitive and motor planning neural networks (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011).

Perhaps a more likely reason for the low number of reported rules and facts is the children's limited working memory capacity (Buszard et al., 2013). However, the correlation between working memory capacity and the number of reported rules and facts was not significant. Also, the children's standardized verbal and visuospatial working memory scores were within the normal age range, except for two children who scored below average on visuospatial working memory capacity. Yet, the raw working memory scores did indicate that the majority of children could only report a maximum of two or three items correctly in the verbal task and two to four items in the visuospatial task. This number closely corresponds to the number of rules and facts they reported. Thus, working memory capacity might have limited the children's ability to apply or build up declarative knowledge: This may have forced them to only focus on one or two rules that actually contributed most to their performance. Clearly, it is an important issue to resolve for future studies whether the observed absence of a relationship among the accumulation of declarative knowledge, working memory capacity, and motor learning is merely constrained by the children's limited working memory capacity or, alternatively, whether they are more influential in promoting acquisition performance—as we are inclined to believe (see below).

As a final point, the children's limited working memory capacity may also point to age as a possible confounder. Both verbal ability and communication skills develop with age, as does working memory capacity (Alloway & Alloway, 2013). We were not able to control for age in the analysis, as this would lead to insufficient power. Nevertheless, visual inspection of the individual results suggested that children across all ages were capable of improving performance from pretest to posttest even though the children who did not improve were all 9 years or older. Hence, learning improvements were not restricted to either younger or older children. It is important that future work takes age into account.

The Roles of Working Memory Capacity and Declarative Knowledge in Acquisition Performance

We found that the number of reported rules and facts during practice together with visuospatial working memory capacity did significantly explain the variance in acquisition performance for the whole practice phase. There were trends that suggested that the larger the visuospatial working memory capacity, and the more declarative knowledge the individual child reported during practice, the more balls were rolled on target, that is, the better the acquisition performance. Similar to the number of rules after learning (see above), it is notable that the average number of reported rules and facts ($M = 1.65$) was low compared with the seven instructions that were provided to the children. The number was also low compared with the four to five rules that adults typically report after an explicit intervention (Maxwell et al., 2001). This suggests that children with low motor abilities can indeed benefit from explicit instructions, but that either their verbal ability to report the rules and/ or their ability to use or apply the rules may be limited (possibly due to working memory capacity limitations). Either way, the low number of rules underlines that a minimum amount of declarative knowledge is already sufficient to successfully start performing and practicing the task (see van Abswoude, Santos-Vieira, van der Kamp, & Steenbergen, 2015, for similar argumentation). Under this scenario, only one or two rules are adequate to get acquisition performance going and this would be sufficient to gain experience for learning (Dreyfus, 2004).

Interestingly, instead of verbal working memory capacity, which is considered instrumental in the accumulation of declarative knowledge (Masters, 1992), we found that visuospatial working memory capacity related to acquisition performance (see also Jongbloed-Pereboom et al., 2017). Possibly, working memory capacity was not employed for remembering and manipulating the verbal rules, but rather for remembering the spatial information of the task. However, the exact reasons for this finding are not particularly clear. Future work should try and replicate the roles of working memory capacity and declarative knowledge during practice and motor learning, also in other populations, to further detail how and when they contribute to performance.

Conclusion

Taken together, children with low motor abilities are able to improve their performance on a gross motor task following practice in an explicit practice context. Yet, we showed that this does not necessarily imply that the motor learning process per se was explicit. The absence of any relations between motor learning and both the number of reported rules, as well as with verbal and visuospatial working memory capacity, suggests that the children were perhaps more likely to have learned the task implicitly. This is not to say that there was no role for declarative knowledge or working memory capacity. Our results suggest that they did positively relate to acquisition performance during practice, even though most children did not report more than two rules and had low raw working memory scores. This could indicate that children with low motor abilities can already benefit from a few explicit instructions during practice; yet actual learning (i.e., the relatively permanent improvements) in these children seems to occur with little or no involvement of cognitive processes, but takes place against the background of conscious practice performance. It is pertinent to further research the exact roles of working memory capacity and declarative knowledge found for acquisition performance and learning also in relation to age, because they lead to important theoretical and practical implications.

The findings highlight that to promote motor skills in children with low motor abilities, including children with DCD, explicit interventions such as instructions, feedback, or problem-solving skills (Schoemaker & Smits-Engelsman, 2015) promote learning, but this may happen indirectly by enhancing the quality of acquisition performance. Our observed discrepancy between the provided practice context (explicit) and the likely learning process (more implicit) warrants more research about the role of explicit instructions and declarative knowledge in implicit and explicit motor learning in both typically and atypically developing children. Possibly, focusing instruction toward better practice rather than toward the ideal movement pattern further optimizes practice and learning. Clearly, further research can benefit daily practice of physical therapy, sports, and remedial teaching.

Notes

1. Initial analysis showed that the vast majority of children with normal to good motor abilities had not improved the performance on the aiming task with practice. In other words, they did not show learning, and hence, these data were not further analyzed.

2. For children, it might be challenging to recall and verbalize the rules and facts about how to perform a motor task, as it requires adequate communication skills (Rieber, 1969). Therefore, we did also administer a questionnaire to gauge to what task aspects the children paid attention. The six aspects that were included in the questionnaire were directly related to six of the seven rules that the children received (not the rule about the keeping the body in a straight line). In a previous study, this questionnaire related to the number of errors made during practice (van Abswoude et al., 2015). Yet, in the current study, correlational analyses did not show the expected relations among the questionnaire, working memory, or the amount of declarative knowledge. Hence, for the sake of brevity, we decided not to report the outcomes of the questionnaire. Yet, the responses in the questionnaire that the children almost always paid moderate attention to the rules, and attention to the rules they used, were typically high.

3. Due to restrictions in camera placement and room size, a cutoff point of 150 cm was used. Balls that ended out of view of the camera or hit the wall received a maximum score of 150 cm.

4. This participant showed an unusually large decrease in performance of −36.5 cm, with a pretest score of 91.8 cm and a posttest score of 128.3 cm.

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