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Original Article

Development of individual instructions based on pupils' mental representations of a gymnastics skill

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Abstract
Problem Statement - In physical education, teachers use instructions to support the learning of motor skills (Wulf, Höß, & Prinz, 1998). Expertise in performing motor skills is characterized by forming and adapting relevant mental representations that are stored hierarchically structured in long-term memory (Land, Volchenkov, Bläsing, & Schack, 2013; Schack & Mechsner, 2006). Scientific findings reveal differences between experts' and novices' mental representation structures in the comparison of different skill levels (Bläsing, Tenenbaum, & Schack, 2009), as a consequence a close relationship between mental representation structure and skill performance is presumed, and a development of mental representation structures over the course of learning could be highlighted (Frank, Land, & Schack, 2016).
Purpose- Therefore, the purpose of this study was to investigate the differences in the effects of two types of instructions (specific vs. general) on pupils' development of mental representation structures and their performance of a cartwheel.
Approach- Sixteen pupils were assigned to one of two conditions: specific or general instructions on the performance of a gymnastics skill (cartwheel). Participants in the intervention group received specific instructions, based on their mental representation structure of the cartwheel, whereas participants in the control group received general instructions.
Results- Results revealed that specific instructions based on pupils' mental representation of a gymnastics skill have a positive impact on their mental representation structure as well as on their motor performance.
Conclusions- It can be concluded that the knowledge about learners' structure of mental representations could constitute an effective means of developing specific instructions for enhancing motor performance.
Key Words: physical education, teachers, cartwheel, performance increase, SDA-M

Introduction

Perceptual-cognitive approaches propose that knowledge about the construction of mental representations is fundamental for the understanding of motor performance (Jeannerod, 2004; Land, Volchenkov, Bläsing, & Schack, 2013; Schack & Hackfort, 2007). Mental representations, understood as conceptual units stored in long-term memory (LTM) that have a functional relationship with the control of motor actions, are essential in selecting and evaluating information in movement execution and thus influence quality and stability of skills (Bläsing, Tenenbaum, & Schack, 2009; Schack, 2010). Practitioners, like coaches or teachers, could use knowledge about the structure of mental representations to influence the process of motor learning. Because expertise in performing motor skills is characterized by forming and adapting relevant mental representations in athletes' LTM (Land et al., 2013), it is proposed to support the process of forming mental representations through specific instructions. This is why the purpose of this study was to answer the question if instructions based on learner's mental representation structure of a gymnastics skill lead to cognitive and motoric changes, indicating an optimization of their mental representation structure and an enhancement of their motor performance of the skill.

One of the various factors that influence the learning of motor skills is the instruction given to the learner, who is in the process of acquiring a skill (Wulf, Höß, & Prinz, 1998). It can be described as actions and measures to optimize the classification, conditions, processes, and results of learning. The aim of instructions is to optimize motor learning and skill acquisition. Therefore, instructions are given before or during practice by, for example, coaches or physical education teachers and include information on how to perform a skill. Instructions may be particularly relevant for the learning of complex skills (e.g., in gymnastics) because learner's attention often needs to be guided on the relevant aspects of the task (Schmidt & Lee, 2011; Wulf et al., 1998).
Practitioners use different instructional strategies. For example, verbal instructions and cues are means of communicating information about how to perform motor skills. However, a problem associated with verbal instructions is that they might contain too little or too much information and do not provide the learner with what he or she needs (Magill, 2007). Hinds, Patterson, and Pfeffer (2001) highlighted that experts provide instructions that are too conceptual and include too few specific details to guide novices. These findings support the

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assumption that experts and novices have different knowledge structures of skills. Therefore, an adaption to the learner's knowledge structure of the skill seems adequate (Magill, 2007). Based on the assumption that human actions are retained and represented in LTM and each human being is equipped with an individual mental representation structure of motor skills (Hommel, 1996; Schack, Bläsing, Hughes, Flash, & Schilling, 2014), it might be possible to address this issue effectively by taking the mental representation structure as basis for individual instructions.

To increase knowledge about the nature and role of mental representations of motor skills in LTM, researchers applied a method called *structural dimensional analysis – motoric* (SDA-M) that examines means of knowledge-based decisions in an experimental setting. Motor skills are subdivided into *basic action concepts* (BACs), conceptual building blocks of an action, and in a specific sorting task these functional substeps of the skill are related to each other. The mental representation structure is revealed on the basis of psychometric data, which is a strong advantage compared to other qualitative approaches (Schack, 2004, 2012).

First examinations demonstrated how movements are stored in LTM and revealed a difference between experts and novices. Schack and Mechsner (2006) investigated mental representation structures of the tennis serve. They compared an expert group, a low-level group and a group of non-players, showing that hierarchical clustering structures can be related systematically to the different quality of performance on different expertise levels. Experts' mental representations first, were organized in a hierarchical tree-like structure, second, were similar between individuals and third, were well matched with the functional and biomechanical demands of the motor skill.

Similar findings could be shown by Bläsing et al. (2009) who examined mental representations of two basic classical ballet movements stored in LTM of dancers with different skill levels. A similar mental representation structure, which referred to the functional phases of the movement, was determined in advanced dancers. Less functional representations were noted in beginners and novices.

A study by Velentzas, Heinen, Tenenbaum, and Schack (2010) examined the mental representation structures of overhand volleyball service routines of the German Youth Female National Team. Results showed that the quality of athletes' mental representation structures correlated with the coach's performance ranking. These findings indicated a close relationship between mental representation and performance. Weigelt, Ahlmeyer, Lex, and Schack (2011) examined mental representations of a judo technique. Findings of this study pointed out, that the SDA-M could be used as a diagnostic tool to measure individual mental representations of motor skills because for two experts insights about specific movement problems could be gained.

In a study of Frank, Land, and Schack (2016) changes in mental representation structures and skill performance over the course of motor learning were examined. Novices trained on a golf-putting task for three days. They were assigned either to a physical practice group, a combined physical plus mental practice group, or a no practice group. Both practice groups showed improvements in motor performance. Findings highlighted that during motor learning mental representations of a skill adapt functionally in the direction of an elaborate representation structure. Taken together, mental representations of motor skills are stored hierarchically structured in LTM. In the comparison of different skill levels, differences between experts' and novices' mental representation structures are documented, therefore a close relationship between mental representation structure and skill performance is presumed, and a development of mental representation structures over the course of learning could be highlighted. Since research in physical education regarding the structure of learners' mental representations and the relation of mental representations and motor performance might benefit from aforementioned findings, the purpose of this study was to investigate the differences in the effects of two types of instructions (specific vs. general) on pupils' development of mental representation structures and their performance of a cartwheel. Taking into account the results of studies on mental representations and motor performance, it was expected that both types of instructions would lead to functional changes of the mental representation structures, along with motor performance improvement *(hypothesis 1)*. Furthermore, it was expected that specific instructions would be relatively more effective than general instructions in the development of mental representation, since the specific instructions take into account the individual structuring of mental representations of each pupil *(hypothesis 2)*. In addition, it was hypothesized that specific instructions would lead to a better motor performance than general instructions *(hypothesis 3)* (Kim, Frank, & Schack, 2017).

Materials and Methods

Participants and Design

Sixteen female pupils participated in the present study (age: M = 12.18, SD = 0.39). All pupils attended gender separated physical education classes in grade seven in a state school and reported few or no experience in gymnastics. Prior to the beginning of the study, all participants, as well as their parents, were informed about the general procedure. Parents and pupils gave their written consent. The study was carried out according to the ethical guidelines of the university's ethics committee and with permission of the state supervisory school authority.

To realize an intervention study with a between-subject design, participants were assigned as matched pairs based on their pretest mental representation structure to one of two groups: an intervention group (n = 8; age: M = 12.20, SD = 0.40) and a control group (n = 8; age: M = 12.17, SD = 0.37). The study consisted of a pretest, an intervention phase, and a posttest (Table 1). Participants in the intervention group received specific instructions that were developed on the basis of the mental representation structure of the pretest results, whereas participants in the control group received general feedback. Both groups passed a 1.5 hours training phase and were tested prior to and after this intervention for their mental representation structure of the cartwheel, as well as for their motor performance of the cartwheel.

Table 1. Design of the study including a pretest, an intervention phase, and a posttest within three weeks

	Pretest (Week 1)	Intervention phase (Week 2)	Posttest (Week 3)
Intervention group ($n = 8$)	SDA-M & videotaping of cartwheel	**Specific instructions** $1^{1/2}$ hours of practice (including change of practice stations)	SDA-M & videotaping of cartwheel
Control group ($n = 8$)		**General instructions** $1^{1/2}$ hours of practice (including change of practice stations)	

Measures and Instruments

Gymnastics Skill. The cartwheel was chosen as a fundamental floor exercise in gymnastics, as the athlete rotates about every axis of the body. Gerling (2011) recommends the subdivision of the cartwheel into three main phases: the preparation phase (starting position and frontal axis rotation anterior), the main phase (longitudinal axis rotation, transverse axis rotation, longitudinal axis rotation) and the end phase (frontal axis rotation posterior and end position). Characteristics of a well-performed cartwheel are a large range of movement, a straight movement execution without change of direction, a fluent movement sequence, and body tension with straightened legs and arms (Härtig & Buchmann, 2004). The cartwheel is part of the German curriculum of physical education for Lower Saxony, in the „experience and learning field of gymnastics and movement arts“ that contains rolling, swinging, jumping and balancing (Ministry of Education and Cultural Affairs of Lower Saxony, 2007).

Assessment of Mental Representations. To assess pupils' mental representation structure of the gymnastics skill, *structural dimensional analysis - motoric* (SDA-M) was employed. The SDA-M serves to determine relations between *basic action concepts* (BACs) and the groupings of a given set of BACs and proceeds in several steps (for details, see Schack, 2012). In the present study the following steps were performed: In a first step, a split procedure on a pre-determined set of eight BACs (1) stand straight & raise arms, (2) lunge forward & lower upper body, (3) twist upper body & swing up first leg, (4) position hands aligned on the floor one after the other, (5) pull up second leg, (6) handstand position with open legs, (7) place feet one after the other on the floor & release hands, (8) set body upright and raise arms, is performed, resulting in a distance scaling between the BACs. The display format of the BACs was adapted to the proposal of Hennig, Velentzas, and Jeraj (2016), introducing a combination of picture and text items. For each of the BACs, a picture combined with a textual description was used. The set of BACs for the cartwheel was generated based on an expert questioning (n = 8) and textbooks (see, Hennig et al., 2016). The splitting task (i.e., first step of the SDA-M) proceeds as follows: in a paper-pencil questionnaire, pairs of two BACs are presented in randomized order, so that each of the BACs is being displayed together with another BAC. Participants are asked to decide whether the two BACs, presented in one pair, are considered to relate to each other during movement execution or not. Participants chose either a negative sign (minus) or positive sign (plus) in the paper-pencil test depending on whether the elements are judged as belonging to or not belonging to each other. After each BAC has been compared to every other BAC, the splitting task is completed. In a second step, a hierarchical cluster analysis is used to outline the structure of the given set of BACs, resulting in a tree diagram for each participant. The tree diagrams, showing the individual mental representation structures of the cartwheel, serve as a basis for the development of specific instructions for each pupil in the intervention group.

As a following step, a hierarchical cluster analysis was carried out to outline the structure of the given set of BACs (for details, see Schack, 2012). In order to calculate the similarity to an expert reference structure, the Euclidean distance for the comparison of each participant's *z*-matrix solution with the mean experts' *z*-matrix solution was calculated.

To determine the reference matrix, mental representation structures for the cartwheel of a group of four gymnastics experts were assessed. The experts reported $M = 14.75$ years of experience as gymnastics coaches, which was the selection criterion for expertise in this study (Chi, 2006; Swann, Moran, & Piggott, 2014).

Assessment of Motor Performance. To assess pupils' motor performance of the gymnastics skill, the performance of the cartwheel has been videotaped for each pupil for pre- and posttest. The camera (Canon EOS 550D) that videotaped the performance was placed orthogonal to the movement direction. Pupils performed one cartwheel per test date. The videotaped performances of the cartwheel were used for kinematic analysis. Coordinates of the points on which participants' hands and feet were placed on the mat were calculated for each participant using the movement analysis software utilius® easyinspect (ccc-software, Leipzig). Criterion for a well-performed cartwheel was straightness (Härtig & Buchmann, 2004), defined as the distance from a centerline (a straight line parallel to gymnastics mat starting from first foot y-coordinate).

General and Specific Instructions. Participants in the intervention group received specific, individual instructions, based on their mental representation structure of the cartwheel in the pretest. They got specific instruction cards, containing pictures and explanations for the respective substep of the movement (BAC), which were prepared on the basis of the results of the pretest. The tree diagrams of the pupils were analyzed and differences to an expert reference structure have been detected. For each pupil, one BAC, for which the strongest deviation to the expert structure could be determined, was selected for the instruction card. Figure 1 a and b display two examples for specific instruction cards, referring to two different BACs. Participants in the control group attended the regular training session. They got general instructions on a card, displaying and explaining the whole movement (Figure 1 c).

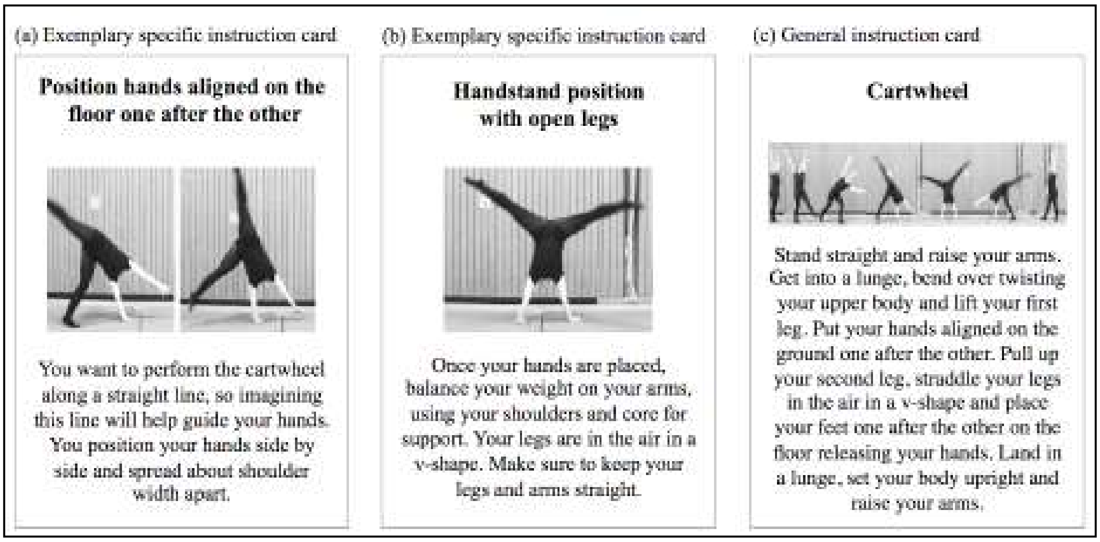

Fig. 1. Two examples for specific instruction cards for pupils in the intervention group, referring to two different BACs (a; b), and the general instruction card for the control group (c), describing the whole movement.

Procedure

Pretest. Participants were informed about the general purpose and procedure of the study and completed the informed consent form, as well as a questionnaire on their experience in gymnastics. To ensure anonymous participation the questionnaires were filled in with an ID. First, participants were informed about how to perform a cartwheel. A gymnastics coach demonstrated and explained the single steps of the cartwheel and performed the skill. Additionally, participants watched a video presenting a gymnast performing the cartwheel. Next, they were instructed to fill in the SDA-M questionnaire for the cartwheel. After completion of the questionnaire, participants were asked to execute a cartwheel on prepared gymnastics mats. Pupils' performance of the cartwheel was recorded on video.

Intervention phase. Participants in the intervention group received specific, individual instructions, based on their mental representation structure in the pretest. They got specific instruction cards, containing explanations and pictures for the respective BAC needed. Participants in the control group attended the regular training session. They got general instructions on a card, displaying and explaining the whole movement.

The practice phase of 1.5 hours was organized in such a way that pupils of both groups could practice at the same time. Different practice stations for the cartwheel were realized: one practice station for each BAC, using different arrangements of sports devices and a general practice station for practicing the whole movement, using gymnastics mats. All practice stations were arranged in a circle in the gym. Pupils passed all practice stations but the intervention group focused on the task demanded at the practice station for the BAC on their instruction cards, which means that they started and ended at this station. The control group focused on practicing at the general practice station. An example for a pupil of the intervention group should illustrate the procedure: if a student had not correctly represented BAC 4 (position hands aligned on the floor one after the other) in the pretest, she received an instruction card for BAC 4 (Figure 1 a). This instruction card showed pictures referring to the corresponding part of the movement and a text that focused the attention of the student on the partial substep. First, the instruction card was exactly studied and internalized by the pupil. Second, fitting to the card, the student found a practice station in the gym where she began to practice. For BAC 4, there was a straight line marked on a gymnastics mat with adhesive tape and chalk to mark the position of the hands. Third, after having practiced the positioning of the hands several times at the station, the pupil practiced also at the other stations. Lastly, she ended up again at the station for BAC 4 and repeated the task there. The total practice time of 1.5 hours (including the change of practice stations) was standardized and each pupil practiced 12 minutes at the practice station for the BAC on her instruction card and 6 minutes at every other station.

Posttest. Following the intervention phase, all participants completed the splitting task again in order to determine their final mental representation structure of the cartwheel. In addition, participants' performance of the cartwheel was recorded on video again, too.

Data Analysis

A significance criterion of α = 5 % was defined a priori for all reported results. All data sets passed the Kolmogorov-Smirnov-Test for normal distribution. To determine any between-group differences in the independent variable group (intervention vs. control) for the two test dates (pre vs. post), two independent samples t-tests were performed. To determine any within-group differences in the dependent variables (mental representation and motor performance) from pre to post intervention, two paired samples *t*-tests were performed. Cohen's *d* was calculated as an effect size for all reported *t*-values.

Results

It was expected that both types of instructions would lead to functional changes of the mental representation structures, along with performance improvement (*hypothesis 1*). Means and standard errors (*M* ± *SE*) show, that both types of instructions had a positive impact on the dependent variables. Intervention group's deviation from the reference mental representation structure in Euclidean distance got smaller from pretest (5.969 ± 0.186) to posttest (5.439 ± 0.180), as well as control group's results (pretest 5.872 ± 0.244; posttest 5.824 ± 0.182). And intervention group's deviation from the reference line in motor performance measured in meters got smaller from pretest (0.109 ± 0.036) to posttest (0.027 ± 0.034), as well as control group's results (pretest 0.087 ± 0.044; posttest 0.075 ± 0.032).

Regarding the mental representation structure, *hypothesis 2* assumed that specific instructions based on an individual mental representation structure have a positive impact on the change of pupils' mental representation structure of a gymnastics skill. To verify this assumption, mental representation structures of both groups of pupils were tested to similarity to an expert mental representation structure. Means and standard errors of the deviation from the reference structure in Euclidean distance were calculated and in order to examine statistical differences between the two groups, independent-samples *t*-tests were conducted. Figure 2 displays that the intervention group shows closer values to the reference than the control group in the posttest results. For the intervention group, a *t*-test for the comparison of the means of pre- and posttest showed a significant result $t(7) = 2.551$, $p = .019$, Cohen's $d = 0.723$. The intervention groups' representations were more similar to that of an expert group after the intervention as compared to the control group. For the control group the *t*-test showed no significant result for the comparison of the two test dates $t(7) = 0.196$, $p = .425$, Cohen's $d = 0.056$.

Regarding the motor performance, *hypothesis 3* claimed that specific instructions based on an individual mental representation structure has a positive impact on pupils' motor performance of a gymnastics skill and therefore, intervention group's motor performance, measured by parallelism to a straight line, becomes better from pre- to posttest. To verify this assumption, the motor performance of both groups of pupils was compared from pre- to posttest. Means and standard errors of the deviation from a straight reference line were calculated and in order to examine statistical differences between the two groups, independent-samples *t*-tests were conducted. Figure 3 displays that the intervention group shows a smaller deviation from the reference line than the control group in the posttest results. For the intervention group, a *t*-test for the comparison of the means of pre- and posttest showed a significant result $t(7) = 2.089$, $p = .026$, Cohen's $d = 0.587$. The intervention groups' motor performance improved from pre- to posttest. For the control group the *t*-test showed no significant result for the comparison of the two test dates $t(7) = 0.263$, $p = .398$, Cohen's $d = 0.083$.

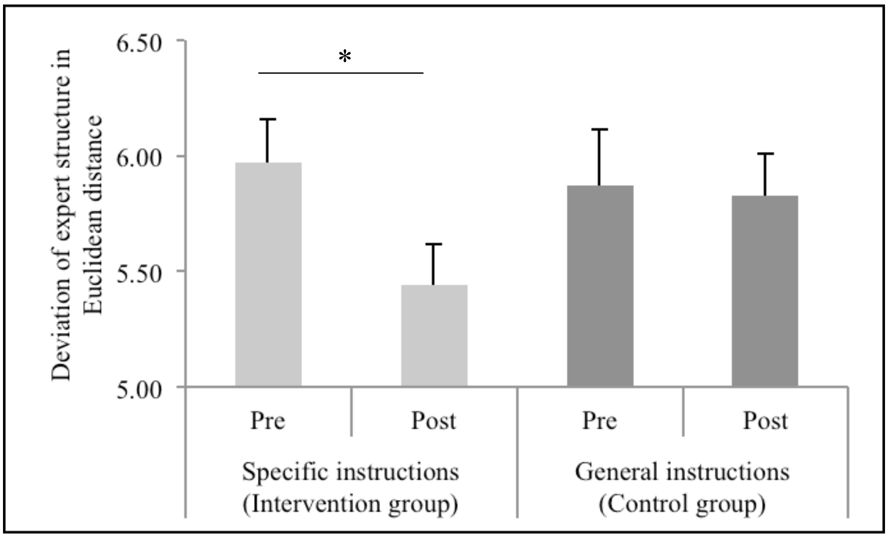

Fig. 2. Means and standard errors for two types of instructions (specific vs. general) for the two test dates (pre vs. post) for the mental representation structure of the cartwheel. The y-axis shows the deviation of the experts' mental representation reference structure in Euclidean distance. Significant differences are marked with an * ($p < .05$).

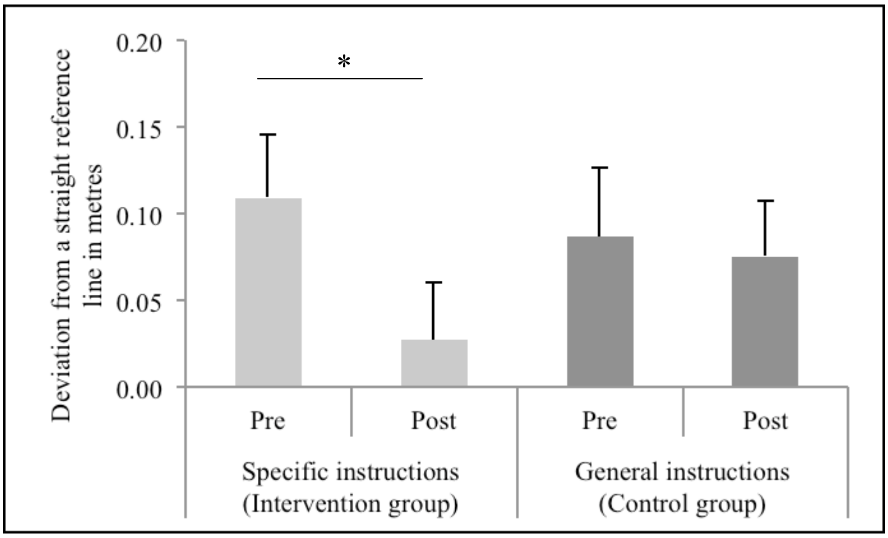

Fig. 3. Means and standard errors for two types of instructions (specific vs. general) for the two test dates (pre vs. post) for the motor performance of the cartwheel. The y-axis shows the deviation of a straight reference line on the gymnastics mat starting from the y-coordinate of the first placed foot. Significant effects are marked with an * ($p < .05$).

Discussion

Physical education teachers' instructions support pupils in learning new motor skills. Research focusing on mental representations indicates that mental representations of motor skills are stored hierarchically structured in LTM and differentiates depending on skill level. Therefore, a close relationship between mental representation structure and skill performance is presumed, and a development of mental representation structures over the course of learning could be highlighted. This is why the aim of this study was to analyze the impact of specific and general instructions on pupils' cognitive and motoric development. Overall results indicate that specific instructions based on mental representation structures have a positive impact on pupils' skill representations in long-term memory as well as on their motor performance.

Descriptive analysis of the data showed functional changes of the mental representation structures, along with performance improvement for the intervention group and also a minimal positive development for the control group. These results would confirm *hypothesis 1*, but for the control group the t-test showed no significant result for the comparison of the pre- and posttest. Further on, results revealed that specific instructions based on pupils' mental representation of a gymnastics skill have a significant positive impact on their mental representation structure as well as on their motor performance. In line with *hypothesis 2*, data indicate that in comparison to the control group, the intervention group shows a greater approximation to an expert reference mental representation structure. In line with the *hypothesis 3*, the kinematic analysis indicates that the intervention group shows a stronger improvement in motor performance than the control group.

The results of this study are in line with the findings of Weigelt et al. (2011) showing that the SDA-M could be used as a diagnostic tool. Pupils' mental representation structures of pretest could be used as basis for instructions that led to improved motor performance. What is interesting in this respect, however, is that it seems possible to be able to use knowledge about the structuring of mental representations, even among young inexperienced learners. This might complement the findings of studies examining experienced athletes (e.g., Weigelt et al, 2011; Velentzas et al., 2010). Further more, the results of this study are in line with findings of Frank et al. (2016) indicating that mental representation structures develop over the course of learning. Here, however, already a very short practice time seems to lead to functional changes in pupils' mental representation structure.

Focusing on the group of participants chosen in this study, it is important to consider that instructions play an important role in physical education. Learners have to be provided with the right information and instructions regarding their motor performance to be able to enhance their skills. But in physical education practice, the time frame for motor learning is limited. One teacher has to provide instructions for learning groups of often 20 or more pupils. Mostly, time does not permit a detailed observation of each pupil. Therefore, the detection of pupils' individual errors and needs is not ensured. The knowledge about leaners' structure of mental representations could help choosing and providing the needed instructions. If a teacher assesses the mental representation structures of his or her pupils, one major advantage would be the possibility to develop arrangements for differentiated instruction provision. It would be possible to give specific, individual instructions for each pupil depending on his or her own needs, strengths and weaknesses, and the current performance level.

There are limitations of this study and two specific aspects should be highlighted. First, a gymnastics skill was selected in this study to exemplify a fundamental floor exercise in gymnastics. However, further research could focus on skills with different demands, especially on skills that are often practiced in PE. The impact of instructions could depend on the type of task. Maybe it is effective regarding discrete skills (e.g., the cartwheel in gymnastics) that can easily be subdivided into phases but not regarding continuous skills (e.g., swimming). Second, with regard to the gender of the participants, it would be interesting to have a mixed group of pupils since most PE classes are not gender separated. It would be interesting in this context to investigate a possible interaction of gender and task. Maybe specific instructions that are developed on the basis of mental representation structures are effective for girls in gymnastics and for boys in soccer but not for boys in gymnastics.

With regard to future research, it would be interesting to take a closer look at the relation between the mental representation structures of PE teachers and their pupils. An interesting question could be whether the development of learners' mental representations is influenced by their teacher's mental representation structure. This could help to provide insights into the communication between teachers and learners and possible ensuing difficulties.

Conclusions

It can be concluded that in motor learning knowledge about the structure of mental representations is essential for teachers and learners. Teachers might benefit because it would be possible to choose and give appropriate instructions. Learners current performance level could be assessed, and specific instructions could be provided that help improving their motor skills. Therefore, the acquisition and analysis of the structure of mental representations could constitute an effective means of optimizing the quality of physical education.

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