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The Effects of Motor Imagery Training on Performance and Mental Representation of 7- to 15-Year-Old Gymnasts of Different Levels of Expertise

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Imagery training with adult athletes is widely used to improve performance. One underlying mechanism is the optimization of mental movement representations. However, past research has focused mainly on adults and has left open for further research on whether imagery also improves mental representations and performance in young athletes. The present study examined these questions in a sample of 56 female gymnasts aged 7 to 15 years. In a cross-over experimental design (imagery first vs. imagery last), regular training with imagery was compared with regular training only in high- versus low-expertise athletes. The 4-week long imagery training had positive effects on performance only for the high-expertise athletes in the imagery-last condition. The results of the Structural Dimensional Analysis of Mental Representation method regarding changes in the mental representations were inconsistent. Thus, imagery training can promote motor learning in young athletes only under some conditions. We discuss possible reasons for the heterogeneous results and ways for improving the strength and reliability of the intervention effects.

Keywords: imagery, expertise, youth, performance, mental representation

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In the context of sports, imagery has been defined as

> the creation and recreation of an experience generated from memorial information, involving quasi-sensorial, quasi-perceptual, and quasi-affective characteristics, that is under the volitional control of the imager, and which may occur in the absence of the real stimulus antecedents normally associated with the actual experience. (Morris, Spittle, & Watt, 2005, p. 19)

Instances of imagery can differ along several dimensions, for example, the imagery type (cognitive vs. motivational, general vs. specific; Paivio, 1985), the intended outcome (e.g., improvement of skills or strategies vs. modification of cognition vs. regulation of arousal and anxiety; Guillot & Collet, 2008; Martin, Moritz, & Hall, 1999), or when it is implemented (e.g., training, competition, and rehabilitation; Martin et al., 1999). Complementing the models describing how and when imagery works (Cumming & Williams, 2013; Guillot & Collet, 2008; Martin et al., 1999), the physical, environment, task, timing, learning, emotion, and perspective (PETTLEP) approach gives specific guidelines on how imagery interventions should be implemented (Holmes & Collins, 2001).

Imagery trainings are widely used and have consistently been found to be an effective training component to enhance motor skills (Wein-

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berg, 2008). A literature review concluded that 70% to 99% of world-class athletes use imagery as component of their training, and up to 94% of coaches report using the technique for athletic training purposes (Jones & Stuth, 1997). A meta-analysis with 62 effect sizes from 35 studies estimated that mental practice affects motor skill performance with a mean effect size of $d = 0.53$ (Driskell, Copper, & Moran, 1994). Moreover, studies demonstrated that imagery can improve not only skills, strategies, and problem-solving but also motivation, self-confidence, arousal, and anxiety (Guillot & Collet, 2008; Martin et al., 1999).

Imagery Training and Mental Representations

One mechanism by which imagery affects performance is that it helps to modify the mental representations of action (Land, Frank, & Schack, 2014), thus improving the athletes' expertise levels (Ericsson, 2007; Schack & Mechsner, 2006). It is assumed that the mental representations are hierarchically organized memory structures comprising cognitive units specified as basic action concepts (BACs; Schack & Mechsner, 2006) and that the arrangement and clustering of these BACs control and guide skill execution. For example, the starting position and keeping the core muscles tight represent cognitive chunks of the movement cast to handstand in gymnastics supporting the preparation phase of the movement (for more details see Table S1 in the supplemental materials).

The cognitive action architecture approach (Schack, 2004; Schack & Ritter, 2013) postulates that motor learning refers to the modification and adaption of the respective representation structures in long-term memory. Consequently, the relations and the groupings of the BACs (i.e., structures of the mental representations) are modified during learning. Research provided evidence that mental representations of motor skills functionally adapt over the course of physical training (Frank, Land, & Schack, 2013), imagery training (Frank, Land, Popp, & Schack, 2014), and combined training (Frank, Land, & Schack, 2016). In a study comparing physical practice, imagery practice, and combined practice, the physical practice group showed some changes in the representation structure over time, whereas both, the imagery practice and the combined practice group, revealed significant changes in their representations of the motor skill (Frank et al., 2014), indicating structure learning on a representational level. The effectiveness of imagery interventions can consequently be investigated by means of performance changes and by assessing the refinement of mental representations guiding movement execution in an increasingly reliable manner, as it considers learning from within (Frank, 2016).

Imagery Training With Children and Adolescents

In contrast to the abundant literature on imagery with adults, few studies investigated imagery in younger athletes. This is surprising because most successful athletes started training and participating in competitions early in their childhood (Baker, Horton, Robertson-Wilson, & Wall, 2003; Capranica & Millard-Stafford, 2011). Findings on the effectiveness of imagery training in adult athletes cannot be transferred one-to-one to young athletes because studies found differences between adults and younger athletes with respect to motor skills, mental imagery, and their respective interrelations (Frick, Daum, Wilson, & Wilkening, 2009; Gabbard, 2009). In particular, the association between motor imagery ability and motor performance gets stronger with age (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Choudhury, Charman, Bird, & Blakemore, 2007). These developmental changes raise the question to what extent findings about imagery training can be generalized from adults to children and adolescents. Research just recently developed appropriate methods to assess the effectiveness of imagery interventions with children and adolescents (Hall, Munroe-Chandler, Fishburne, & Hall, 2009; Martini, Carter, Yoxon, Cumming, & Ste-Marie, 2016), which is one explanation for the existing gap in literature.

The few studies conducted with children and adolescents demonstrated that young athletes are able to and do use imagery in sports contexts. In focus groups, 110 athletes from team and individual sports aged 7 to 14 years reported using cognitive and motivational imagery as part of their training (Munroe-Chandler, Hall, Fishburne, O, & Hall, 2007). In a questionnaire survey, 16- to 18-year-old athletes from a total of 13 different sports reported that they use imagery as part of their training (Parker & Lovell, 2009). In a study conducted with youth gymnasts, both imagery use and the ability to form images positively related to sports performance (Simonsmeier & Buecker, 2017).

Studies examining the effects of imagery interventions with children and youth athletes found mixed results for their effects on performance. In a study with 143 youth soccer players between the ages of 7 and 14 years, the effect of a cognitive specific imagery training, which targeted dribbling, passing, shooting, and checking off, were compared with a motivational general imagery training, which targeted energy and anxiety regulation (Munroe-Chandler, Hall, Fishburne, Murphy, & Hall, 2012). In comparison with the motivational general imagery training, cognitive specific imagery improved speed but not accuracy on a subsequent test of soccer skills. In a study with 40 table tennis players aged 7 to 10 years, seven of the children participated in imagery training combined with relaxation exercises and video observations of famous players (Li-Wei, Qi-Wei, Orlick, & Zitzelsberger, 1992). Two other groups participated in regular training or regular training combined with video observations of famous players. The imagery group showed significantly stronger improvements of the performance accuracy and the technical quality of their forehand attack compared with the other two groups. A study conducted with 40 female gymnasts aged 7 to 14 years found evidence for the effectiveness of a PETTLEP-based imagery intervention for improving performance of a straight jump on the beam. The gymnasts engaged in a 6-week imagery program with three sessions per week, imagining the jump twice in each session. The imagery group's performance improvements over time were large with $d = 1.19$ and comparable in magnitude to the effectiveness of the physical practice group (Smith, Wright, Allsopp, & Westhead, 2007).

By contrast, other research did not find evidence for the effectiveness of imagery training on performance of youth athletes. For example, a study investigating the effect of a PETTLEP imagery intervention on motor performance of young futsal players did not significantly enhance their performance (Quinton et al., 2014). The effectiveness may be influenced by the intensity of imagery and by stimulus, response, or meaning propositions in the imagery script, as these implementation characteristics varied across studies. Studies demonstrated significant improvements in performance due to imagery implemented interventions lasting between 6 and 22 weeks with two or three sessions per week (Munroe-Chandler et al., 2012; Smith et al., 2007), whereas Quinton et al. (2014), who did not find a significant effect, implemented an intervention with less intensity (two sessions per week within a 5-week period). Further, the scripts of the effective interventions either included stimulus and response propositions (Munroe-Chandler et al., 2012) or were based on the PETTLEP model (Smith et al., 2007) to maximize functional equivalence between the actual movement and the imagery (Holmes & Collins, 2001; Wakefield, Smith, Moran, & Holmes, 2013).

The Present Study

In sum, previous studies with adults demonstrated reliable positive effects of imagery training on the mental representation of complex movements and on motor performance. However, little is known about the effectiveness of imagery and the underlying cognitive processes in children and adolescents. Against this background, we conducted a study using a crossover experimental design with 56 female gymnasts aged 7 to 15 years in which we compared regular practice combined with imagery training to regular training only. As an additional factor, we considered participants' expertise (low vs. high). The 4-week long imagery training and the subsequent motor performance and cognitive representation assessment focused on a cast to handstand on bars. We aimed to answer three research questions: First, does imagery training improve the performance of gymnasts aged 7 to 15 years? Second, does the imagery training lead to a functional development of the young gymnasts' mental representations in long-term memory? Finally, are the effects of the imagery training moderated by the gymnasts' expertise level? Based on the aforementioned imagery training studies with adults, we hypothesized that all three questions can be answered with a "yes."

Methods

Gymnastics Task

The training and the performance assessment in our study focused on the cast to handstand on bars. We structured the movement in the two functional phases in which each phase has the purpose to complete a subgoal that supports and prepares to reach the main goal of movement execution (Göhner, 1992; Hossner, Schiebl, & Göhner, 2015). For the cast to handstand, the first functional phase serves as a preparation phase and the second functional phase is the main phase. The preparation phase starts in the support position from where the gymnast brings her shoulders over the bar, performs a shoulder shrug, and moves her legs in front of the bar. She then decreases the leg–torso angle and explosively moves her legs back while pushing out the shoulders. The shoulders remain in front of the bar at this time. After the preparation phase, the main phase starts in which the gymnast executes the actual cast by increasing the arm–torso angle and lifting her back. The gymnast blocks her shoulders when she reaches an arm–torso angle of 180 degrees, which is the handstand position. The task is visualized in Figure 1. The cast to handstand is essential because it is a prerequisite for many other more advanced skills on bars.

Design

We used a cross-over experimental design with two training phases, that is, an imagery training phase and a regular training phase, which served as a control condition. The main advantage of this design is that individual characteristics are held constant across the two experimental conditions because each person participates in both phases. Each phase was 4 weeks long. The imagery training phase included regular physical practice with additional imagery training. The regular training phase included regular physical practice only. The amount of physical practice was the same in every week. The teams were randomly assigned to the imagery-first group or the imagery-last group by a software before the baseline assessment. The imagery-first group participated first in the imagery training phase and then in the regular training phase. For the imagery-last group, the order of the two phases was reversed. All participants were tested before the first training phase (T1), between the two training phases (T2), and after the second training phase (T3).

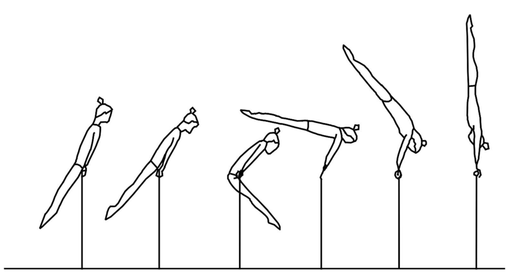

Figure 1. Visualization of the gymnastics task cast to handstand on bars (Gruhl, Condovici, & Weber, 1999). The first three positions relate to the preparation phase, and the last three positions relate to the main phase.

Procedure

At T1, the experimenter introduced herself and provided general information about the study. Each participant signed a consent form to participate in the study. At each measurement point (i.e., T1, T2, and T3), data were assessed in a gym during the teams' regular practice sessions. To assess performance, we recorded each gymnast on video while she performed the cast to handstand on bars twice. We assessed the gymnasts' movement representations using the structural dimensional analysis of mental representation (for more details see mental representation section in the below text). The gymnasts completed the assessment of mental representations individually in the locker room on a laptop computer. Only at T1, we assessed the athletes' imagery use and imagery ability. After the intervention (T2 for the imagery-first group and T3 for the imagery-last group), the athletes filled out a post manipulation check questionnaire consisting of four items.

Imagery Training

At the beginning of the imagery training phase, the athletes participated in a 20-min workshop, which was designed to facilitate understanding of the concept of imagery, to enhance the gymnasts' understanding of the importance of imagery for motor learning specifically, and to increase their commitment to use imagery within their imagery training program. The workshop was based on a workshop used in the study by Cumming, Hall, and Shambrook (2004). After the workshop and a brief introduction to the imagery script, the gymnasts listened to an audio imagery script guiding them through the inner rehearsal of the gymnastics task. The instructions used the wording of the BACs (see section Mental Representation) of the casts to handstand and incorporated visual and kinesthetic cues. After listening to the script for the first time, the experimenter and the gymnasts discussed the gymnast's experience and the experimenter answered questions.

Subsequently, the athletes listened to the audio script and engaged in imagery during their regular training sessions. In each imagery session, the athletes would listen to the whole script once and image the movement three times. Each imagery session took about 5 min, which was the maximum amount of time the coaches were willing to spend for the imagery training during their practice sessions. Each athlete was instructed to use four imagery sessions a week. Thus, each athlete imagined the body movement 48 times in total (4 weeks × 4 sessions per week × 3 times per session) during the imagery training phase. The imagery script included various aspects emphasized as important in theoretical models (Holmes & Collins, 2001). The script included kinesthetic cues, the gymnasts imagined the movement in their regular environment wearing their regular gear (*physical*), and the gymnasts performed the imagery in their regular gym whenever possible (*environment*). They imaged the movement at different speed (one time slower compared with the physical execution of the task and two times in real-time; *timing*) and always from an internal perspective (*perspective*). Each athlete documented their imagery sessions in an imagery diary so that we could check how regularly they engaged in the imagery and whether distractions or difficulties occurred. The coaches also documented all imagery sessions and whether any disturbances occurred.

Measures

Performance. In collaboration with two independent and experienced judges with international licenses, we developed a coding system for the performance of the cast to handstand on bars. The movement executions used are based on the 2013 version of the *Code of Points* (Fédération Internationale de Gymnastique, 2013), which represents an international framework for judgment in gymnastics. The coding system had three main categories: technical quality, temporal quality, and quality of execution. Errors were judged to be small, medium, or large, and respective 0.1-, 0.3-, and 0.5-point deductions were applied in all three categories. For major technical errors, 0.8 and 1-point deductions were additionally used. The total error score was calculated as the sum of the errors in all three categories and ranged from 0 to 7. Thus, the lower the error scores the better the performance.

Three judges with licenses at the provincial or national level rated the athletes' performance independently through video analysis. The judges did not know which person was assigned to which experimental condition. The gymnasts had two attempts to execute the cast to handstand, which were both recorded on video. As a first step, the better try was identified by Judge 1. Then, Judge 2 and Judge 3 rated the videos of the better attempts of each measurement point independently. All three videos of the three different measurement points of each gymnast were presented in a series. The order of the videos was randomized by measurement points and persons. Final error scores were the mean of the ratings of Judge 2 and Judge 3. In rare cases, where the difference between the scores of two judges was greater than two standard deviations from the mean, we calculated the mean of Judge 1 with Judge 2 or Judge 3, respectively, whichever scores were closer together. The error scores had good interrater reliabilities across all three measurement points with Pearson correlations of .90 at T1, .86 at T2, and .90 at T3.

Mental representation. We assessed the gymnasts' mental representations using the Structural Dimensional Analysis of Mental Representation (SDA-M, Schack, 2004, 2012). The method assesses the mental representation of a motor action in long-term memory, providing psychometric data on the representation's structuring and dimensioning. It determines the relations between and the grouping of the BACs of a motor skill.

The SDA-M consists of several steps. First, a split procedure delivers a distance scaling between predetermined BACs. The split procedure was implemented as follows: while one randomly chosen BAC was displayed on a computer screen as a standard unit (anchor), the rest of the BACs ($N-1 = 9$ BACs) were presented below the anchor in a randomly ordered list. For each of the BACs being displayed together with the anchor concepts, participants had to decide whether the given BAC is related to the anchor concept or not during the execution of the movement. The task was completed after each BAC had taken the anchor position once and had been compared with the remaining BACs. During the whole procedure, the BACs were presented written on the computer screen, as pictures, and read out loud by the experimenter. The list of the BACs used in the present study is shown in Table S1 in the supplemental materials. The wording of the BACs was developed in cooperation with the coaches of all participating teams to ensure that all gymnasts were familiar with the wording.

Second, the structure of each participant's mental representation was determined by way of a hierarchical cluster analysis. The information about the distance of BACs (split procedure) was transformed into dendrograms showing the structure of the different BACs. A cluster therefore represents the individually determined grouping of BACs resulting from the distance scaling. Mean group dendrograms were calculated for each group and each measurement point. To compare cluster solutions, we conducted two analyses. First, we analyzed invariance within- and between-groups to explore differences between cluster solutions (for more details, see Schack, 2012). Two cluster solutions can be seen as variant (i.e., significantly different) if $\lambda < .68$, whereas two cluster solutions can be seen as invariant (i.e., the same) if $\lambda \geq .68$ (Lander, 1991). The BACs in a given cluster solution were considered to be related when being linked below the critical value $d_{crit} = 4.51$, and BACs were considered not to be related when being linked above this critical value. Second, we explored the similarity between cluster solutions and a reference cluster solution (an internationally competing female gymnast) using the Adjusted Rand Index ranging from −1 to 1 (ARI; Rand, 1971; Santos & Embrechts, 2009), with high ARI values indicating high degrees of similarity between the athletes' and the experts' cluster solutions. Because a deterministic correct cluster solution for movements does not exist, we used a reference cluster solution of an expert to determine the quality of the gymnasts' cluster solutions. The experts' data was assessed via the previously described SDA-M method.

Imagery ability. Imagery ability was assessed by the Sport Imagery Ability Questionnaire (SIAQ; Williams & Cumming, 2011). It consists of five subscales and 15 items in total. Williams and Cumming (2011) reported a good internal reliability for all SIAQ subscales. Because there was no German version of the SIAQ, three persons independently translated the items and unified their translations using child appropriate language. In our study, internal consistencies of the subscales ranged from $\alpha = .69$ to $\alpha = .85$.

Imagery use. We used the Sport Imagery Questionnaire for Children (SIQ-C; Hall et al., 2009) to assess the extent of imagery use. The questionnaire was designed for athletes aged between 7 to 14 years. It consists of five scales and 21 items in total. As the questionnaire was only available in English, three independent translators translated the items to German and unified their translations for our study. The internal consistencies ranged from $\alpha = .67$ to $\alpha = .87$.

Manipulation check. After the gymnasts completed the imagery intervention, they were administered a postmanipulation questionnaire consisting of four items. They rated the intervention via multiple choice questions relating to their perceived effectiveness of imagery in general (Item 1, ranging from *not helpful at all* to *very helpful*), their perceived effectiveness of the imagery intervention (Item 2, ranging from *strongly worsened* to *strongly improved*), their imagery use in their last three training sessions (Item 3, ranging from *very rare* to *very often*), and their affective evaluation of the imagery intervention (Item 4, ranging from *very little joy* to *very much joy*) on a 5-point Likert scale. Items 1 to 3 were derived from the manipulation check implemented in a previous imagery intervention study by Munroe-Chandler et al. (2012).

Results

Participants

We recruited 58 volunteering female gymnasts from eight different teams through convenience sampling. Two of them had to be excluded from the analyses because they got injured during the study period. The resulting 56 gymnasts were between 7 and 15 years old ($M = 9.63$, $SD = 2.43$) and had participated in their sport between 1 and 14 years ($M = 4.79$, $SD = 2.92$). They practiced between 3.50 and 25.50 hours per week ($M = 8.26$, $SD = 4.87$).

Gymnasts were categorized as having low expertise when competing on a regional level and as having high expertise when competing on a provincial or national level. We categorized the participants by expertise and not by age because expertise had been found to be more important than age as determinants of performance (Hambrick et al., 2014). The sample included 34 athletes classified with low expertise and 22 with high expertise (Table 1). As could be expected, persons on the high-expertise level had a higher weekly training duration, $t(54) = 9.64$, $p = .00$, $d = 2.38$, and showed better performance at T1, $t(41) = 3.340$ $p = .00$, $d = 1.18$, as compared with persons on the low-expertise level. Athletes on the two expertise levels did not differ in their age, $t(53) = 1.88$, $p = .07$, $d = 0.58$, imagery use, $t(47) = 0.64$, $p = .53$, imagery ability, $t(47) = 1.12$, $p = .27$, or years of gymnastic training, $t(54) = 1.03$, $p = .31$. None of the gymnasts had participated in systematic imagery training before. All athletes and their parents provided written informed consent before the data collection and all signed an assent form.

Manipulation Check

Several manipulation checks showed that the athletes engaged in the imagery intervention as expected and that the results are unbiased by the control variables assessed. First, the athletes' imagery diaries and the coaches' protocols of the imagery sessions indicated that all 56 gymnasts participated in all 16 imagery sessions as intended. Second, we analyzed the items of the manipulation check questionnaire. All items had mean values in the upper half of the scale, indicating that the athletes engaged in imagery and considered imagery as meaningful and enjoyable. Third, we investigated the relationship between imagery ability, imagery use, the manipulation check items, and performance change over the course of the intervention period. The descriptive statistics for imagery ability and imagery use are given in Table 1. None of the variables significantly correlated with each other (all ps $\geq .35$), except for imagery ability and imagery use, $r = .40$, $p = .00$. Fourth, t-tests showed that neither the two training groups nor the two expertise groups differed with respect to imagery ability or imagery use (all ps $\geq .10$). Imagery ability and imagery use are consequently unlikely to have biased the following results.

Performance

Pertaining to the effect of imagery intervention on performance, we conducted a 3 (measurement point) × 2 (intervention group) × 2 (expertise level) repeated-measures analysis of variance (ANOVA) with the error scores as the dependent variable. In a second analysis, we included age as a control variable. Table 1 displays the overall error scores for the measurement points, intervention groups, and expertise levels. Lower scores indicate better performance in the cast to handstand on bars. The results of the repeated-measures ANOVA are given in Table 2 along with the results of an analysis of covariance (ANCOVA) with the same independent and dependent variables plus age entered as a control

Table 1
Sample Mean Values and Standard Deviations (in Brackets) of Age, Weekly Training Duration, Years in Gymnastics, and Error Scores by Experimental Group, and Expertise Group

	Imagery-first group			Imagery-last group		
Variable	Low expertise	High expertise	Overall	Low expertise	High expertise	Overall
N	22	9	31	12	13	25
Age	9.94 (2.49)	8.33 (1.41)	9.41 (2.29)	10.58 (2.58)	9.46 (2.63)	9.88 (2.59)
Weekly training duration	5.21 (1.52)	11.00 (3.00)	6.89 (3.34)	5.42 (1.15)	14.58 (4.87)	10.18 (5.85)
Years in gymnastics	5.03 (2.81)	3.16 (1.69)	4.50 (2.65)	5.54 (2.51)	4.65 (3.77)	5.08 (3.19)
Imagery use at T1	3.17 (0.78)	2.86 (.95)	3.08 (0.83)	3.54 (0.71)	3.37 (0.67)	3.46 (0.68)
Imagery ability at T1	3.61 (0.57)	3.46 (0.71)	3.57 (0.60)	3.68 (0.55)	3.45 (0.32)	3.57 (0.45)
Error scores at T1	3.92 (1.24)	2.98 (0.77)	3.69 (1.12)	3.91 (1.08)	2.33 (0.71)	3.30 (1.23)
Error scores at T2	3.92 (1.28)	2.43 (0.95)	3.55 (1.36)	3.63 (0.85)	3.02 (1.35)	3.38 (1.08)
Error scores at T3	3.99 (1.30)	2.12 (0.79)	3.55 (1.36)	3.62 (1.04)	2.39 (0.84)	3.13 (1.12)

Note. Lower error scores indicate better performance.

Table 2
Effects of Measurement Point, Intervention Group, and Expertise Level on Performance in a Repeated Measures ANOVA and in a Repeated Measures ANCOVA Controlling for Age

	ANOVA				ANCOVA			
Effect	*df*	*F*	*p*	part. η^2	*df*	*F*	*p*	part. η^2
Age (as covariate)					1	19.30	.00	.37
Time	2	2.53	.09	.06	1	0.43	.65	.01
Group	1	0.04	.84	.00	2	1.26	.27	.04
Expertise	1	13.05	.00	.25	1	29.91	.00	.48
Time × Age (as covariate)					1	0.15	.86	.01
Time × Group	2	1.75	.18	.04	2	0.90	.41	.03
Time × Expertise	2	1.98	.15	.05	2	2.32	.11	.07
Group × Expertise × Time	2	5.59	.01	.13	2	5.40	.01	.14

Note. ANOVA = analysis of variance; ANCOVA = analysis of covariance.

variable. The ANOVA and the ANCOVA yielded the same pattern of results. As expected, there was a main effect of expertise level on performance. The high-expertise group had a lower error score than the low-expertise group with Cohen's *d*s of 1.25, 0.98, and 1.58 at the three measurement points. The ANOVA also indicated a significant three-way interaction of measurement point, intervention group, and expertise level.

We performed a series of *t*-tests to locate the source of this effect. These indicated significant performance improvements for the high-expertise participants during their respective intervention phase only for the imagery-last group ($d = .88$, $p = .04$, from T2 to T3) but not for the imagery-first group ($d = 0.56$, $p = .09$, from T1 to T2). As the effect size of the imagery-first intervention group was high, the nonsignificance of the *t*-test was likely due to low statistical power. No performance improvements occurred for low-expertise participants during their respective imagery training phase (all ps $\geq .48$) or for all participants during their respective regular-training phase (all ps $\geq .11$). This result is independent of the athletes' age as the triple interaction effect was found in the ANOVA and in the ANCOVA controlling for age. In sum, mental imagery improved young athletes' performance but only for the high-expertise athletes in the group that participated in regular practice first and regular practice combined with imagery second.

Mental Representation

We followed the steps of the SDA-M to investigate the athletes' mental representations. The results of the cluster analysis are visualized in the dendrograms shown in Figure S1 in the supplemental materials. The experts' cluster solution provided two clusters and closely matched the functional structure of the movement described in the section gymnastics task (i.e., the preparation phase included BACs 1–6 and the main phase BACs 7–10).

The imagery-first groups' mean cluster solution included three clusters at T1 and T2 and four clusters at T3. Descriptively, the imagery-first groups' representation of the cast to handstand at T1 had three clusters: one cluster relating to the preparation phase (BACs 2, 3, 4), one relating to both the preparation and main phase (5, 6, 7, 8), and one relating to the main phase (BACs 9, 10). The three groupings are still present at T2 but with a more refined cluster for the preparation phase (BAC 1 included). At T3, the preparation phase was further refined into two parts, the first describing the starting point of the movement (BACs 1, 2) and the second describing the first actions (BACs 2, 4). The other groupings remained the same.

The imagery-last group demonstrated three clusters at T1, three at T2, and two at T3. At T1, the solution included one cluster relating to the preparation phase (BACs 3, 4) and two clusters relating to both the preparation and the main phase (BACs 2, 7 and BACs 5, 6, 8, 9, 10). At T2, the cluster solution changed with one cluster relating to the preparation phase (BACs 3, 6) and two relating to the preparation and the main phase (BACs 5, 8, and BACs 9, 10). The representation again changed at T3 with only two clusters representing a preparation phase (BACs 1, 2, 3, 4) and a mixture of the preparation and the main phase (BACs 5, 8, 9, 10).

By way of invariance and similarity analysis, we determined whether the gymnasts' representations changed and whether they got more similar to the experts' representations during the imagery training phase. For each (sub)group and pair of measurement points, we first checked whether the athletes' λ score (Table 3) was smaller than .68. This would indicate a low stability, that is, a change in the athletes' representations over time. Only when this was the case, we additionally examined the ARI scores (Table 3) to see whether the change increased or decreased the similarity between the athletes' and the experts' representations. Against our expectations, representational changes during the imagery phase were found only for the imagery-last group (λ = .46 for T2 vs. T3) but not for the imagery-first group (λ = .70 for T1 vs. T2). As expected, the change in the imagery-last group increased the similarity of the athletes' and the experts' representations (from ARI = .03 to ARI = .31).

Next, invariance and similarity analyses were run for high- and low-expertise gymnasts. These are based on separate cluster analyses so that the results do not necessarily match the results of the cluster analyses for the whole imagery-first group and the whole imagery-last group. The expected changes during the imagery training phase (i.e., λ < .68 and an increasing ARI) were found for the high-expertise participants in the imagery-first group and for the low-expertise participants in the imagery-last group but neither for the low expertise participants in the imagery-first group nor for the high-expertise participants in the imagery-last group. Overall, the results of the SDA-M method yielded inconclusive results in the present study. The similarity between the athletes' and the experts' representations even decreased over time in some cases, for example, in the imagery-first group from T2 to T3. However, this was not accompanied by performance decreases.

Discussion

Differences between children and adults in when and how they use imagery (Munroe-Chandler, Hall, Fishburne, & Strachan, 2007) raised the question whether imagery training is as effective for young athletes as it has been shown to be for adults. The results of our study demonstrate that imagery training can improve young athletes' performance and mental representations but does so only under certain conditions.

Our first research question concerned the effect of mental imagery on young athletes' performance. We found a positive effect only for high-expertise athletes in the group that participated in regular practice first and in regular practice combined with imagery second. With $d = 0.88$, this was a strong effect by the standards of Cohen (1992). Mental imagery also had a strong positive effect of $d = 0.56$ in high-expertise athletes who participated in regular training plus mental imagery first and in regular training only later, but this effect did not reach statistical significance, probably due to a lack of statistical power resulting from the relatively small sample in our field study. For the low-expertise participants in both groups, the effect of imagery training on performance was very weak

Table 3
Group Lambda Scores Indicating Similarity of the Mental Representation and Group ARI Scores Indicating Similarity of Mental Representation With an Expert Representation at the Three Measurement Points

	Similarity over time (λ)				Similarity to the experts' representation (ARI)					
	Imagery-first group		Imagery-last group		Imagery-first group			Imagery-last group		
Expertise level	T1 vs. T2	T2 vs. T3	T1 vs. T2	T2 vs. T3	T1	T2	T3	T1	T2	T3
High	0.55	0.57	0.40	0.48	−0.12	−0.05	0.12	0.12	0.31	0.31
Low	0.57	0.58	1.00	0.47	0.27	0.04	−0.05	−0.10	−0.10	0.04
Total	0.70	0.57	0.54	0.46	0.12	0.27	0.07	−0.06	0.03	0.31

Note. Two cluster solutions are significantly different (i.e., variant) if λ < 0.68; two cluster solutions are invariant if λ ≥ 0.68. An ARI value of −1 indicates that two cluster solutions are different; a value 1 denotes that the cluster solutions are the same.

and not significant. The fact that only high-expertise participants, who competed on provincial or national levels, but not low-expertise participants, who participated on regional levels, profited from the intervention suggests that imagery might be more challenging for young athletes than for adults, in which the effects were not limited to participants with high-expertise (Blair, Hall, & Leyshon, 1993). Possibly, the young low-expertise participants in our study lacked the experience necessary to identify and focus on the relevant muscle functions during imagery, or they lacked the strength or the coordination to actually perform the movements, which they had previously imagined. Further, it might be that the low-expertise athletes were not able to correctly image the movement, which might have led to less improvement in the movement execution. Previous research has indeed demonstrated that less experienced athletes have a less developed imagery ability. This has been shown over a variety of different assessments, such as in self-reported measures (Overby, 1990; Parker & Lovell, 2012), objective performance measures (Overby, 1990), and neurophysiological measures (Guillot et al., 2008; Herholz, Lappe, Knief, & Pantev, 2008).

Summarizing, the results relating to the first research question suggest that imagery is effective to enhance performance in young athletes but only under certain conditions. Similar results were found in a study conducted with young soccer players, in which performance improvements due to imagery training occurred only in the younger subsample of athletes and for the speed performance measure but not the accuracy performance measure (Munroe-Chandler et al., 2012). This may explain the mixed results found for the effectiveness of imagery interventions with children so far (Munroe-Chandler et al., 2012; O, Munroe-Chandler, Hall, & Hall, 2014; Quinton et al., 2014) and provides valuable insights under which conditions imagery with young athletes is effective to improve performance.

Our second research question concerned effects of mental imagery on young athletes' mental movement representations. We found improvements in the mental representations due to the imagery training for both intervention groups (imagery-first and imagery-last group). However, for the expertise (sub) groups in our design, the SDA-M method indicated representational improvements in some cases, no change in other cases, and a worsening of the representations in still other cases despite the fact that the performance of these groups did not change significantly over time. The worsening of representations in some (sub) groups is hard to explain given that all participants practiced the cast to handstand on bars four times a week with their coaches during the whole study. A possible explanation for the inconsistent findings is that the SDA-M method, which had mostly been used with adults before, does not work as well with youth participants. The SDA-M method is based on similarity ratings for pairs of body movements (BACs). This raises the question whether children's mental movement representations are as differentiated as adults' and whether children's similarity ratings are as reliable as adults'. A previous study using the SDA-M method with children found distinct clusters for children aged 9 years and less stable and organized clusters in 7- and 8-year-old children for grasp postures (Stöckel, Hughes, & Schack, 2012). The mental representation of children might therefore not be as well-developed as the mental representation of adults, as it is still in a formation process due to learning. Differences in skill level and movement experiences might be a potential factor explaining the variance found in mental representations across participants and over time. The mental representation of young experienced athletes might be better developed and more stable than those of their younger less-experienced counterparts because of more training hours and deliberate practice. Previous research has already demonstrated differences in mental representations associated with the skill level in adult athletes (Bläsing, Tenenbaum, & Schack, 2009; Schack & Mechsner, 2006), which is likely to also apply for younger athletes.

Our third research question concerned moderating influences of the young athletes' expertise level on the effects of the imagery intervention. As described above, participants with high expertise profited more from the mental imagery training regarding performance improvements, at least in the imagery-last group. Additionally, the main effect of expertise was the strongest of all effects in our main analysis. Participants with high or low expertise also differed in terms of their representational change in response to the intervention. This is in line with Ericsson and Lehmann's (1996) statement: "Expert . . . performance is highly reproducible and, when compared with the performance of novices, has yielded the largest reliable differences observed by behavioral researchers among healthy adults" (p. 296). Our study provides support that this statement also applies to children and adolescents. Thus, expertise and associated differences in experience and skills are important potential moderators to consider in future studies on imagery training with young athletes.

Generalizability of the Findings

In our view, our main finding, that an imagery intervention can improve young athletes' performance at least under some conditions, is unlikely to be due to methodological artifacts. Our study had several methodological strengths. We conducted a field study with a high ecological validity for young athletes' actual training. The athletes' commitment to the intervention was optimized in a small pretraining workshop. We used a cross-over design, in which each person participates in the treatment and the control condition so that differences between people cannot distort performance differences between the conditions. We counterbalanced the order of the treatment condition and the control condition to control for any order effects. The participants were also randomized into the imagery-first condition and the imagery-last condition to keep the two groups as similar as possible, even though we could only randomize small groups of athletes but not individual athletes due to practical constraints in our field study, leaving potential bias due to team characteristics such as the coach. We additionally compared the two groups with respect to individual characteristics including imagery use and imagery ability. Finally, the implementation checks did not indicate any differences in how much the groups engaged in imagery training, how much they enjoyed it, or how effectively they judged the imagery training to be.

The study has however also some limitations regarding methodological characteristics. First, the sample size was small in some subgroups of the analysis, especially in the high-expertise subgroups. Second, the training times of the two high-expertise groups varied more strongly than the training times of the low-expertise groups, which might also have had an influence on the results. Third, we used judge scores for the performance measures. We tried to assess performance as objective as possible by using experienced and well-trained judges, by blinding the judges, and by presenting the videos in a randomized order. One could additionally include biomechanical analysis of the movement as an objective performance measure (Bartlett, 2007).

Our study raises several questions to be addressed in future research. First, the inconsistency of the current finding might be due to the high similarity of the treatment condition (5-min imagery training integrated into training as usual) and the control condition (training as usual). Both groups engaged in regular training in both conditions. Future studies can investigate whether reducing the similarity of the treatment condition and the control condition (e.g., by focusing on completely different movements and exercises in the control condition) yields more reliable positive effects of imagery training on performance. A second implication concerns the treatment intensity. For practical reasons, we could only integrate 16 imagery intervention sessions with duration of 5 min each into the athletes' regular training sessions in our field study. This is a rather low intensity compared with imagery training in other studies (for an overview see Cooley, Williams, Burns, & Cumming, 2013). It is possible that a higher treatment intensity (i.e., longer training phase resulting in more imagery sessions) would lead to broader and more consistent effects on performance. As yet, few studies investigated mental imagery training in young athletes so that no conclusions about the optimal treatment intensity overall or for different age groups can be drawn.

The PETTLEP approach (Holmes & Collins, 2001) provided valuable impulses when designing the imagery intervention, also when working with junior athletes. Future research could investigate the effectiveness of imagery interventions using an imagery script more closely following the PETTLEP approach when working with young athletes. Adapting the imagery in response to learning and the current performance level might be even more relevant with younger athletes that mainly focus on developing skills rather than refining them. Related, future research could more strongly appoint the meaning the athletes attribute to imagery, as this may also influence effects of imagery training (Cumming & Williams, 2013; Holmes & Collins, 2001).

Finally, the present scarcity of imagery training studies with young adults also implies that the generalizability of findings over different types of sports still remains to be investigated. Possibly, mental imagery might have a different effect in team sports than in individual sports or in technically more or less demanding sports. For example, contrary to the present findings, a study on mental imagery in soccer found it to be generally effective independent of the players' expertise levels (Blair et al., 1993). With respect to the SDA-M method for investigating athletes' mental representations, more research including systematic age-group comparisons and psychometric analyses is needed to investigate to what extent the reliability and validity of the obtained results differs between children, adolescents, and adults and between different sports. The task of evaluating the similarity of body movements as required by the SDA-M is relatively abstract, raising the question whether age groups or athletes with variant expertise differ in their ability to access their mental movement representation by way of simulation and to derive similarity ratings from their representations. This may be due to differences in the ability to distinguish between the BACs or the competence to transfer previous kinesthetic experiences to the judgment task. Further, the presentation format of the BACs (i.e., written, visual, and combined) may affect accuracy of measurement.

The results of the present study provide a valuable starting point for future research and make it seem promising to more closely investigate the transfer and the retention of the imagery training effects. It would also be of interest to examine to what extent the present findings obtained in training settings generalize to athletes' performance in competitions. Correlational and replication studies with larger samples assessing the link between mental representation and performance in different disciplines would contribute to a better understanding of the relation between cognition and behavior in young athletes.

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