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# Is imagery better than reality? Performance in imagined dart throwing

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## Abstract

We investigated whether deviations from optimal performance are predicted in motor imagery. In Experiment 1, novices and experts imagined and executed dart throws. In imagination, they reported the final position of the dart. Experts performed better than novices in execution and imagination. Distance to the target and bias were smaller in imagination than in execution. In Experiment 2, we dissociated the roles of feedback from proximal and distal action elements for predictions. Three groups of novices estimated the dart's final position in imagination, in execution without visual feedback, or in execution with delayed visual feedback. Estimates did not differ significantly between groups, indicating that (the lack of) feedback did not influence predictions. Deviations from optimal performance were lower in estimated than in actual performance. In conclusion, although predictive mechanisms may be similar in imagination and execution, the full extent of deviation from optimal performance is not predicted.

### Keywords

Motor imagery; Action consequences; Feedback; Expertise; Darts; Forward models



## 1 Introduction

Motor imagery (MI) designates the simulation of an action, without its actual execution (Jeannerod, 1995). In addition to the action itself MI may include the environment, objects, and, most importantly, the consequences of the imagined action (see Holmes & Collins, 2001). Imagined action consequences may include all changes in the actor and the environment that are directly caused by the action. The question arises, whether imagined action consequences resemble actual action consequences. In particular, in actual actions deviations from optimal performance occur, which play a crucial role for motor learning (Thoroughman & Shadmehr, 2000). To know to which extent discrepancies from the intended action consequences occur in MI might therefore be important for applications of MI like mental practice. In the present experiments, we investigated to which extent discrepancies from the intended action consequences emerge in MI and whether these discrepancies are similar to those in motor execution (ME). For this aim we used a dart



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throwing task, which has the advantage that discrepancies from the intended action consequences often occur when the action is executed. In Experiment 1, the accuracy of a dart's final position was compared between expert and novice dart players in imagination and execution. In Experiment 2, estimates of the dart's final positions were compared between an imagination group, an execution group without visual feedback, and an execution group with delayed visual feedback.

In recent years, many similarities between MI and ME have been reported. Similar brain areas, like the frontoparietal cortex and the cerebellum, are activated during MI and ME (Hanakawa, Honda, Okada, Fukuyama, & Shibasaki, 2003; Lorey et al., 2013; Lotze et al., 1999) and in electrophysiological studies similar oscillatory power changes are observed in MI and ME (Hermes et al., 2011; Schnitzler, Salenius, Salmelin, Jousmäki, & Hari, 1997). On the behavioral level, it often takes the same time to imagine and to execute an action (e.g. Decety, Jeannerod, & Prablanc, 1989). Further, factors that influence ME durations often influence MI durations similarly (e.g. Dahm & Rieger, 2016; Decety & Michel, 1989). From such observations, it is concluded that MI and ME rely on similar mechanisms and that MI involves an internal simulation of the action (O'Shea & Moran, 2017).

However, several differences between MI and ME have also been observed. For instance, MI takes longer than ME, when imagining to walk with 25 kg extra load (Decety et al., 1989) and when action durations are very short (< 3 s; Grealy & Shearer, 2008). MI can also be shorter than ME, for instance when (part of) an action requires little attention, such as the approach run to a springboard before a jump (Calmels, Holmes, Lopez, & Naman, 2006). Furthermore, the duration of MI compared to ME depends on expertise (Reed, 2002) and familiarity with the action (Rieger, 2012). In addition, imagery speed can be altered voluntarily (Boschker, Bakker, & Rietberg, 2000). If imagery speed is instructed, novices profit from extra time, whereas experts profit from time pressure (Beilock & Gonso, 2008).

In most behavioral studies, the durations of MI and ME are compared (for an overview see Guillot, Hoyek, Louis, & Collet, 2012). However, from durations the content of MI can only be indirectly inferred. For instance, durations are not informative about vividness and accurateness of the imagined action. To investigate the content of MI, measures different from duration are required. For instance, pointing has been used as a method to compare imagined and executed walking (Campos, Siegle, Mohler, Bülthoff, & Loomis, 2009). Pointing to a certain location follows a similar trajectory during sighted walking and blind walking, but follows a different trajectory in imagined walking. This indicates difficulties in updating the own position in space in imagination.

In the present study, we were interested in one specific aspect of the content of MI, namely whether deviations from optimal performance are reflected in imagined action consequences. In ME, people commit errors, make mistakes or perform imprecisely. These failures in optimal performance provide essential information for motor learning, as they offer the opportunity to correct and adapt an action and to update motor programs or internal models of the action (Thoroughman & Shadmehr, 2000). Action errors may however not be adequately represented in MI. For instance, fewer typing errors than actually occur are spontaneously imagined. This is even the case when attention is drawn to the potential occurrence of errors (Rieger, Martinez, & Wenke, 2011). However, if people are instructed to imagine specific pointing errors, the errors evoke adaptive changes of the visuo-motor system: aftereffects of visuomotor adaptation similarly emerge when prism glasses are actually worn and when their use is imagined (Finke, 1979), indicating that action errors may have a functional value in MI.

What are possible mechanisms involved in the representation of action consequences in MI and by which mechanisms can deviations from optimal performance be detected in MI? According to the framework of internal models (e.g. Wolpert, Diedrichsen, & Flanagan, 2011), when one intends to achieve certain action consequences, inverse models select the corresponding motor commands (Fig. 1). The motor commands are sent to the effectors, and, in addition, an efference copy of the motor command is made. The efference copy is used by forward models to predict action consequences on the body and in the environment which are likely going to occur (Davidson & Wolpert, 2005). In ME, error detection can occur based on three different comparison mechanisms: a comparison of intended and actual action consequences, a comparison of predicted and actual action consequences, and a comparison of intended and predicted action consequences (Blakemore, Wolpert, & Frith, 2002). The latter comparison may result in error detection even before the action is terminated, even though some errors may still be committed (Maidhof, Rieger, Prinz, & Koelsch, 2009). In MI, actual consequences do not occur. Thus, comparisons with actual consequences are not possible. However, if forward models predict action consequences in MI, a comparison of intended and predicted action consequences may take place and errors may be detected this way. Such a framework is in line with theoretical assumptions which view MI as an entire simulation of the action (Grush, 2004; Iachini, 2011; Jeannerod, 2001).

However, not everyone would agree that MI consists of a simulation using the motor system. The question how imagery is performed has been debated for many years (Kosslyn, 1994). The central question of the imagery debate is on what kind of representations the subjective experience of imagining something is based. According to the propositional view (Pylyshyn, 2002), imagery is based on abstract, amodal, arbitrary symbols, i.e. the representations are separate and distinct from the modality in which imagery is performed. According to the analog view, modal systems are used to perform imagery. Characteristics of the modality, in which imagery is performed, determine how the content of imagery is represented and processed (Kosslyn, 2005). The imagery debate, which has mainly been discussed against the background of visual imagery, can also be applied to MI (cf. Iachini, 2011).

This issue seems to be particularly relevant in MI, as actual actions need to be inhibited in MI, which may take place at different levels (Guillot et al., 2012; Rieger, Dahm, & Koch, 2017), and may even occur before an efference copy of the motor command can be made (Berthoz, 1996). Some authors therefore assume that MI mainly shares similarities with action planning and less so with action execution (Glover & Baran, 2017; Jeannerod, 1995). However, one may also more drastically argue, in accordance with the propositional view, that MI makes no use of the motor system, is based on tacit knowledge, and only an epiphenomenon of other, abstract mental processes (Pylyshyn, 2002). In this view, MI is performed by drawing on abstract knowledge about the movement and its previous consequences, but the subjective experience of mentally performing it has no causal relation

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to the mentally unfolding action (Annett, 1996). For instance, if one knows that one's own skills are limited, one may intentionally incorporate errors into MI rather than detecting errors based on a simulation. Thus, investigating to what degree and how action errors and deviations from optimal performance are represented in MI might shed some light on the mechanisms and types of representations underlying MI.

To investigate deviations from optimal performance target aiming tasks without time pressure are particularly suitable, because there is no speed-accuracy tradeoff. Such a task is playing darts. In darts, performance is measured based on the accuracy of the darts' final positions on the dartboard. Accuracy is continuous and two-dimensional, which allows the calculation of several accuracy measures: the mean distance to the target, the consistency across throws, and the bias to systematically deviate from the target in a certain direction (Hancock, Butler, & Fischman, 1995). The distance to the target is visible at each single throw when throwing a dart at a dartboard. Thus, in dart throwing, one should be aware of the approximate distance. However, consistency and bias are not directly visible on the dartboard at each single throw. Rather, information over several throws must be accumulated and participants are therefore less likely to be aware of their own consistency and bias. Even if participants become aware of a bias at some point, it is reasonable to assume that they try to compensate for it, resulting (at least in their mind) on average in no bias.

There is no actual action feedback in MI. Therefore, error detection based on the observed effects cannot occur. This should result in fewer detected errors in MI than in ME. Hence, reported performance in MI should be better than in ME. If MI is based on an internal simulation of the whole action including the prediction of action consequences, differences between MI and ME should be similar in all three accuracy measures. However, if conscious knowledge about one's performance capabilities, rather than a simulation, underlies MI, distance to the target should be similar in MI and ME. In contrast, bias should be lower in MI than in ME, because participants most likely do not think they have a bias. Further, consistency may not necessarily be lower, because participants know that they do not consistently throw into the bullseye, but it should not correlate with actual performance.

In Experiment 1, we examined deviations from optimal performance (distance to the target, consistency, and bias) in imagined and executed dart throws. We compared experts and novices, because experts' internal models of the task might be more precise, resulting in more adequate imagery (cf. Rieger, 2012). MI of dart throwing includes both: imagery of the action itself and imagery of the action consequences in the environment (e. g. imagining the dart's final position on the dartboard). In Experiment 2, we controlled for the role of feedback from proximal action elements (from the action itself such as kinesthesis) and the role of feedback from distal action elements (from action consequences, i.e. seeing the dart's final position) by comparing an imagination group, an execution group without feedback, and an execution group with delayed feedback.

## 2 Experiment 1

In Experiment 1 we examined the accuracy of imagined and executed dart throws in experts and novices. In an execution condition (EXE) participants threw darts aiming for the

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bullseye. In an imagination condition (IMA) participants imagined dart throws aiming for the bullseye from a first-person perspective and indicated on the dartboard where the dart had hit in their imagination.

In contrast to novices, experts have practiced a certain task multiple times. In darts, experts throw closer to the target, vary less in movement velocity, and take more time for action preparation than novices (Schorer, Jaitner, Wollny, Fath, & Baker, 2012). We therefore expected that experts throw more accurately than novices.

Expertise and action familiarity also influence MI (Reed, 2002; Rieger, 2012). Experts usually have more explicit and implicit task-related knowledge and have automatized certain aspects of the task (Farrington-Darby & Wilson, 2006). In novices, representations of task-related actions may not be adequately specified (Schack, 2004) and structured (Schack & Mechsner, 2006). For accurate representations in MI stable internal action representations or internal models of the action are required. Accordingly, similar durations and positive correlations between MI and ME are observed in ten-finger typists when they type with ten fingers, but not when they type with two fingers, and they are also not observed in hunt-and-peck typists (Rieger, 2012). In spring diving MI durations are longer than ME durations in intermediate divers, but similar in expert divers. Most likely, intermediate divers focus more on details of the action in MI, because the actions are less automatized (Reed, 2002). If more precise action representations in experts influence the imagination of deviations from optimal performance, the difference between IMA and EXE should be smaller in experts than in novices. Furthermore, novices may have difficulties simulating dart throwing and they may rely on knowledge-based strategies instead of a simulation during MI. In this case, consistency and bias should particularly differ between IMA and EXE in novices.

Representations of the content of an action may differ between expertise levels and action conditions. Thus, we asked participants to report how strongly they represented/how much attention they paid to different aspects of the dart throws in IMA and EXE. Because it has previously been shown that some task-related representations are weaker in MI than in ME (Dahm & Rieger, 2016; Rieger & Massen, 2014), we expected weaker representations in MI than in ME. We further expected a larger difference between MI and ME in novices than in experts, because representations of dart throws may be less precise in novices than in experts (Rieger, 2012; Schack, 2004).

## 2.1 Methods

**2.1.1 Participants—**Dart experts were recruited from regional dart clubs. Novices were recruited via an announcement in a local newspaper and from acquaintances of the experimenters. The data of four experts and three novices were excluded from analysis, because one expert player said he was not able to perform IMA, two experts and two novices had no variability in IMA, and the data of one expert and one novice showed bivariate outliers (see Supplemental material). The final sample consisted of 20 expert dart players (one left-hand thrower; age: $M = 29.9$ years, $SD = 8.9$ years) and 21 novice dart players (one left-hand thrower; age: $M = 30.9$ years, $SD = 8.8$ years). All participants were male. On average, experts played darts 129 times a year ($SD = 59$), took part in 18 competitions per year ($SD = 17$), and had played for 6 years ($SD = 6$ years). Novices played darts once a year

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(*SD* = 2) and did not take part in any competitions. The experiment lasted approximately 2 h and was approved by the local ethics committee. All participants gave informed consent and received 20 Euros for participation.

**2.1.2 Material—**We used a custom-build dartboard, which consisted of a 59 cm × 59 cm poster. In the center of the poster a regular dartboard was depicted. A light grey grid outlined small squares (5 mm side length), which enabled the experimenter to identify the exact dart positions. The poster was attached to a pinboard. Height of the bullseye (173 cm) and the throwing position (237 cm distance from oche to wall) conformed to international standards. Darts were 22 g Tungsten steeldarts with medium roughness, standard flights, and a nylon-shaft of medium length. Questions on the strength of representation of proximal action elements (feeling of the throw, gripping the dart, arm movement, release of the dart; e.g. "I felt how my fingers released the dart") and distal action elements (dart flying, dart hitting the board) were answered on six-point rating scales (from 'not at all' to 'very clear'). We chose to use single questions referring to specific task elements instead of established questionnaires on motor imagery ability, because we were interested in the specific representations during dart throwing. Moreover, this allowed us to compare the strength of representations in MI and ME.

**2.1.3 Procedure and design—**Five experts of the final sample performed the experiment in a separate room of the facilities of their dart club. All other participants performed the experiment in the laboratory. In both locations the same equipment, including the custom-build dartboard was used.[1] Instructions were presented in written form. In all conditions, participants were asked to stand at the oche and aim for the bullseye. In EXE, the participant threw the dart and the experimenter recorded the position of the dart on the dartboard. Then the participant went to the dartboard, picked up the dart, and went back to the oche. In IMA participants were asked to keep their arms without any motion hanging loosely down at their sides with the dart in the hand. They were instructed to imagine exactly how it feels to throw, and to imagine how the dart flies to the dartboard and hits it. After each imagined throw participants showed the experimenter the position where they had imagined the dart hitting the dartboard. They then went back to the oche and continued with the next throw.

At the start of the experiment participants received one dart and performed five actual throws to get used to the material and setting. After that participants performed a pretest in which they executed ten throws. Participants then performed 50 imagined or 50 executed throws. In a posttest, they executed ten throws. After that, another pretest, the other action condition, and another posttest followed. After each action condition participants reported their strength of representation of different elements of the dart throw. The order of action conditions was counterbalanced across participants. Pretest and posttest were conducted to control for learning during the experimental conditions.

[1]Visual inspection of the data of experts tested in the facilities of their dart club and in the laboratory did not indicate differences in data patterns.

#### 2.1.4 Data analysis

Dependent variables were calculated according to the recommendations of Hancock et al. (1995; see Fig. 2). We calculated the average *distance* to the bullseye (mean radial error), *consistency* of the final positions of the dart (bivariate variable error), and *bias* (subject-centroid radial error), which represents the radial distance of the participants' centroids from the bullseye. All dependent variables were normally distributed and analyzed with repeated measures analyses of variance. If data violated the assumption of sphericity Huyn-Feldt corrected degrees of freedom are reported. Further comparisons were conducted using t-tests with Sidak adjusted pairwise comparisons. Where appropriate we report minimum ($p_{min}$) or maximum ($p_{max}$) statistical values. Statistical significance was set at $p < .05$. We further calculated correlations between IMA and EXE. Correlations were compared using Fisher's z-Test.

## 2.2 Results

#### 2.2.1 Control analysis: distance to the bullseye in pretests and posttests

To analyze whether performance improved in the course of the experiment we conducted a repeated measures analysis of variance (ANOVA) with the between factor expertise (experts, novices) and the within factors action (EXE, IMA) and test (pretest, posttest) on distance. Means and standard errors of the distance to the bullseye in pretests and posttests are shown in Fig. 3. A significant main effect of expertise, $F(1, 39) = 50$, $p < .001$, $\eta_p^2 = .56$, indicated that experts threw closer to the bullseye ($M = 3.5$ cm) than novices ($M = 7$ cm). All remaining effects were not significant (test: $F < 1$; action: $F < 1$; test × action: $F(1, 39) = 2.4$, $p = .127$, $\eta_p^2 = .06$; test × expertise: $F(1, 39) = 1.8$, $p = .18$, $\eta_p^2 = .05$; action × expertise: $F(1, 39) = 1.5$, $p = .22$, $\eta_p^2 = .04$; test × action × expertise: $F < 1$), indicating that performance did not significantly improve from pretests to posttests.

#### 2.2.2 Distance, consistency, and bias

Means and standard errors of distance to the bullseye, consistency, and bias are shown in Fig. 4. A multivariate analysis of variance (MANOVA) with the between factor expertise (experts, novices) and the within factor action (EXE, IMA) was calculated with distance, consistency, and bias as dependent variables. A significant main effect of expertise, $F(3, 37) = 11.1$, $p < .001$, $\eta_p^2 = .47$, indicated that in experts the final position of the dart had a smaller distance to the bullseye ($M = 3.3$ cm), was more consistent ($M = 3.8$ cm), and had less bias ($M = 0.8$ cm) than in novices (distance: $M = 6.6$ cm; consistency: $M = 7.4$ cm; bias: $M = 1.6$ cm). A significant main effect of action, $F(3, 37) = 7.4$, $p = .001$, $\eta_p^2 = .38$, indicated that distance was smaller and that bias was lower in IMA (distance: $M = 4.6$ cm; bias: $M = 1$ cm) than in EXE (distance: $M = 5.3$ cm; bias: $M = 1.4$ cm). The main effect action was not significant in consistency ($p = .101$). The interaction between action and expertise was not significant ($F < 1$).

Because we assumed that no bias should be observed in IMA if participants did not perform a simulation, we performed t-tests against zero for bias in all conditions. Bias was significantly different from zero in all conditions (experts EXE: $t(19) = 6.5$, $p < .001$, 95% KI [0.7, 1.3]; experts IMA: $t(19) = 6.4$, $p < .001$, 95% KI [0.4, 0.8]; novices EXE: $t(20) = 7.9$, $p < .001$, 95% KI [1.3, 2.3]; novices IMA: $t(20) = 6.2$, $p < .001$, 95% KI [1, 1.9]).

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#### 2.2.3 Percentage of absolute difference between IMA and EXE

To analyze the differences between IMA and EXE irrespective of overall performance, we calculated the percentage of absolute difference between IMA and EXE for the three dependent variables according to the following formula: (|IMA – EXE|/EXE × 100) (cf. Munzert, 2008, see Fig. 5). An ANOVA with the between factor expertise (experts, novices) and the within factor measure (distance, bias, and consistency) was performed on the percentage of absolute difference. A significant main effect of measure, $F(1.1, 42.4) = 25.3$, $p < .001$, $\eta_p^2 = .39$, indicated a larger difference between IMA and EXE in bias (difference: $M = 58\%$) than in distance (difference: $M = 25\%$; $p < .001$) and consistency (difference: $M = 24\%$; $p < .001$). Distance and consistency did not differ significantly from each other ($p = .83$). All remaining effects were not significant (expertise: $F < 1$; expertise × measure: $F(1.1, 42.4) = 2$, $p = .162$, $\eta_p^2 = .05$.)

#### 2.2.4 Correlations between EXE and IMA

Correlations between EXE and IMA for distance, bias, and consistency, separately for experts and novices, are shown in Table 1. All correlations were significant except the correlation for bias in novices, which did however not differ significantly from the correlation for bias in experts ($p = .19$).

#### 2.2.5 Strength of representation

Data on the strength of representation were averaged a) over proximal action elements and b) distal action elements. Means and standard errors of strength of representation are shown in Fig. 6. An ANOVA with the between factor expertise (experts, novices) and the within factors action (EXE, IMA) and action element (proximal, distal) was calculated. A significant main effect of action element, $F(1, 39) = 9.6$, $p = .004$, $\eta_p^2 = .2$, was modified by a significant interaction between action element and action, $F(1, 39) = 4.1$, $p = .0496$, $\eta_p^2 = .1$. The representations of proximal action elements in IMA were weaker than the representations of proximal action elements in EXE, ($p = .014$), distal action elements in IMA ($p < .001$), and distal action elements in EXE ($p = .011$). The latter three did not significantly differ from each other ($p_{min} = .087$). All remaining effects were not significant (expertise: $F < 1$; action: $F < 1$; expertise × action: $F(1, 39) = 1.6$, $p = .21$, $\eta_p^2 = .04$; expertise × action element: $F < 1$; expertise × action × action element: $F < 1$).

### 2.3 Discussion

As expected, experts performed better than novices: they threw closer to the bullseye, were more consistent, and had less bias. This was not only observed in EXE, but also in IMA, indicating that the differences in skill level are accounted for in MI. Further, individual differences within groups were reflected in positive correlations between EXE and IMA.

One may regard it as a limitation that experts performed the experiment in different locations, but novices did not. The context in which motor imagery occurs, for instance a sport-specific environment, may lead to more adequate motor imagery (as it leads to more improvement in subsequent motor performance, Smith, Wright, Allsopp, & Westhead, 2007). Nevertheless, it is unlikely that experts tested in the facilities of their dart club

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performed imagery in a different way than experts tested in the laboratory, because the data patterns of the experts tested in different locations were similar.

Surprisingly, ratings of the strength of representation did not differ between experts and novices. One explanation is that the strength of representation in dart throwing is dependent on the characteristics of the task itself and not on one's experience with it. This does not necessarily mean that the task was similarly represented in experts and in novices. It could be that rather than the strength of representations, the structure of representations differs between experts and novices (which we did not investigate). For instance, hierarchically structured representations of a tennis serve are similar in experts, but not in novices (Schack & Mechsner, 2006), indicating that expertise influences the structure of representations.

Contrary to our expectations, we did not observe significant interactions between action and expertise. We had expected that MI and ME are more similar in experts than in novices, because we assumed that internal models of dart throwing are more precise in experts. Our data do however not provide any evidence that novices are less precise in imagining dart throwing than experts. This is further supported by the significant correlations between IMA and EXE in both groups. Only one correlation, the correlation in bias in novices, was not significant. One may argue that bias may not be adequately represented in novices' imagery. However, the correlation in novices did not significantly differ from the correlation in experts. Thus, there is no evidence that novices perform imagery less adequate than experts.

In all variables, less deviation from optimal performance was observed in IMA than in EXE. This finding is consistent with results from previous studies (Rieger et al., 2011). One explanation is that in MI no feedback from the action and its consequences is available. If participants simulated the action, participant's simulations might not fully suffice to compensate for the lack of feedback.

Representations of proximal action elements were weaker in IMA than in EXE. We speculate that this might be caused by the lack of kinesthetic and tactile feedback in IMA compared to EXE. In IMA, kinesthetic and tactile feedback need to be simulated which apparently does not fully compensate for actual feedback. No significant differences were observed in representations of distal action elements between IMA and EXE. Representations of distal action elements rely on vision. The representation of visual feedback in IMA may have been supported by vision of the dartboard, which was visible in both, IMA and EXE.

Because a) there is no evidence for more precise internal models in experts than novices, b) representations of proximal action elements were weaker in IMA than in EXE, and c) less deviation from optimal performance occurred in IMA than in EXE, the question arises whether all participants performed MI by simulating the action (Jeannerod, 2001) or by using knowledge of their skill (Pylyshyn, 2002). The correlations between IMA and EXE in consistency and partly in bias are in favor of the assumption that participants indeed performed a simulation, because these variables are supposedly outside of participants' conscious awareness. The percentage of the absolute difference between IMA and EXE was larger in bias than in distance and consistency, which might speak against a simulation in

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MI. Nevertheless, bias was still significantly higher than zero. This favors the simulation approach because otherwise bias should not have been significantly different from zero. In addition, compared to the expertise effects the differences between IMA and EXE were relatively small, which indicates that participants for the most part performed MI similar to ME.

In sum, the results in Experiment 1 indicate that a simulation takes place in MI. However, experts' internal models are not superior to novices' internal models with respect to the prediction of action consequences in MI.

## 3 Experiment 2

In Experiment 1, we observed that independent from expertise action consequences are imagined more accurate in MI than they are in ME. One explanation for differences between MI and ME is that in MI feedback is not available. The absence of feedback contributes to differences between MI and ME, in particular when action consequences provide crucial information about the progress of the action (Rieger & Massen, 2014). To dissociate the roles of feedback from proximal action elements and feedback from distal action elements for differences between MI and ME in dart throwing, we investigated three groups of participants: an imagination group (IMA), an execution group without feedback (EXE-FB), and an execution group with delayed feedback (EXE+FB). Because expertise did not interact with the action conditions in Experiment 1, we investigated only novices in Experiment 2. In Experiment 1, imagination data were based on participants' reports, whereas execution data were based on actual performance. Because internal predictions might not be accurate even if an action is executed, in Experiment 2 participants wore visual occlusion glasses, which turned non-transparent after the (actual or imagined) release of the dart in all groups and we asked participants to imagine the dart hitting the dartboard and to estimate the final position of the dart.

In the IMA group, neither feedback from proximal nor distal action elements was available. In the EXE-FB group, feedback from proximal but not distal action elements was available. Thus, differences between the IMA and the EXE-FB group may be attributed to the lack of feedback from proximal action elements in the IMA group. In the EXE+FB group, feedback from proximal action elements and delayed feedback about the final position of the dart was available. Thus, differences between the EXE-FB and EXE+FB group may be attributed to the lack of feedback from distal action elements in the EXE-FB group (i.e. the final positions of previous dart throws, in neither condition feedback from the flight of the dart is available).

In ME (and thus in the EXE-FB and the EXE+FB group), an efference copy of the motor commands should exist. The efference copy can be used by forward models to predict the action consequences. In MI (and thus IMA), it is not clear whether an efference copy exists and/or whether forward modeling occurs. In all conditions, it is unknown how accurate predictions about action consequences are. If forward modelling (based on an efference copy) occurs in MI (Grush, 2004), estimates of the final position of the dart should be similar in the EXE-FB and the IMA group. Estimates in the EXE+FB group might be more accurate, because feedback about the dart's final position from previous throws may serve to update internal models or to acquire knowledge about throwing performance, which can be used for subsequent estimates.

In Experiment 1, we subsumed representations of the throwing phase under proximal action elements, which we assumed to consist mainly of kinesthesis and touch. However, representations of the throwing phase may also include vision (though while playing darts it is not usual to watch oneself performing those proximal action elements). We therefore extended the assessment of proximal representations and separately asked about visual and kinesthetic/tactile representations. Because occlusion of visual sight may impact the strength of visual and kinesthetic representations, we additionally assessed strength of representations after a pretest and a posttest which were performed without occlusion of the glasses.

## 3.1 Methods

**3.1.1 Participants—**Participants were students (nearly) without experience in playing darts. They were randomly assigned into the IMA group, the EXE-FB group, and the EXE +FB group ($N$ = 24 each) with the restriction that gender was similarly distributed. Table 2 shows sex, handedness, age, and dart experience. ANOVAs revealed no significant differences between the groups. The experiment lasted approximately 90 min and was approved by the local ethics committee. All participants gave informed consent. Participants received 15 Euros or course credit for participation.

**3.1.2 Material—**Materials and experimental setup for the dart throwing task were similar to Experiment 1. In all conditions, participants indicated the imagined final position of the dart on an additional poster on which the dartboard was depicted (report poster), which was placed 1.5 m behind the oche. Visual feedback was controlled with glasses which were especially designed for this study (similar to Lee, Kil, & Kim, 2014). Under transparent conditions, the glasses allowed a view similar to sunglasses. Occlusion of the glasses was triggered by the change of an electromagnetic field when releasing the steeldart or a metal block (7 cm × 3.5 cm × 2 cm, 45 g). For this, a small inductance coil was placed on the fingernail of participants' thumb. A cable connected the coil with the glasses. The cable did not hamper participants' mobility. The glasses were worn throughout the whole experiment, but were transparent during pretest and posttest.

Strength of visual and kinesthetic/tactile representations of proximal action elements (finger grip, arm movement, release of the dart) and visual representations of distal action elements (dart trajectory, dart hitting the dartboard) were assessed using single items on six-point rating scales (from 'not at all' to 'very clear'), e.g. "I felt how my fingers released the dart" and "I saw how my fingers released the dart".

**3.1.3 Procedure—**In the EXE+FB group participants were asked to throw the dart. The glasses turned non-transparent the moment they released the dart. Participants were asked to imagine how the dart flies towards the dartboard and imagine the dart hitting the dartboard. After each throw, participants turned around towards the report poster. The experimenter switched the glasses to transparent. Participants indicated on the report poster the estimated

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final position of the dart, which was recorded by the experimenter. Then, participants were asked to turn around and to look at the actual position of the dart on the dartboard while standing at the oche. The experimenter recorded the actual position and removed the dart. Then they continued with the next throw. In the EXE-FB group the procedure was basically the same, but participants did not see the actual position of the dart. They were asked to stay with their back towards the dartboard while the experimenter recorded the actual position of the dart and removed the dart from the dartboard. Only afterwards they turned back to face the dartboard.

In the IMA group participants were asked to keep their arms motionless, hanging loosely down at their sides with the dart in the dominant hand. They held the metal block in the non-dominant hand. They were instructed to imagine exactly how it feels to throw the dart, and to release the metal block just at the moment they imagine to release the dart. Upon release of the metal block the glasses turned non-transparent. As in the EXE+FB and the EXE-FB group, participants were asked to imagine how the dart flies towards the dartboard and how it hits the dartboard. After turning towards the report poster, the experimenter switched the glasses to transparent and participants indicated the final position of the dart.

As in Experiment 1, participants performed 5 actual throws to get used to the material and setting. Then the experiment started with a pretest consisting of 10 actual throws with the glasses set to transparent, followed by the experimental block consisting of 50 throws in the respective condition, and a posttest consisting of 10 actual throws with the glasses set to transparent. Strength of representation was assessed after the pretest, the experimental block, and the posttest.

#### 3.1.4 Data analysis—

Data analysis was similar to Experiment 1. In the execution groups, we further calculated correlations between estimated and actual x-positions and between estimated and actual y-positions of each throw for every participant. The group mean was calculated using Fishers' z transformed values. The average correlations we report are reconverted from the average Fisher's z-values.

## 3.2 Results

#### 3.2.1 Control analysis: Distance to the bullseye in pretest and posttest—

Means and standard errors of actual distance to the bullseye in pretest, experimental block, and posttest are shown in Fig. 7. To control for performance improvements from pretest to posttest an ANOVA with the between factor group (EXE+FB, EXE-FB, IMA) and the within factor test (pretest, posttest) was calculated on actual distance. A significant main effect of test, $F(1, 69) = 5.4$, $p = .023$, $\eta_p^2 = .07$, indicated that, surprisingly, actual distance was significantly larger in the posttest ($M = 12.7$ cm) than in the pretest ($M = 11.6$ cm). All remaining effects were not significant, both $F < 1$.

Visual inspection of the data showed that occlusion of the glasses might have affected participants throwing performance. To investigate this, an ANOVA with the between factor group (EXE+FB, EXE-FB) and the within factor test (pretest, experimental block, posttest) was calculated on actual distance. A significant main effect of test, $F(1.7, 78.7) = 34.6$, $p < .$

001, $\eta_p^2 = .43$, indicated that the actual distance was greater in the experimental block ($M$ = 16.7 cm) than in the pretest ($M$ = 11.5 cm, $p$ < .001) and the posttest ($M$ = 12.5 cm, $p$ < .001). In this analysis, pretest and posttest did not differ significantly from each other ($p$ = .32). The main effect of group and the interaction between group and test were not significant, both $F$ < 1.

#### 3.2.2 Position estimates: distance, consistency, and bias—Means and standard errors of distance, consistency, and bias based on position estimates are shown in Fig. 6. A MANOVA with the between factor group (EXE+FB, EXE-FB, IMA) revealed no significant effect of group, $F$(6, 136) = 1.6, $p$ = .15, $\eta_p^2 = .07$.

#### 3.2.3 Actual performance and estimated performance in the execution groups—A MANOVA with the between factor group (EXE+FB, EXE-FB) and the within factor dart position (actual, estimated) was calculated with the dependent variables distance, consistency, and bias. A significant main effect of dart position, $F$(3, 44) = 28.8, $p$ < .001, $\eta_p^2 = .66$, indicated that actual distance ($M$ = 16.7 cm) was larger than distance based on position estimates ($M$ = 12.2 cm). Actual bias ($M$ = 12.9 cm) was larger than bias based on position estimates ($M$ = 5.2 cm). The values for consistency based on actual positions ($M$ = 12 cm) were lower than for estimated positions ($M$ = 14.6 cm) indicating more consistency in actual throws than in estimated throws. The main effect group, $F$(3, 44) = 2.5, $p$ = .068, $\eta_p^2 = .15$, and the interaction between group and position, $F$(3, 44) = 2.2, $p$ = .099, $\eta_p^2 = .13$, were not significant.

Correlations between values based on actual and estimated dart positions for distance, consistency, and bias are shown in the upper part of Table 3 (for scatterplots see Supplemental material). For distance and bias the correlations were significantly higher in the EXE+FB group than in the EXE-FB group ($p_{max}$ = .018). For consistency the correlation was significantly lower in the EXE+FB group than in the EXE-FB group ($p$ = .006).

We further calculated the correlation between the actual and estimated x-positions of the dart and between the actual and estimated y-positions of the dart for each participant. The means of those correlations are shown in the lower part of Table 3. All correlations were significant and did not differ significantly between groups (x-positions: $t$(46) = 0.6, $p$ = .54; y-positions: $t$(36.6) = 0.1, $p$ = .91).

#### 3.2.4 Strength of representation—As in Experiment 1, data on strength of representation were averaged a) over proximal action elements and b) distal action elements. Means and standard errors of strength of representation are shown in Fig. 8. An ANOVA with the between factor group (EXE+FB, EXE-FB, IMA) and the within factors test (pretest, experimental block, posttest) and modality (kinesthetic/tactile, visual) was performed on strength of representation of proximal action elements. A significant main effect of modality, $F$(1, 69) = 228, $p$ < .001, $\eta_p^2 = .77$, indicated stronger kinesthetic/tactile ($M$ = 4.7) than visual representations ($M$ = 3.2). The significant interaction between test and modality, $F$(1.9, 130)





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= 1.6, $p = .039$, $\eta_p^2 = .05$, was modified by a significant three-way interaction between test, modality, and group, $F(3.8, 260) = 1.5$, $p = .028$, $\eta_p^2 = .08$. Visual representations of the EXE-FB group were weaker in the experimental block than in the pretest and posttest ($p_{max}$ = .047).

An ANOVA with the between factor group (EXE+FB, EXE-FB, IMA) and the within factor test (pretest, experimental block, posttest) was performed on strength of representation of distal action elements. A significant main effect of test, $F(1.6, 109.8) = 105$, $p < .001$, $\eta_p^2 = .6$, indicated weaker representations in the experimental block ($M = 2.5$) than in the pretest ($M = 5$; $p < .001$) and the posttest ($M = 4.9$; $p < .001$). A significant main effect of group, $F(2, 69) = 10.3$, $p < .001$; $\eta_p^2 = .23$, was modified by a significant interaction between group and test, $F(3.2, 219.7) = 9.5$, $p < .001$, $\eta_p^2 = .05$. Representations were significantly weaker in the EXE+FB and the EXE-FB group than in the IMA group in the experimental block ($p_{max} < .001$), but not in pretest and posttest ($p_{min} < .71$).

### 3.3 Discussion

In both execution groups, the larger distance of actual throws in the experimental block than in the pretest and posttest indicates that performance was impaired by the occlusion of the glasses. This was not expected, because the glasses were only occluded when the dart was no longer in contact with the fingers, i.e. the throw itself was completed. Because occlusion was contingent upon the release of the dart, it could be that participants anticipated the occlusion and that this anticipation changed the throwing technique, resulting in impaired performance. Alternatively, participants may have felt they have difficulties aiming at the target because they anticipated the abrupt interruption of visual feedback.

Counter-intuitively, the control analysis on performance in the pretest and the posttest revealed performance deterioration. This effect was however not significant in the second control analysis. The performance deterioration may be attributed to fatigue and declining concentration at the end of the experiment. However, performance deterioration was not observed in Experiment 1. Both experiments took the same time and included several breaks to fill in questionnaires, which renders fatigue effects rather unlikely. More likely, performance deterioration occurred due to a carry-over effect from the experimental blocks. Either participants still anticipated the occlusion of the glasses in the posttest (although they did not occlude), or internal models became less stable during the experimental blocks.

Because occlusion of the glasses occurred similarly in all groups, the performance deterioration in the experimental blocks should not affect the interpretation of the group comparisons. However, the question arises whether performance deterioration is reflected in estimates. Distance and bias based on estimates were smaller than actual distance and bias. In contrast, consistency based on estimates was lower (higher value) than consistency of actual throws. Interestingly, consistency based on estimates and actual consistency correlated significantly lower in the EXE+FB group than in the EXE-FB group. It is likely that participants in the EXE+FB group noticed that their estimates were inaccurate which influenced their subsequent estimates.

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One may argue that participants in the EXE+FB group used knowledge about the own performance from previous throws rather than an internal simulation. However, estimates in the EXE+FB group were not more similar to actual execution than estimates in the EXE-FB group. Thus, knowledge from delayed visual feedback about the performance in the previous dart throws did not improve estimates in subsequent dart throws, indicating that overall the influence of knowledge on estimates was likely rather low. Further, the positive correlations between estimated and actual x-positions and y-positions, which were calculated for each participant based on individual throws, are consistent with the assumption that participants performed an internal simulation of the action consequences of each throw. Such correlations have already been reported in previous studies (Künzell, 2005) and show that estimates are not random.

Alternatively, participants in the EXE+FB group applied unusual monitoring strategies (attention to e.g. arm velocity or arm orientation) in order to achieve more accurate estimates. Assuming that estimates are based on an internal simulation of action consequences, changes in monitoring strategies may have led to imprecise internal simulations of the throws and their consequences, resulting in lower consistency of estimated dart positions.

We have now argued that the EXE+FB and the EXE-FB group used an internal simulation of action consequences. Did the IMA group also use an internal simulation? No significant differences between the three groups were observed in distance, consistency, and bias based on the final position estimates. Thus, there is no indication that estimates might be based on different processes in MI and ME. Estimates most likely were based on an internal simulation in ME, this should be the case in MI too.

It was actually surprising that no significant differences were observed between groups. Thus, neither feedback from proximal action elements, which was present in the EXE+FB and the EXE-FB group but not in the IMA group, nor feedback from distal action elements, which was present in the EXE+FB but not in the EXE-FB and the IMA group, had an impact on estimates in the present task. This is surprising, because the lack of feedback has been regarded as an essential factor that contributes to differences between MI and ME (Campos et al., 2009; Rieger et al., 2011; Rieger & Massen, 2014). However, in the previous studies the tasks were coloring rectangles (Rieger & Massen, 2014), typing (Rieger et al., 2011), and continuous pointing (Campos et al., 2009). In those tasks feedback had to be continuously updated. In the present task, only one event – the final position of the dart – was estimated. The (lack of) feedback might contribute more to differences between MI and ME in situations in which feedback is an important indicator of the progress of the ongoing action. Further, durations of an action (as measured in Rieger et al., 2011; Rieger & Massen, 2014) might be more susceptible to this than estimated deviations from optimal performance.

Based on previous findings in a reaching task (Dahm & Rieger, 2016), we had speculated that for the proximal action elements of ME visual representations are less important than kinesthetic/tactile representations. This was observed in all groups. Most importantly, for proximal action elements visual and kinesthetic representations in the IMA group did not

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significantly differ from the representations in the execution groups. This is different from a previous observation, which indicated weaker kinesthetic representations in imagined than in executed reaching (Dahm & Rieger, 2016). It might be that visual feedback from the hands is more important in reaching than in darts. One explanation is that during goal-directed movements, vision is usually directed towards the movement target and not towards the limb that is moving (Helsen, Elliott, Starkes, & Ricker, 2000). In reaching, the hands reach into the area of the targets at the end of the movement. Hence, MI of reaching might be (partly) performed by visual MI. In darts, the hands do not reach the target of the action (the bullseye) and additionally, a specific position in which the hand movement ends does not exist. Therefore kinesthetic/tactile feedback may be more important in darts than in reaching, which is consequently represented in MI of playing darts.

All groups reported weaker visual representations of the action consequences during the experimental block than during the pretest and posttest. Thus, visual information is represented stronger under visual sight of the dart trajectory and its final position, than when this is imagined. Interestingly, in the experimental block the representation of distal action elements was weaker in the EXE+FB and the EXE-FB than in the IMA group. One explanation is that in the execution groups the requirement to switch from ME to MI when sight is occluded resulted in lower strength of representation. The sudden creation of a conscious image may take time and effort. In contrast, in the IMA group, participants continued with their imagination of proximal and distal action elements. This is consistent with findings which show that alternations between MI and ME result in longer durations than either full execution or full imagination (Dahm & Rieger, 2016).

## 4 General discussion

In the present experiments, we investigated whether action consequences are internally predicted in MI. For this aim, deviations from optimal performance in dart throwing were analyzed in MI and ME. We calculated two-dimensional error scores (distance to the bullseye, consistency, and bias; Hancock et al., 1995) of imagined and actual dart throws. In *Experiment 1,* novices and experts executed and imagined dart throws to the bullseye. Experts performed better than novices in both, imagination and execution. Irrespective of expertise, distance to the target and bias were smaller in imagination than in execution. In *Experiment 2,* three groups of novices a) imagined dart throws, b) executed dart throws without visual feedback, or c) executed dart throws with delayed visual feedback. After each throw they estimated the final position of the dart. The estimated positions of the dart did not differ significantly between groups. Position estimates resulted in smaller distance and less bias than actual positions. Consistency based on estimates was larger (indicating lower consistency) than actual consistency in execution with feedback, but not in execution without feedback.

Even though some participants (which were excluded from analysis) always imagined throwing exactly into the bullseye, most participants imagined different final positions of the dart. We were initially not sure whether participants would actually do this. Even though error reports in imagined actions have previously been obtained, for instance in typing, some types of errors, in particular execution errors, are rarely reported (Rieger et al., 2011). In typing, errors either occur or not, whereas in darts accuracy is continuous and two-dimensional. Thus, the observation that errors can be imagined does not automatically imply that participants will simulate different final positions in MI of dart throwing. However, our results indicate that most of our participants were able to detect deviations from optimal performance in imagination.

The results from both experiments show that participants perform dart throws more accurately in MI than in ME. This indicates that the actual extent of deviations from optimal performance is not entirely represented in MI. This is in line with previous results showing fewer errors in imagined than in executed typing (Rieger et al., 2011). If estimates are based on an internal simulation of the action, fewer deviations from optimal performance in MI than in ME may be due to several reasons.

It may be that the extent of predicted deviations from optimal performance is not entirely reported. In executed typing, for example, some errors that are corrected (and therefore detected), are not reported (Rieger et al., 2011). Errors were either detected and corrected automatically or just forgotten at the moment of the report. In the present study it is however unlikely that the extent of deviation from optimal performance was forgotten, because participants were asked to report the final dart position after each single throw.

Another explanation for the lower extent of deviation from optimal performance in MI than in ME is that deviations are not entirely predicted in MI. One reason may be that forward modelling does not occur in MI, either because there is no efference copy in MI or because forward models do not use the efference copy. However, our data indicate that this is unlikely. In Experiment 1, imagination and execution correlated positively in variables that are most likely outside of participants' awareness. Further, bias was higher than zero. Additionally, differences between imagination and execution were relatively small compared to the expertise effects. In Experiment 2, the existence of an efference copy can be assumed for the execution conditions (Wolpert et al., 2011). In the execution groups, deviations from optimal performance (distance and bias) based on estimates were however lower than actual deviations. Furthermore, deviations based on estimates did not significantly differ between ME and MI, indicating that most likely similar processes take place in MI and ME.

There are some further, more plausible, explanations. First, forward models may be imprecise. Second, they may not predict all aspects of actions. Third, error signals (discrepancies between intended and internally predicted action consequences) that indicate deviations from optimal performance may not be monitored in MI. In MI attention is directed at aspects of an action which are automatic in ME. This makes MI cognitively more demanding than ME (Glover & Baran, 2017) and thus fewer resources may be available for error monitoring.

One further explanation is that error signals are ignored in MI because participants want to perform well. Wanting to perform well may result in a motivational bias towards better performance. The bias may influence MI, because the action and its consequences can be intentionally manipulated in MI (Guillot et al., 2012). For instance, irrespective of the movement, in MI one may adjust the imagined dart's trajectory so that the dart flies towards

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the bullseye. The motivation to perform well may either result in intentional control of action consequences in MI (Guillot et al., 2012) or in an (unintentional) bias towards better performance. It seems unlikely that participants manipulated their reports intentionally. In Experiment 1, a significant correlation between execution and imagination in consistency (which is assumed to be outside participants' conscious awareness) was obtained both in experts and novices. In Experiment 2, significant correlations between actual and estimated dart positions were observed in the execution groups.

With reference to the imagery debate, the present findings are in favor of the analog view of imagery. We showed that action errors that are not consciously available (e.g. the bias) are represented in MI. This speaks against the view that MI is an epiphenomenon of abstract knowledge about the movement and its consequences (Pylyshyn, 2002). More likely, the motor system is involved in MI and an internal simulation of the entire action occurs (Grush, 2004). This does not rule out that propositional representations exist in addition to analogous representations, but analogous representations are not sufficient to explain imagery entirely (Kosslyn, 1994).

In the applied field, MI is repeatedly and systematically used in mental practice in order to improve performance (Driskell, Copper, & Moran, 1994). However, mental practice is less effective than physical practice (Driskell et al., 1994; Ingram, Kraeutner, Solomon, Westwood, & Boe, 2016). One reason for this may be that deviations from optimal performance play a crucial role for motor learning (Thoroughman & Shadmehr, 2000), but occur less often in mental practice than in physical practice. However, the present study suggests that in MI - and consequently in mental practice - at least some deviations from optimal performance are imagined. Those imagined deviations from optimal performance may contribute to the effectiveness of mental practice (cf. Finke, 1979). Nevertheless, in mental practice it may be beneficial on a motivational level to imagine action consequences more similar to the desired outcome than they are in execution: The imagination of erroneous action consequences (so called negative outcome imagery) leads to performance decrements due to a loss of self-efficacy (Taylor & Shaw, 2002). In the future, it might be interesting to address the impact of deviations from optimal performance in mental practice further. Even though it might be beneficial motivationally to imagine the desired action consequences, mental practice might be more effective if realistic action consequences are imagined based on internal simulations (including deviations from optimal performance).

In conclusion, using a dart throwing task, we showed that participants most likely perform an internal simulation in MI and that the influence of knowledge-based strategies, if it exists, is rather low. The present study further demonstrates, to our surprise, that predictive mechanisms in MI are similar in experts and novices. The lack of feedback does not seem to contribute to differences between MI and ME in the present task. In MI, less deviation from optimal performance than in ME was observed, most likely because forward models are imprecise, do not predict all aspects of an action, or because error monitoring is neglected in MI.

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## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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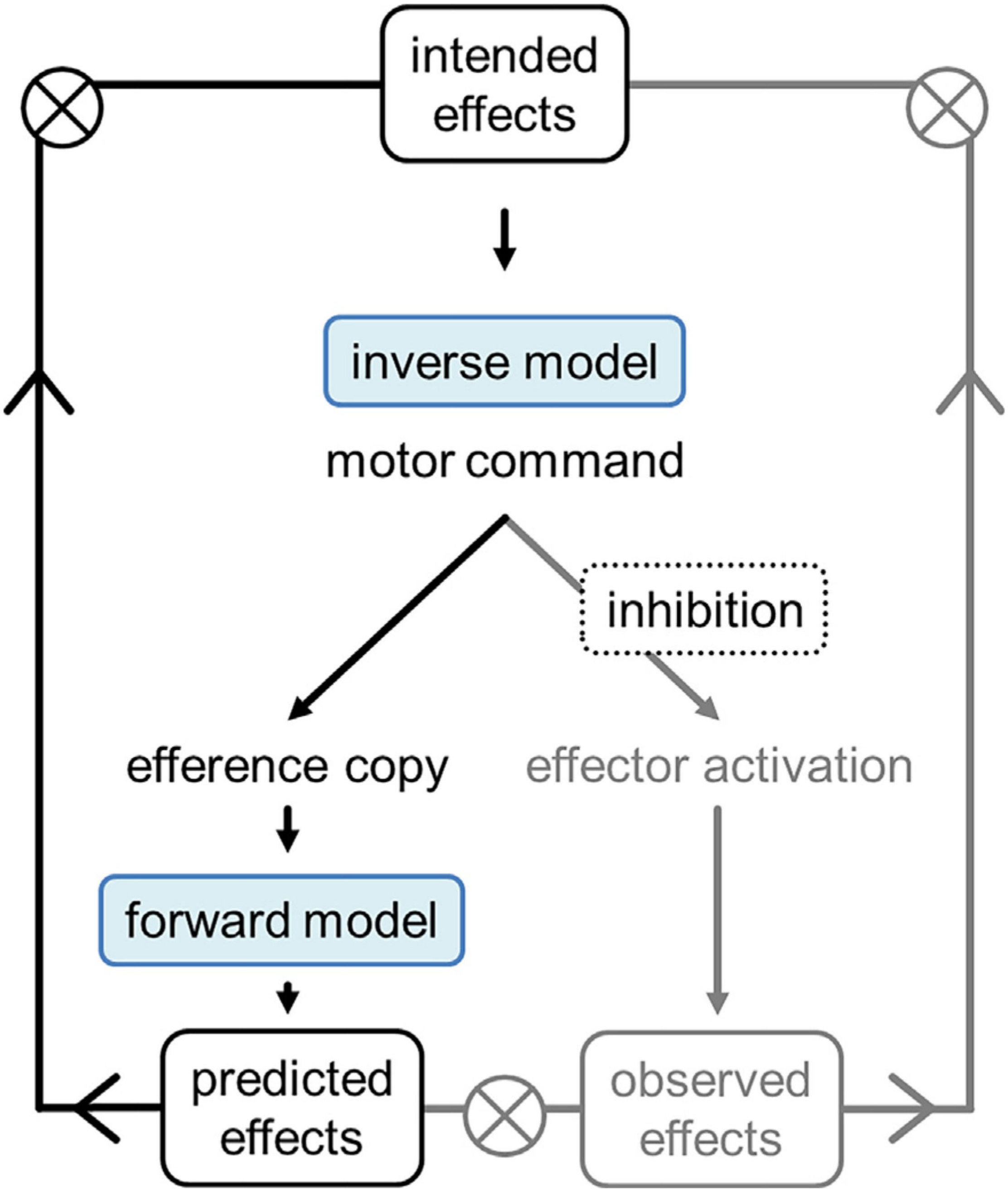


**Fig. 1.**

Framework of internal models. Intended effects are compared with predicted effects in both, motor execution and motor imagery. Additionally in motor execution, actual effects are observed and compared with intended and predicted effects. Comparisons are depicted as a cross in a circle. The mechanisms in grey do not (or to a lesser degree) take place in motor imagery because activation of the effectors is inhibited (adapted and modified from Blakemore et al., 2002).

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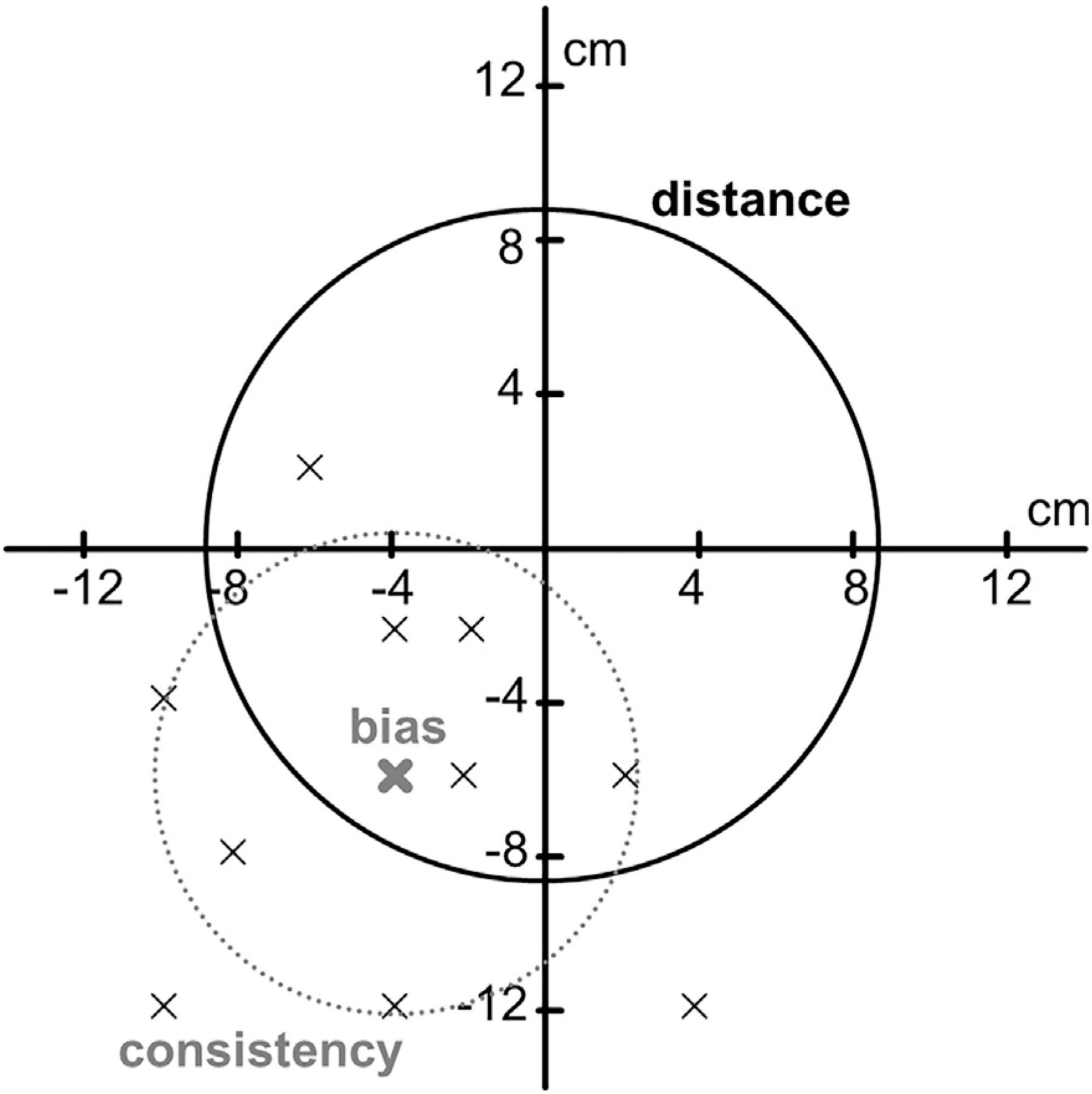


**Fig. 2.**
Depiction of the final positions of ten darts throws (thin black crosses), demonstrating distance to the bullseye (8.7 cm, black circle), consistency (6.3 cm, grey circle), and bias (7.2 cm, grey bold cross).

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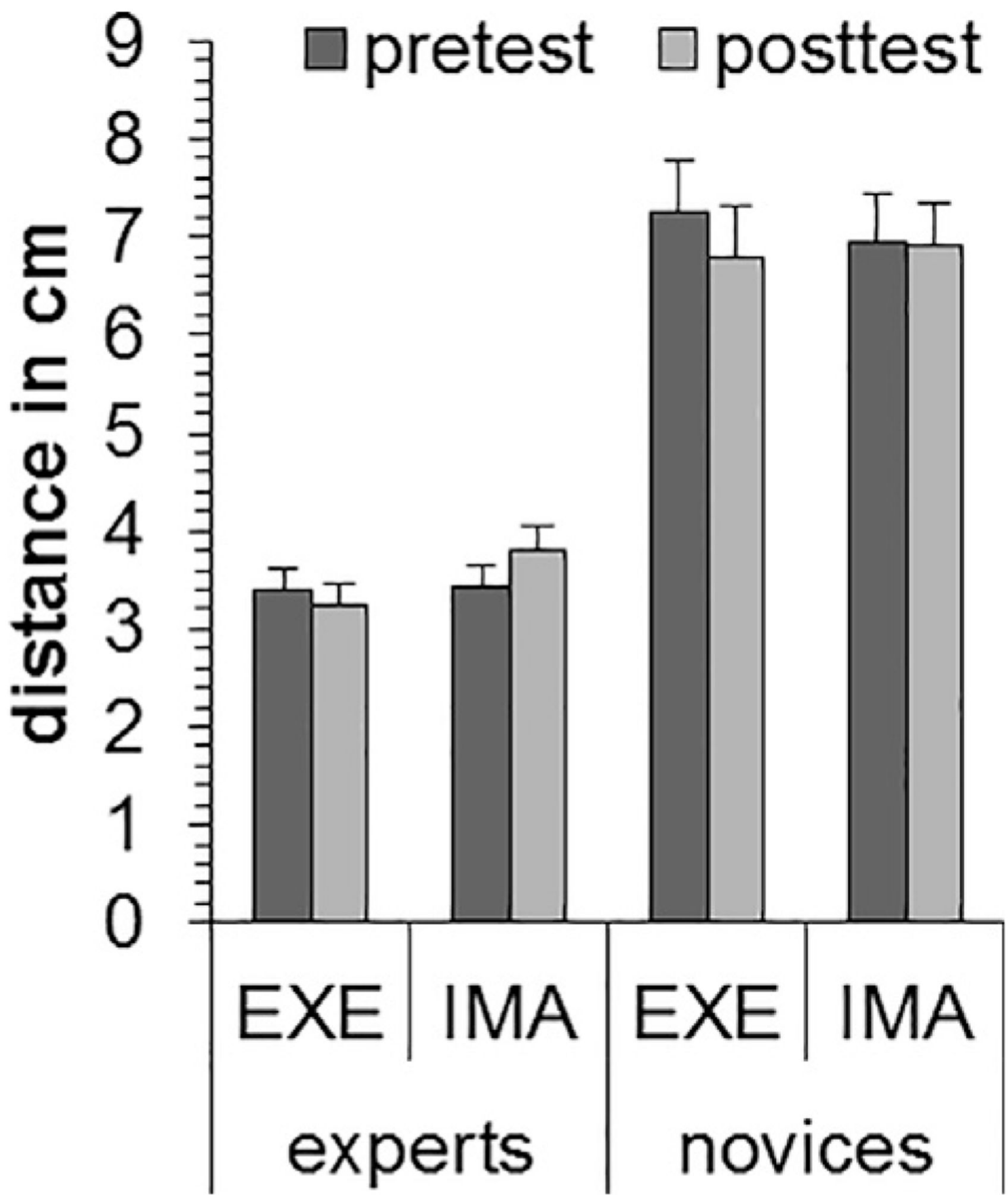


**Fig. 3.**

Means and standard errors of distance to the target before (pretest) and after (posttest) execution (EXE) and imagination (IMA) for experts and novices.

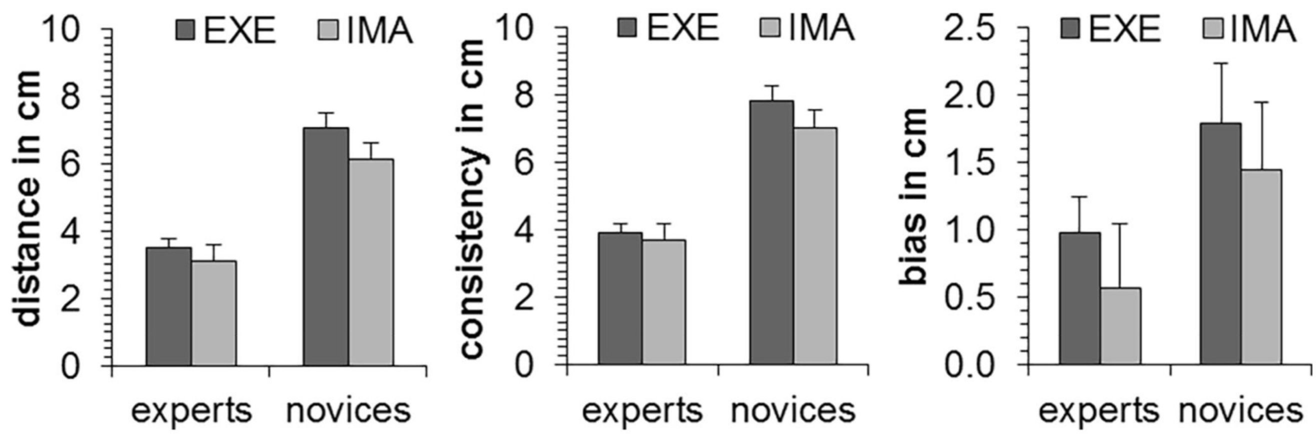


**Fig. 4.**

Means and standard errors of distance, consistency, and bias in execution (EXE) and imagination (IMA) for experts and novices.

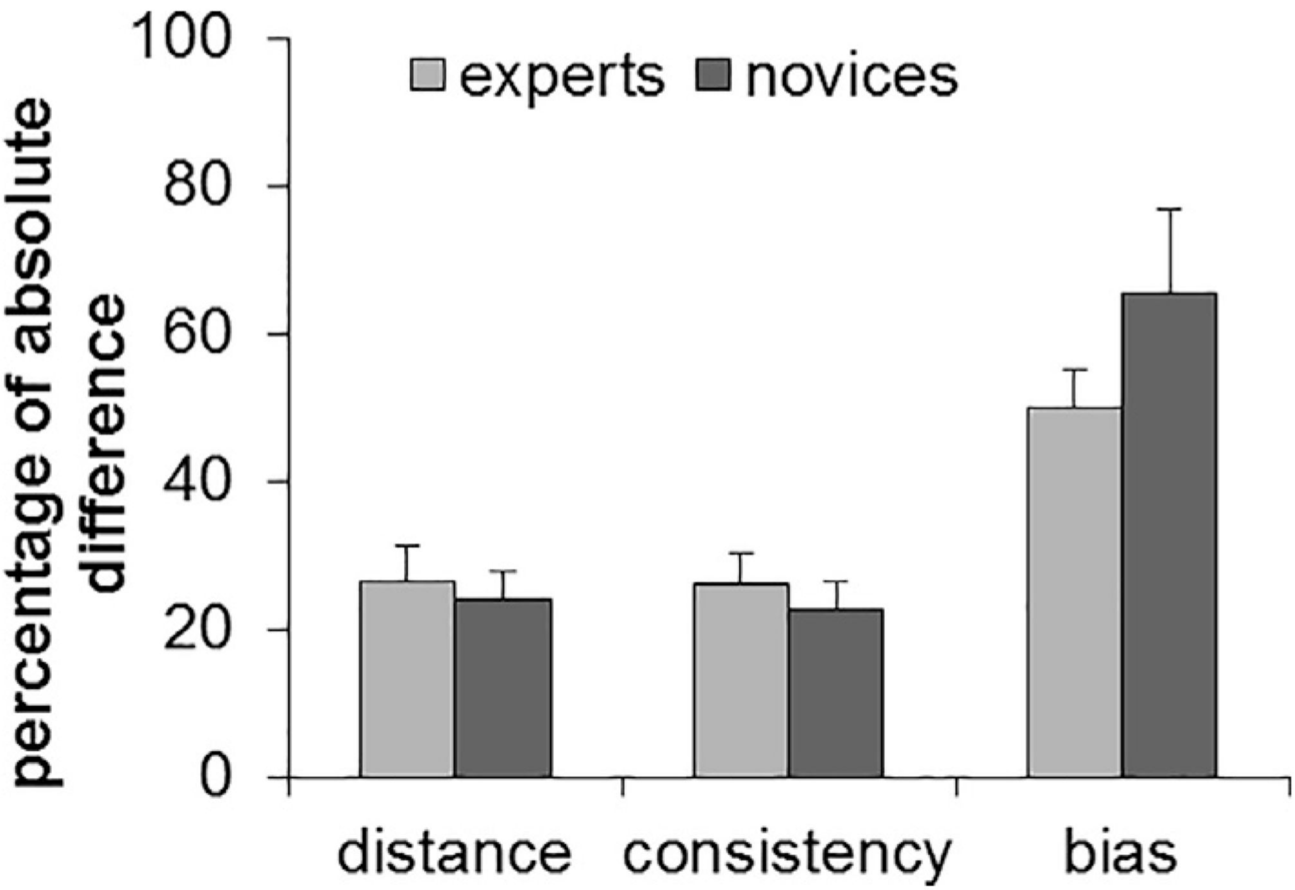


**Fig. 5.**

Percentage of the absolute difference (|IMA – EXE|/EXE × 100) between imagination (IMA) and execution (EXE) in distance, consistency, and bias, for experts and novices.

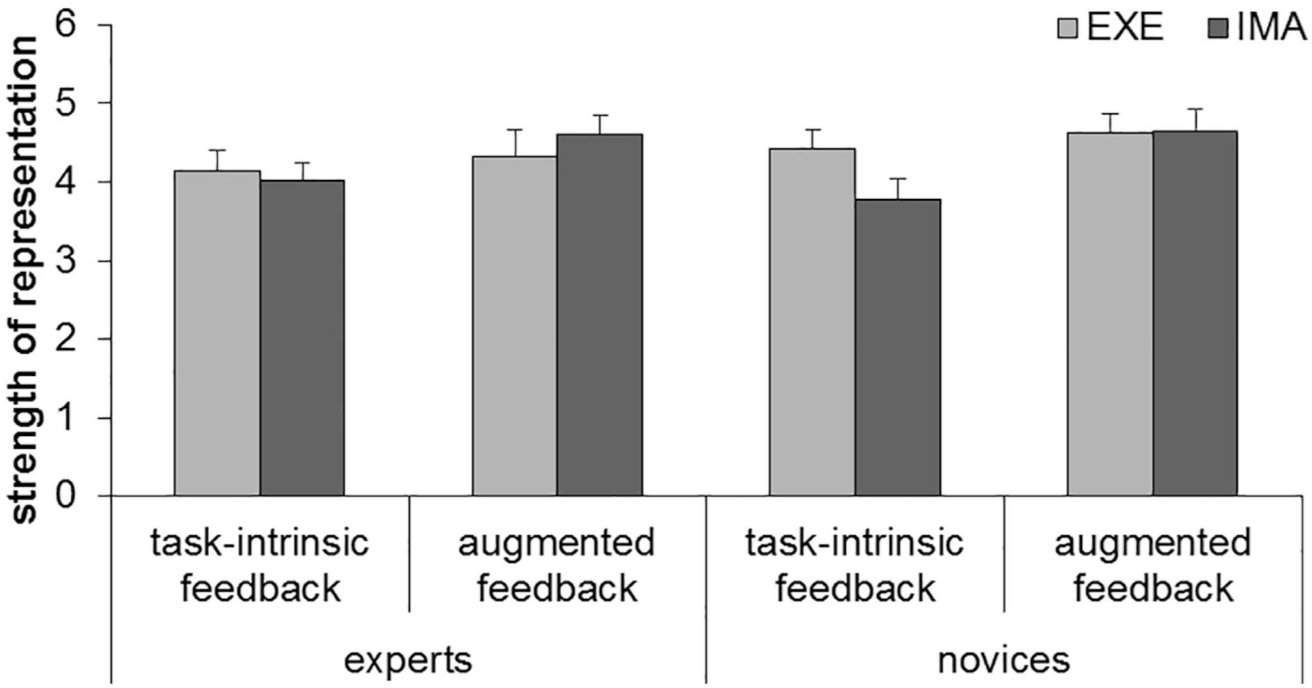


**Fig. 6.**

Means and standard errors of strength of representation in execution (EXE) and imagination (IMA) for experts and novices. Proximal action elements include how it feels to perform the throw, the fingers gripping the dart, the arm movement, and the release of the dart. Distal action elements include the dart's trajectory and its final position.

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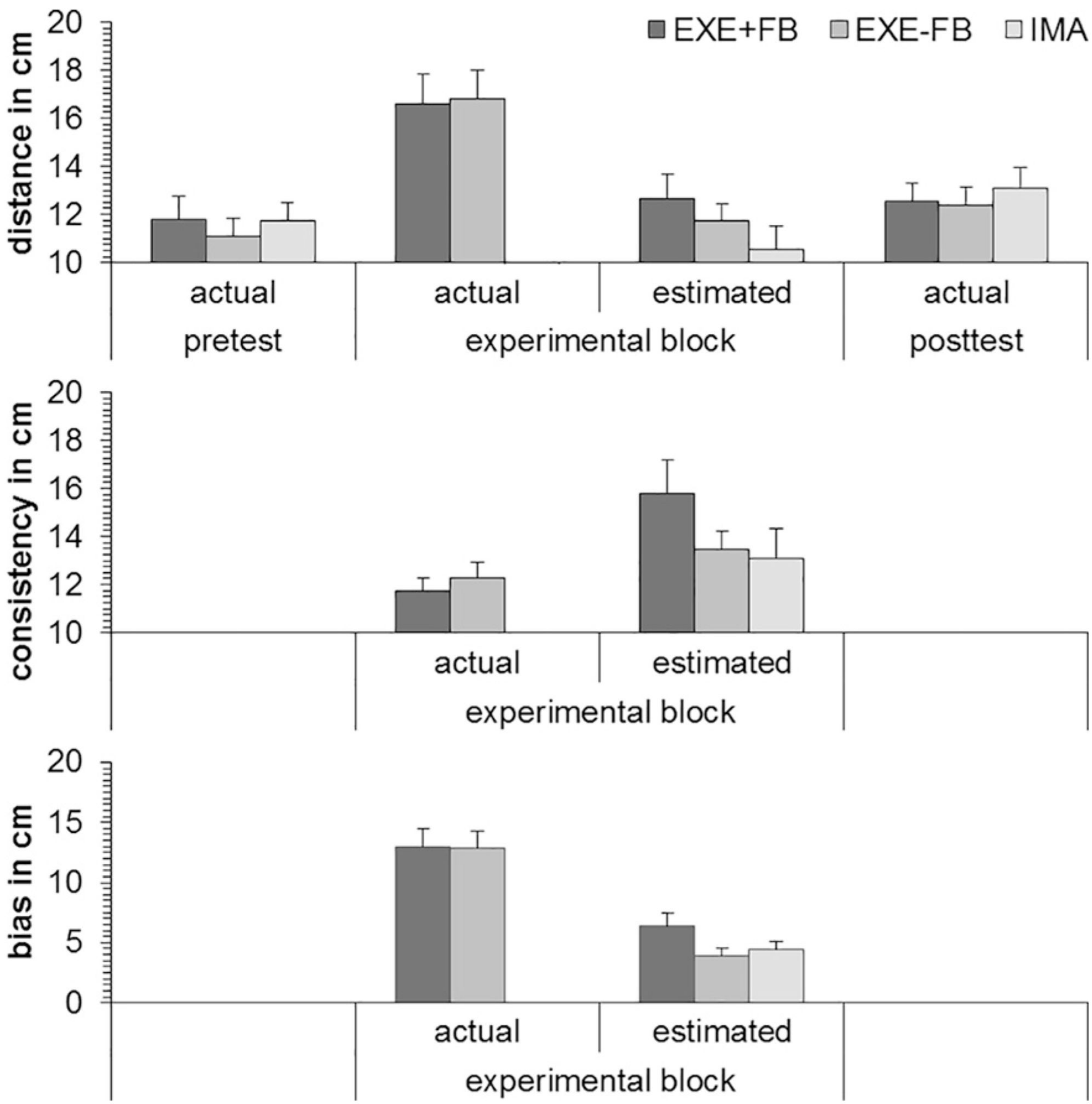


**Fig. 7.**

Means and standard errors of distance to the bullseye, consistency, and bias based on actual and estimated dart positions in the execution group with delayed feedback (EXE+FB), the execution group without feedback (EXE-FB), and the imagination group (IMA).

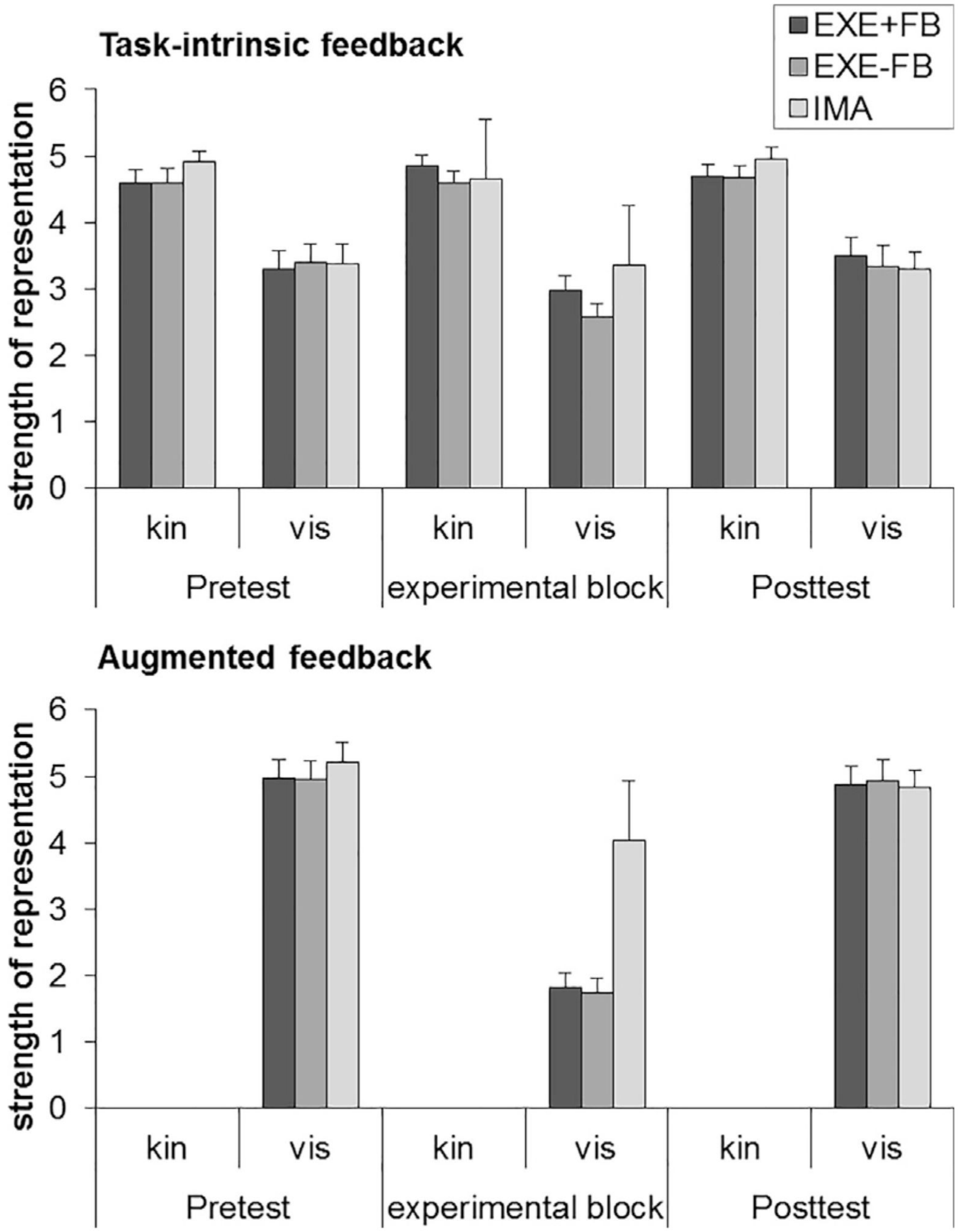


**Fig. 8.**

Means and standard errors of the strength of representation in the execution group with delayed feedback (EXE+FB), the execution group without feedback (EXE-FB), and the imagination group (IMA). Kinesthetic/tactile (kin) and visual (vis) representations of proximal action elements include the finger grip, the arm movement, and the release of the dart. Distal action elements include the dart trajectory and the dart hitting the dartboard.

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**Table 1**

Pearson correlations between executed and imagined dart throws for experts ($N = 20$) and novices ($N = 21$).

| | Experts | Novices |
|---|---|---|
| Distance | 0.72* | 0.67* |
| Consistency | 0.71* | 0.66* |
| Bias | 0.65* | 0.32 |

*Note.*

* $p < .05$; Experts: critical $r = .36$; Novices: critical $r = .37$.

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## Table 2

Demographic data and data related to darts experience of the execution group with delayed visual feedback (EXE+FB), the execution group without visual feedback (EXE-FB), and the imagination group (IMA). The distribution of sex and handedness as well as means (*M*), standard deviations (*SD*), and results of ANOVAs (F-values, p-values, effect size $\eta_p^2$, $df1 = 2$, $df2 = 69$) for age and data related to darts experience are shown.

| | EXE+FB | EXE-FB | IMA | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| Sex (male/female), *N* | 8/16 | 8/16 | 6/18 | | | |
| Handedness (left/right), *N* | 1/23 | 2/22 | 1/23 | | | |
| Age in years, *M* (*SD*) | 24.5 (6.3) | 22.8 (3) | 22.9 (3.8) | 1.1 | .35 | .03 |
| Number of times darts was played during the last year, *M* (*SD*) | 2.88 (10.1) | 2.33 (4.7) | 0.67 (1.1) | < 1 | .47 | .02 |

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### Table 3

Pearson correlations between actual and estimation based distance, consistency, and bias as well as means of individual correlations between actual and estimated x-positions and y-positions, separately for the execution group with delayed visual feedback (EXE+FB) and the execution group without visual feedback (EXE-FB).

| | **EXE+FB** | **EXE-FB** |
|---|---|---|
| Distance | 0.84* | 0.24 |
| Consistency | 0.36* | 0.84* |
| Bias | 0.72* | 0.13 |
| x-positions | 0.42* | 0.46* |
| y-positions | 0.37* | 0.38* |

*Note*.

*$p < .05$; one-tailed critical $r = .34$.