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# Enhancing performance expectancies through visual illusions facilitates motor learning in children

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ABSTRACT

In a recent study by Chauvel, Wulf, and Maquestiaux (2015), golf putting performance was found to be affected by the Ebbinghaus illusion. Specifically, adult participants demonstrated more effective learning when they practiced with a hole that was surrounded by small circles, making it look larger, than when the hole was surrounded by large circles, making it look smaller. The present study examined whether this learning advantage would generalize to children who are assumed to be less sensitive to the visual illusion. Two groups of 10-year olds practiced putting golf balls from a distance of 2 m, with perceived larger or smaller holes resulting from the visual illusion. Self-efficacy was increased in the group with the perceived larger hole. The latter group also demonstrated more accurate putting performance during practice. Importantly, learning (i.e., delayed retention performance without the illusion) was enhanced in the group that practiced with the perceived larger hole. The findings replicate previous results with adult learners and are in line with the notion that enhanced performance expectancies are key to optimal motor learning (Wulf & Lewthwaite, 2016).

## 1. Introduction

Enhancing learners' expectancies for future performance has been shown to be an important factor in motor skill learning, and enhanced expectancies are a key factor in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). Learners' expectancies (e.g., self-efficacy) can be enhanced in various ways. For instance, defining "good" performance liberally, thereby increasing individuals' experience of success, has been demonstrated to facilitate learning (e.g., Palmer, Chiviacowsky, & Wulf, 2016; Trempe, Sabourin, & Proteau, 2012). In the study by Palmer et al., participants were asked to learn a golf-putting task. One group was informed that putting within the larger of two concentric circles surrounding the target would constitute good putts. Another group was told that balls coming to rest in the smaller circle would represent good performance. The group whose success was defined by the larger circle performed more accurately, with smaller error to the central target, during the practice phase. More importantly, that group also showed more effective learning, as measured by delayed retention and transfer tests with the circles removed. Thus, having experienced a higher percentage of successful putts during practice had lasting benefits. Furthermore, providing learners with positive feedback – for instance, feedback after relatively successful rather than unsuccessful trials – has been found to enhance their confidence in their ability to perform well in the future and facilitate learning (e.g., Chiviacowsky & Wulf, 2007; Clark & Ste-Marie,

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2007; Saemi, Porter, Ghotbi-Varzaneh, Zarghami, & Maleki, 2012). Similarly, social-comparative feedback indicating better-than-average performance or improvement (e.g., Lewthwaite & Wulf, 2010; Wulf, Chiviacowsky, & Lewthwaite, 2010) has been shown to enhance learning.

In another series of studies, researchers have used visual illusions (e.g., Witt, Linkenauger, & Proffitt, 2012; Wood, Vine, & Wilson, 2013) to manipulate the perceived size of a target (i.e., golf hole). When the golf hole was surrounded by smaller circles it appeared to be larger, and when it was surrounded by larger circles it appeared to be smaller (Ebbinghaus illusion). The question these researchers tried to answer was whether the perception of a larger target could increase putting accuracy. They found that putting accuracy was indeed higher when the target appeared larger rather than smaller. In an effort to determine a possible underlying mechanism of this effect, Wood and colleagues demonstrated that the apparent target size affected the "quiet eye" duration (Vickers, 1992). That is, the target was fixated longer when the target appeared larger rather than smaller. Wood et al. concluded that motor planning was aided with the longer target fixation, leading to more effective putting performance. It could also be argued that the task appeared less difficult or daunting and more likely to result in holing the putt – thereby enhancing performers' expectancies for movement success – which in turn contributed to more effective performance.

A follow-up study by Chauvel, Wulf, and Maquestiaux (2015) appears to provide some support for this contention. These authors included a delayed retention test without visual illusions to determine whether the effects seen during practice (with visual illusions present) would have an effect on *learning*. Motor learning is typically measured by retention or transfer tests, with the independent variables removed, conducted after a delay of at least one day (Schmidt & Lee, 2011). These conditions allow memory consolidation to take effect (Shadmehr & Holcomb, 1997). Moreover, removal of the independent variables ensures that potential temporary effects of these variables are not confounded with relatively permanent changes in performance (i.e., learning). The results of Chauvel et al.'s study showed that the performance-enhancing effects of the larger-looking hole were relatively permanent. Thus, learning was more effective in a group that practiced with a perceived larger hole compared with a group that practiced with a smaller looking hole. Chauvel and colleagues also assessed self-efficacy and found that participants' self-efficacy, or confidence in their ability to hit the target, was increased in the former group as well. In addition, self-efficacy predicted practice performance, and performance during practice predicted learning (i.e., retention performance). Overall, those findings indicated that the effects of practice under conditions involving visual illusions can be relatively permanent and persist when the illusions are removed – presumably due to their influence on perceptions of task difficulty and related performance or outcome expectations.

Chauvel et al.'s (2015) findings were recently challenged by Cañal-Bruland, van der Meer, and Moerman (2016). These authors used a marble-shooting task and were unable to replicate the previous findings (Chauvel et al., 2015; Witt et al., 2012; Wood et al., 2013). Cañal-Bruland et al. instead found performance improvements from a pre- to a post-test for a group with a perceived smaller target (and a control group), but not for a group with a perceived larger target. What might explain the discrepant findings? Aside from task differences, the two studies differed in other respects as well (e.g., number of practice trials). Yet, a likely and parsimonious explanation for the different results is the fact that Cañal-Bruland et al. had relatively large group differences on the pre-test. The group that later experienced the larger looking hole already had smaller errors than the other groups on the pre-test. Thus, the groups with a perceived smaller target or no visual illusion (control group) had more room for improvement from pre- to post-test. Nevertheless, additional research seemed to be in order to verify the beneficial learning effects resulting from enhanced learner expectancies by means of visual illusions.

In the present study, we therefore use methods similar to those used in previous studies (Chauvel et al., 2015; Witt et al., 2012; Wood et al., 2013). However, in contrast to those studies, in which adults were used as participants, 10-year old children participated in the present study. Children appear to be less sensitive to the Ebbinghaus illusion than adults (Doherty, Campbell, Tsuji, & Phillips, 2010). In particular, below age 7, children's discrimination of circle sizes was found to be more accurate compared with adults. That is, children's judgments were less affected by the size of the surrounding circles. Even at age 10, children were less sensitive to the illusion than adults were in the study by Doherty and colleagues (2010). Thus, in the present attempt to replicate Chauvel et al.'s findings, we used a more "challenging" population. Similar to Chauvel et al., we used a golf putting task. After a pre-test, two groups practiced the task with the hole being surrounded by smaller or larger circles (Ebbinghaus illusion) and then performed a delayed retention test without surrounding circles to assess learning. In addition to putting accuracy, we measured participants' perceptions of hole size and self-efficacy before and after practice, as well as before the retention test. We predicted differences in perceived hole size resulting from the visual illusions, as well as differential effects on self-efficacy and learning (i.e., retention performance). Correlational and regression analyses were used to explore possible relationships between learning, perceived hole size, and self-efficacy.

## 2. Method

### 2.1. Participants

Thirty 10 year-old boys ($M$ = 10.66 and $SD$ = 0.41) participated in the study at an Iranian university. A G*Power analysis showed that a total of 28 participants would be sufficient to correctly reject the null hypothesis (with $\alpha = 0.05$, $1\text{-}\beta = 0.90$). None of the participants had prior experience with the task. They were naïve as to the purpose of the study, and they gave their assent before participation, and the parents/guardians provided informed consent. The study was approved by the university's institutional review board.

### 2.2. Apparatus and task

The putting task was performed on a level artificial-turf indoor green (400 × 55 cm). A projector, suspended from the ceiling, projected the "hole" and 11 small circles (3.8 cm in diameter) or 5 large circles (28 cm in diameter) that surrounded the target. Participants putted white golf balls from a distance of 2 m (similar to Chauvel et al. (2015)). The distance between the center of hole and the edge of the ball was measured after each trial. If a putt was long and the ball contacted the rear border of the putting green, the maximum measurable deviation of 100 cm was recorded (pre-test: 12% and 14.6% of trials in groups with perceived larger or smaller hole, respectively; practice: 3.6% and 2.9% of trials in groups with perceived larger or smaller hole, respectively; retention: 4.7% and 3.7% of trials for groups with perceived larger or smaller hole, respectively).

### 2.3. Procedure

Participants were randomly assigned to one of two groups: A group that practiced with a perceived larger hole (i.e., small circles surrounding the target) or a group with perceived smaller hole (i.e., large surrounding circles). Participants first completed a 5-trial pre-test without visual illusion. The circles were then projected around the target, and participants were asked to draw a circle that corresponded in size to the target circle on a 15.6 in. laptop computer, using Microsoft Paint. The diameter of the drawn circles was used as a measure of perceived target size (Chauvel et al., 2015; Lee, Linkenauger, Bakdash, Joy-Gaba, & Profitt, 2011). Next, participants filled out a self-efficacy questionnaire consisting of 4 items. On a scale from 1 ("not confident at all") to 10 ("extremely confident"), participants rated their confidence that they would be able to achieve an average deviation of 20, 15, 10, or 5 cm or less, respectively, on the last 10 practice trials (Trials 41–50). Participants then performed 50 practice trials. On the first, third, and fifth 10-trial block, they were given augmented feedback (average deviation in cm) after each trial, primarily to facilitate future self-efficacy ratings. After completing the practice phase, participants were again asked to draw the target circle and to fill out another self-efficacy questionnaire in which they rated their confidence in their ability to produce certain average deviations (20, 15, 10, 5 cm or less) on the retention day (48 h later). Also, before the retention test, participants were asked to draw the target circle, this time without the surrounding circles, and to fill out a self-efficacy questionnaire regarding their upcoming performance. They then performed a 10-trial retention test without visual illusion.

### 2.4. Data analysis

Deviations from the target (in cm), or radial errors, were averaged across blocks of trials (5 trials for the pre-test, 10 trials for practice and retention). Univariate analyses of variance (ANOVAs) were used for the pre-test and retention test. A 2 (groups) × 5 (blocks of 10 trials) ANOVA with repeated measures on the last factor was used to analyze the practice data. Both perceived hole size (in cm) and self-efficacy scores, averaged across the 4 items, were analyzed in a 2 (groups) × 2 (time: before practice, after practice) repeated-measures ANOVA for the practice phase and a one-way ANOVA for the retention test. Finally, although the experimental approach (and sample size) of this study was not designed to assess relationships among variables, we explored key relationships with correlational and linear regression analyses to gain insights for future work.

## 3. Results

### 3.1. Perceived hole size

Both groups were affected by the visual illusion. When the hole (10.4 cm) was surrounded by larger circles, the drawn circle was smaller both before (9.3 cm) and after (9.3 cm) practice. When the hole was surrounded by smaller circles, the drawn circle was larger (11.8 and 11.3), respectively (see Fig. 1). The main effect of group was significant, $F\ (1, 28) = 18.92$, $p < 0.001$, $\eta_p 2 = 0.40$. The main effect of time and the interaction of group and time were not significant, $F$s $(1, 28) < 1$.

Before the retention test, with the visual illusion removed, perceived hole size still differed between groups, corresponding to the visual illusion experienced during practice. This difference was significant, with $F\ (1, 28) = 17.30$, $p < 0.001$, $\eta_p{}^2 = 0.38$.

### 3.2. Putting accuracy

Putting performance of the two groups did not differ significantly on the pre-test, $F\ (1, 28) = 1.18$, $p > 0.05$ (see Fig. 2). During the practice phase, both groups reduced their deviations from the hole. The group with the perceived larger hole generally outperformed the group with the perceived smaller hole. The main effects of block, $F\ (4, 112) = 17.13$, $p < 0.001$, $\eta_p 2 = 0.38$, and group, $F\ (1, 28) = 5.67$, $p < 0.05$, $\eta_p{}^2 = 0.17$, were significant. There was no Group x Block interaction, $F\ (4, 112) < 1$.

Two days later, on the retention test without visual illusion, deviations from the hole were again smaller for the group that practiced with the perceived larger hole ($M = 47.2$ cm) than for the group with the perceived smaller hole size ($M = 57.1$ cm), $F$ (1, 28) = 15.8, $p < 0.001$, $\eta_p{}^2 = 0.35$. Thus, the apparently larger hole size resulted in advantages for learning.

### 3.3. Self-efficacy

Both groups had similar self-efficacy ratings before the practice phase, but the group with the perceived larger hole had higher

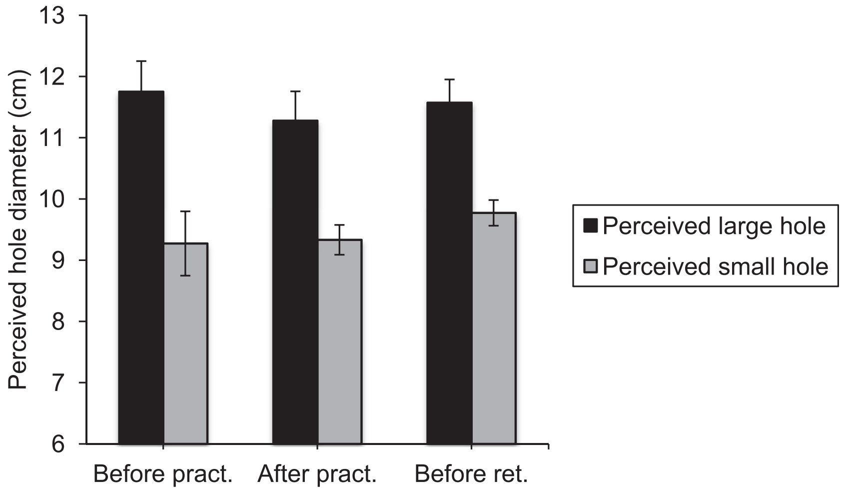


**Fig. 1.** Perceived hole size before practice (i.e., after the pre-test), at the end of practice, and before the retention test, as a function of the visual illusion.

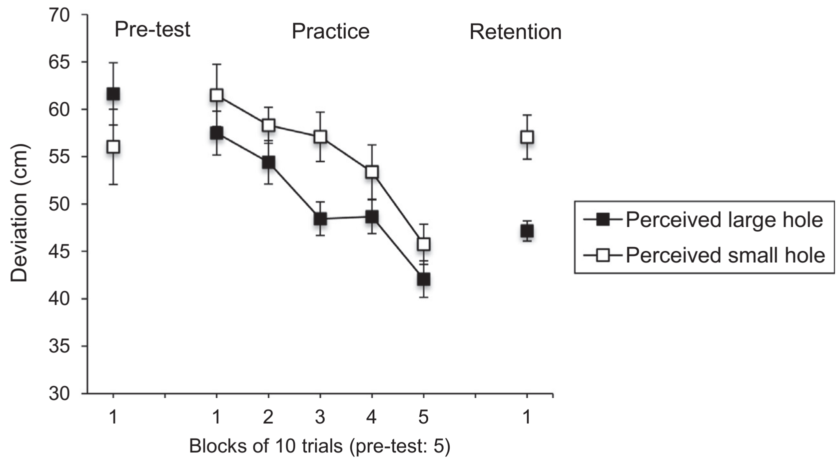


**Fig. 2.** Putting performance (i.e., deviation from the hole) of the two groups during practice (with visual illusion) and retention (without visual illusion).

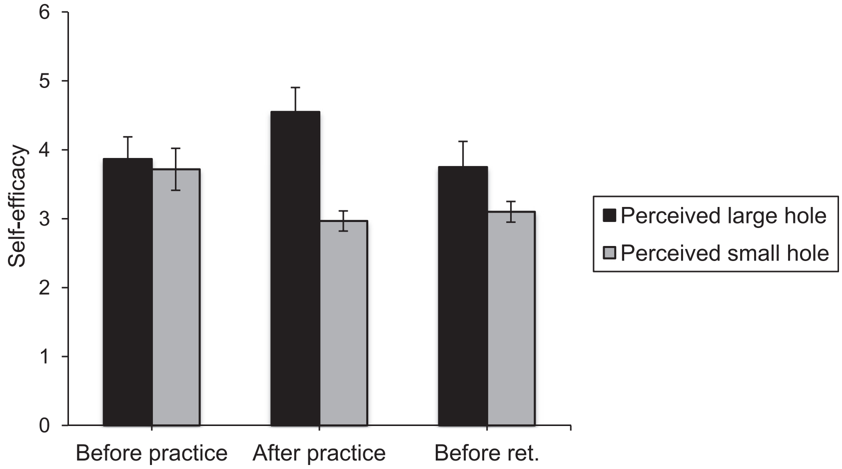


**Fig. 3.** Self-efficacy of the two groups before practice (i.e., after the pre-test), after practice, and before the retention test, as a function of the group's perceived size of the hole.

**Table 1**
Pearson correlations of practice performance, retention performance, perceived hole size, and self-efficacy.

| | Practice performance (averaged across trials) | Retention performance (averaged across trials) | Perceived hole size (pre-practice) | Perceived hole size (post-practice) | Perceived hole size (pre-retention) | Self-efficacy (pre-practice) | Self-efficacy (post-practice) | Self-efficacy (pre-retention) |
|---|---|---|---|---|---|---|---|---|
| Practice performance (averaged across trials) | 1 | 0.349* | −0.043 | −0.188 | −0.217 | 0.139 | −0.162 | 0.199 |
| Retention performance (averaged across trials) | | 1 | −0.448*** | −0.337** | −0.357** | 0.126 | −0.284 | −0.047 |
| Perceived hole size (pre-practice) | | | 1 | 0.507*** | 0.485*** | −0.184 | 0.342* | 0.192 |
| Perceived hole size (post-practice) | | | | 1 | 0.423** | −0.307* | 0.543*** | 0.078 |
| Perceived hole size (pre-retention) | | | | | 1 | 0.187 | 0.689**** | 0.342* |
| Self-efficacy (pre-practice) | | | | | | 1 | 0.261 | 0.366** |
| Self-efficacy (post-practice) | | | | | | | 1 | 0.524*** |
| Self-efficacy (pre-retention) | | | | | | | | 1 |

*Note:* N = 30. Pre-practice measures were taken after visual illusion manipulation. Post-practice measures were completed on Day 1 after practice trials were completed. Pre-retention measures were completed two days later prior to retention performance testing.

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

self-efficacy than the group with the perceived smaller hole at the end of practice (see Fig. 3). The main effect of group was significant, $F\,(1,\,28) = 6.87$, $p < 0.05$, $\eta_p{}^2 = 0.20$. Also, the interaction of group and time, $F\,(1,\,28) = 8.33$, $p < 0.01$, $\eta_p{}^2 = 0.23$, was significant. The main effect of time was not significant, $F\,(1,\,28) < 1$.

Before the retention test without the visual illusion, the group with the perceived larger hole during practice still tended to show high self-efficacy. However, this effect failed to reach significance, $F\,(1,\,28) = 2.63$, $p = 0.116$, $\eta_p{}^2 = 0.09$.

### *3.4. Relationships among variables*

Table 1 presents correlations between performance, perceived hole size, and self-efficacy assessments at the different study time points. Caution in interpretation should be exercised given the sample size. Perceived hole sizes at different time points were moderately inter-correlated, as were self-efficacy measurements after the initial assessment. In a regression analysis, perceived hole size before the retention test predicted retention performance (i.e., learning), $F\,(1,\,28) = 4.09$, $p = 0.053$, standardized regression coefficient = $-0.357$, explaining 9.6% of the adjusted variance. Perceived hole size before the retention phase, in turn, was predicted by self-efficacy after practice (standardized regression coefficient = 0.593) and by perceived hole size prior to practice (standardized regression coefficient = 0.282), $F\,(2,\,27) = 16.19$, $p < 0.0001$, Adjusted $R^2 = 0.512$. Retention performance was not directly predicted by self-efficacy.

## 4. Discussion

The Ebbinghaus illusion was effective in the present study. Children's perception of hole size was significantly different when it was surrounded by smaller versus larger circles. As a consequence, children's putting accuracy was different as well. Participants who perceived the target as larger putted more accurately than did those to whom the target appeared smaller. Importantly, this effect was not just temporary. That is, performance differences were not limited to the practice phase when the Ebbinghaus illusion was present (see also Witt et al., 2012; Wood et al., 2013), but were still seen after 2 days and with the illusion removed. On the retention test, the group that had practiced with a perceived larger target outperformed the group that had practiced with the perceived smaller target. Thus, the different practice conditions had a differential impact on learning. These results indicate that the effect first demonstrated by Chauvel et al. (2015) with adult learners generalizes to learning in children.

Perception of hole size, as determined by the size of the circles drawn by participants, was immediately affected by the visual illusion (i.e., before the practice phase), and that perception was essentially unchanged at the end of practice. Relative to the actual target size (10.4 cm), the average drawn circle was larger (11.5 cm) in the group with the perceived larger hole, and smaller in the group with the perceived smaller hole (9.3 cm). Interestingly, perception of target size was still significantly different between groups two days later, before the retention test, even though the visual illusion was no longer present. (This differs from the Chauvel et al., 2015, study with adults in whom those differences were smaller and no longer significant after a one-day retention interval.) Thus, even though children's perception of circle size, especially in younger children, has been shown to be less affected by the Ebbinghaus illusion than that of adults (Doherty et al., 2010), in the present study with 10–11-year olds, the visual illusion resulted in persisting differences in perceived hole size.

Perceived hole size did not predict putting accuracy during the practice phase as it did in Wood et al.'s (2013) study (and in Chauvel et al.'s, 2015, study). Yet, the visual illusions present during practice were related to the perception of hole size two days later before the retention test, or at least the memory of the circles they had drawn previously. Even though the illusions were removed on that day, perceived hole size before the retention test predicted retention test performance. These findings – no relation between perceived hole size and performance when the illusion was present (practice), but a relation when the illusion was not present (retention) – do not preclude possible action-planning differences resulting from differences in perception, as proposed by Wood and colleagues. Yet, a perhaps more plausible explanation for the present findings is that the illusionary target size affected the perceived difficulty of the task and thus participants' expectations for rewarding future performance outcomes (Balcetis & Dunning, 2010; Stern, Cole, Gollwitzer, Oettingen, & Balcetis, 2013). Enhanced expectancies for future performance have been shown to lead to superior learning and are therefore a key factor in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). For instance, in one interesting study, Trempe et al. (2012), using a visuomotor adaptation task, demonstrated that success experience during practice resulting from a perceived "easy" task goal promoted memory consolidation (i.e., learning). Relative to a perceived "difficult" task goal, the perceived easy goal led to enhanced test performance 24 h later. (No such group differences were seen after a 5-min delay, that is, before memory consolidation effects could manifest themselves.) By boosting the reactivation of memories during rest (Ewell & Leutgeb, 2014), reward-related dopamine contributes to the consolidation of motor memories when present during and after motor practice (Sugawara, Tanaka, Okazaki, Watanabe, & Sadato, 2012; Wise, 2004). The OPTIMAL theory makes the prediction that practice conditions that enhance performers' expectancies facilitate motor learning by making dopamine available for online and offline memory consolidation and neuroplastic changes, such as structural and functional connectivity. The enhanced expectations resulting from the perceived larger hole and their temporal pairing with practice may have led to the more effective retention performance seen in participants who practiced with the apparently larger rather than smaller hole (Wulf & Lewthwaite, 2016). Thus, the present findings provide support for this OPTIMAL theory prediction.

Similar to the previous study with adults (Chauvel et al., 2015), self-efficacy differed as a function of perceived hole size. The group with the perceived larger hole reported higher self-efficacy at the end of the practice phase than did the group with the perceived smaller hole. While self-efficacy was initially similar for both groups, it increased across practice in the group with the perceived larger hole, and decreased in the group with the perceived smaller hole. That is, the perception of hole size did not immediately affect learners' confidence in being able to hit the target. Rather performance impacts resulting from the perceived hole size may have contributed to the increasing group differences in self-efficacy. Alternatively, perhaps explicit insights (i.e., self-efficacy as measured in this study) may have gradually matched implicit ones (perceived hole size). Interestingly, self-efficacy at the end of practice was a moderately strong predictor of the perceived hole size prior to subsequent retention performance, as was the initial perception of hole size following the experimental manipulation.

The present findings suggest that the performance of motor skills that involve targets (e.g., shooting, archery, dart throwing) can be enhanced by illusions that make the target appear larger. It is particularly interesting that this effect has been shown to be lasting and generalizable to situations in which the illusion is removed. Nevertheless, many open questions remain. Future research is necessary to determine, for example, how long the effect persists after the end of practice, whether the findings generalize to different tasks, or to what extent they depend on the performers' level of expertise or awareness of the illusion. However, it should be noted that the teacher-learner relationships may not be well served by the deception associated with illusions and that other methods to affect the perceived difficulty of tasks would appear helpful (e. g., Palmer et al., 2016). These include helping learners define task success commensurate with their skill, in order to provide the expectation of positive experience or outcomes that can boost learning (Wulf & Lewthwaite, 2016).

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