Psychological Research
https://doi.org/10.1007/s00426-020-01298-0

ORIGINAL ARTICLE

Ebbinghaus visual illusion: no robust influence on novice golf-putting performance

François Maquestiaux[1,2] · Mahé Arexis[1] · Guillaume Chauvel[3] · Josepha Ladoy[1] · Pierrick Boyer[1] · Marie Mazerolle[1]

Received: 14 December 2019 / Accepted: 25 January 2020

Abstract

Do visual illusions reliably improve sports performance? To address this issue, we used procedures inspired by Witt et al. (Psychol Sci 23:397–399, 2012) seminal study, which reported that putting on a miniature golf course was positively influenced by an increase in apparent hole size induced by the Ebbinghaus visual illusion. Because Witt et al.'s motor task—putting golf balls toward a hole from the distance of 3.5 m—was impossible for participants who were novices in golf (Experiment 1a), we decided to shorten the putting distance (i.e., 2 m instead of 3.5 m) in Experiment 1b. Otherwise, this second experiment closely followed every other aspects of Witt et al.'s procedure (i.e., one small or one standard golf hole surrounded by a ring of small or large circles). However, this attempt to replicate Witt et al.'s findings failed: the Ebbinghaus illusion significantly influenced neither hole perception nor putting performance. In two subsequent experiments, we encouraged the emergence of the effect of the illusion by simultaneously presenting both versions of the illusion on the mat. This major adaptation successfully modified the perceived size of the hole but had no impact on putting performance (Experiment 2), even when the putting task was made easier by shortening the putting distance to only 1 m (Experiment 3). In the absence of detectable effects of the illusion on putting performance, we conclude that the effects of visual illusions on novice sports performance do not represent a robust phenomenon.

Ebbinghaus visual illusion: no robust influence on novice golf-putting performance

The Ebbinghaus illusion (Ebbinghaus, 1902), also called the Titchener illusion, is often taught to students in introductory psychology classes. This visual illusion is spectacular: when presented with two identical circles, an observer generally perceives the one surrounded by small circles as being larger than the one surrounded by large circles. A circle can appear as much as 10–20% larger, or smaller, than it actually is (Mruczek, Blair, Strother, & Caplovitz, 2015). In 2012, Witt, Linkenauger, and Proffitt demonstrated that the powerful effect of the Ebbinghaus illusion is not limited to perception, but also extends to sports performance: golf-putting performance was better when a hole looked bigger than it really was (due to the presence of small surrounding circles) than when it looked smaller (due to the presence of large surrounding circles). In the sections below, we will describe Witt et al.'s (2012) study in detail and present the reasons that cause us to doubt the robustness of their findings. We will also present subsequent studies inspired by Witt et al. (Cañal-Bruland, van der Meer, & Moerman, 2016; Chauvel, Wulf, & Maquestiaux, 2015; Wood, Wine, & Wilson, 2013). In the current study, we wished to establish whether the effects of modified perception on sports performance represent a robust phenomenon.

Witt, Linkenauger, and Proffitt's (2012) study

Witt et al. (2012) evaluated whether putting performance is influenced by the Ebbinghaus visual illusion. In their experiment, 36 participants were asked to make 10 putts toward one hole present on a mat. The hole was either small

Raw data are publicly available at https://sites.google.com/site/frmaquestiaux/home/data-sharing.

✉ François Maquestiaux
francois.maquestiaux@univ-fcomte.fr

1 Laboratoire de Psychologie and Maison des Sciences de l'Homme et de l'Environnement (MSHE) Ledoux, Université de Franche-Comté, UFR SLHS, 30 Rue Mégevand, 25030 Besançon, France

2 Institut Universitaire de France, Paris, France

3 Laboratoire LIRTES, Université Paris-Est, Créteil, France

Published online: 14 February 2020

(5.08 cm in diameter) or standard in size (10.16 cm in diameter) and was surrounded by a ring of 11 small circles (to make it look larger) or a ring of 5 large circles (to make it look smaller). To evaluate the perceived size of the hole in each of the four conditions, "participants stood at a computer approximately 1.7 m from the hole and used MS Paint to draw a circle that matched the hole's size" (Witt et al., p. 397). In the case of the standard hole, manipulating the surround failed to create an Ebbinghaus visual illusion and no effect of the surround on putting performance was detected. For the small hole, however, the illusion influenced the perceived size and this visual effect was accompanied by an effect on putting, with the mean number of successful putts being higher when the hole looked bigger than when it looked smaller (1.75 vs. 0.9 successful putts out of 10; Cohen's *d*: 0.54). Witt et al. interpreted their findings as supporting the view that there is a genuine relationship between perceived size and sports performance.

Witt et al.'s (2012) interpretation possibly holds when considering the small hole condition (i.e., when the Ebbinghaus illusion influenced putting) and provided that one accepts that putting golf balls toward a non-standard hole is representative of the skill exhibited on real golf courses. However, it does not hold in the case of the standard hole condition because no Ebbinghaus illusion effect on perception occurred in this condition and Witt et al. were unable to evaluate the effects on putting. Another aspect of their data weakens the robustness of the reported phenomenon: the analyses were conducted with a reduced sample of participants (i.e., 32 instead of 36 in the initial sample) because four participants were considered as outliers, "as determined by box-plot graphs" (p. 397). It may therefore be the case that the criterion for statistical significance was met in the small hole condition only due to chance (for a more detailed discussion, see, e.g., Luck & Gaspelin, 2017). Finally, it is worthy of note that Witt et al. conducted two independent-samples *t* tests (one for each hole size condition), rather than a two-way ANOVA with hole size (small or standard) and surround type (small or large circles) as within-subjects factors, thus preventing an evaluation of the general impact of the illusion on golf putting.

Subsequent studies

Witt et al.'s (2012) study has inspired a number of studies that have addressed a variety of new questions. For instance, Wood et al. (2013) explored the potential mediating roles of attention and action planning in Witt et al.'s findings. In one experiment, low-skilled golfers (with a mean golfing experience of slightly less than two years) putted toward a small hole (5 cm in diameter) from a distance of 1.75 m. It was found that the quiet eye duration (i.e., the time during which the putter fixates the target without moving the eyes) played a mediating role between perceived target size and putting accuracy.

Chauvel et al. (2015) examined whether the Ebbinghaus visual illusion can influence motor-skill learning. To do so, they first asked participants to practice with 5 blocks of 10 putts each, from the distance of 2 m, toward a horizontal circular target that resembled a standard golf hole. Half of the participants saw the target surrounded by a ring of small circles and the other half saw it surrounded by a ring of large circles. The results showed that, during practice, the group assigned to the condition with small surrounding circles perceived the target as larger than the group assigned to the condition with large surrounding circles. This difference between the two groups is seemingly consistent with the effect of the Ebbinghaus visual illusion. In the first three blocks, the two groups exhibited a comparable level of motor accuracy, thus suggesting that there was no effect of the Ebbinghaus illusion on golf-putting performance. However, in the last two blocks, the group assigned to the condition with small surrounding circles outperformed the group assigned to the condition with large surrounding circles, thus suggesting that the Ebbinghaus illusion did have an effect. Interestingly, this advantage persisted a day later, even though the surrounding circles had been removed.

In another subsequent study, Cañal-Bruland et al. (2016) used marble shooting to examine whether the Ebbinghaus illusion influences motor learning. The results showed that practicing marble shooting with a target that appeared smaller (i.e., surrounded by large circles) actually improved motor performance compared to practicing it with a target that appeared larger (i.e., surrounded by small circles). Cañal-Bruland et al. interpreted this finding as being consistent with the motor control and learning view, according to which "facing a smaller appearing target should enforce performers to be more precise" (p. 385). Even though Cañal-Bruland et al.'s findings question the effect direction reported by Witt et al. (2012) and Chauvel et al. (2013) regarding the impact of visual illusions on motor performance, marble shooting and golf putting are undoubtedly two very different motor skills, thus rendering any attempt to identify the key factors responsible for the divergent findings very speculative.

The current study

In their seminal study, Witt et al. (2012) reported that the Ebbinghaus visual illusion can improve putting performance. However, this finding applied only to the small hole condition (no improvement was detected when the golf hole was of standard size) and was observed only in a reduced sample of participants (data from 4 participants were excluded before carrying out the analyses). Furthermore, Chauvel et al.'s (2015) study also does not provide a solid basis against which to assess whether the illusion really improves golf putting. The reason is that this study manipulated the Ebbinghaus visual illusion as a between-subjects factor, thus making it impossible to distinguish whether the difference in perceived size really stems from an effect of the illusion per se or merely reflects the presence of individual differences between the two groups of participants (i.e., the group only exposed to a ring of small circles and the group only exposed to a ring of large circles; for a demonstration of large individual differences in the magnitude of visual illusions such as the Ebbinghaus illusion, see Grzeckowski, Clarke, Francis, Mast, & Hertzog, 2017). We therefore wished, in the present study, to evaluate the robustness of the findings reported in Witt et al.'s study.

Experiments 1a and 1b were attempts to replicate the study by Witt et al. (2012). Although it was tempting to perform a direct replication (e.g., Pashler & Harris, 2012), Experiment 1a demonstrated that closely copying the methods employed by Witt et al., in particular using the exact same motor task (i.e., putting golf balls toward a hole from the putting distance of 3.5 m), was doomed to failure. Therefore, in Experiment 1b, we used a shorter putting distance (i.e., 2 m instead of 3.5 m) to make the putting task achievable, while keeping every other aspect of Witt et al.'s procedure almost unchanged (i.e., presentation of a single hole on the mat, use of a small or standard hole surrounded by a ring of small or large circles). In Experiments 2 and 3, the two versions of the Ebbinghaus visual illusion were presented simultaneously side-by-side on the mat. This major adaptation (compared to the presentation of only one condition of the illusion in Experiment 1b and in Witt et al.'s study) placed our participants in a situation that allowed them to directly compare the two versions of the visual illusion. The aim of this simultaneous presentation was to augment their experience of the effects of the Ebbinghaus visual illusion on perception. While the putting distance was 2 m in Experiment 2, it was reduced to only 1 m in Experiment 3 to boost the success rate and to increase the likelihood that the participants' motor plans would be reflected in their putting performance.

Whereas Witt et al. analyzed the results of 32 participants, we tested at least 40 participants in each of our three experiments, in which we manipulated the apparent size of the hole (i.e., Experiments 1b, 2, and 3) as a within-subjects factor, thus increasing our chances of detecting an effect of the illusion on golf putting.

Experiment 1a

We wished to follow Witt et al.'s (2012) exact procedure, which consisted of asking participants to putt 10 golf balls toward a hole on a miniature putting green, from a distance of 3.5 m, in 4 distinct conditions: small hole surrounded by small circles, small hole surrounded by large circles, standard hole surrounded by small circles, and standard hole surrounded by large circles. However, as a first step, we carried out a systematic evaluation of the validity of Witt et al.'s motor task (without surrounding circles). To do this, we asked 24 undergraduate students to putt golf balls toward a hole that was small or standard in size from the distance of 3.5 m. Even though Witt et al.'s participants could perform this motor task, our decision to test its validity was prompted by our own experience with golf putting (none of us—the authors—was able to put even one ball out of 10 attempts into a small hole from 3.5 m). This decision also echoes the point made by Ray (1999) in his textbook entitled *Methods: Toward a science of behavior and experience*, when he wrote: "The task of choosing good measures is yours, although you may be greatly aided by previously published studies, as well as by your own experience in experimentation" (p. 61).

Because Witt et al. made no mention of the level of expertise of their participants, we assumed that they had no expertise in golf putting.[1] Based on this assumption, the participants included in the present experiment were all novices in golf.

Method

Participants

Twenty-four undergraduate students with no previous golfing experience were recruited from the University de Franche-Comté in Besançon, France in exchange for a partial course credit.

Material

The golf-putting mat (478 cm long by 239 cm wide) was a smooth, level artificial indoor green. Only one hole was presented on the mat. The hole size was either small (5.5 cm in diameter) or standard (11 cm in diameter).

Procedure

The participants performed ten putts in succession in each of the two hole-size conditions, with no surrounding circles. The order was counterbalanced.

[1] This assumption was confirmed by an informal conversation between Jessica Witt and the first author of the current article during the 2017 Psychonomics meeting in Vancouver, British Columbia, Canada.

Results

The mean number of successful putts was virtually zero for the small hole ($M = 0.04$ putts, SD = 0.20 putts) but was higher for the standard hole ($M = 0.79$ putts, SD = 1.02 putts), $t(23) = -3.72$, $p < 0.01$.

Discussion

The aim of Experiment 1a was to evaluate the validity of Witt et al.'s (2012) motor task. Using Witt et al.'s putting distance of 3.5 m and slightly larger holes (5.5 cm vs. 5.08 cm for the small hole; 11 cm vs. 10.16 cm for the standard hole), the novice participants performed poorly. Their mean number of successful putts was virtually zero with the small hole. If we consider the participants individually, 23 of them (out of 24) were unable to putt even one ball into the small hole, with only one participant sinking one putt out of ten trials. Based on these results, we consider that putting toward a small hole from the distance of 3.5 m is not a valid task for evaluating the effects of the Ebbinghaus illusion on putting, at least for novice participants. This inability is striking when we consider the performance of Witt et al.'s participants when putting toward a slightly smaller small hole from the same distance (i.e., 0.9 successful putts with a ring of large surrounding circles and 1.75 successful putts with a ring of small surrounding circles[2]).

When the hole was of standard size, the novice participants performed better but nonetheless exhibited rather poor motor performances of less than 1 successful putt (out of 10 trials) on average. If we consider the participants individually, 12 of them did not putt even one ball into the standard hole, 7 of them achieved one successful putt, 4 of them achieved 2 successful putts, and one of them made 4 successful putts. In sharp contrast, Witt et al.'s participants achieved an average of about 3.8 successful putts with a slightly smaller standard hole from the same distance.

Overall, the results of this preliminary experiment did not encourage us to consider performing a direct replication of Witt et al.'s (2012) study. Because the motor task appeared impossible for the vast majority of the participants when the hole was small, and also impossible for over half of them when the hole was of standard size, a direct replication would have been doomed from the start.

[2] These values are based on a visual inspection of Fig. 1 in Witt et al.'s (2012) article.

Experiment 1b

In this experiment, we closely followed Witt et al.'s (2012) procedure, except that we used a shorter putting distance of 2 m (instead of 3.5 m in Witt et al.). Novice participants were asked to putt 10 golf balls toward a hole on a miniature putting green in 4 distinct conditions: small hole surrounded by small circles, small hole surrounded by large circles, standard hole surrounded by small circles, and standard hole surrounded by large circles (see Fig. 1).

Method

Except where noted, the procedure was identical to that used in Experiment 1a.

Participants

Forty undergraduate students with no previous golfing experience were recruited from the University de Franche-Comté in Besançon in exchange for a partial course credit.

Material

A ring of 11 small black circles (3.5 cm in diameter) or 5 large black circles (28 cm in diameter) was projected downwards around the small or standard hole.

Procedure

The participants were asked to putt ten times in succession in each of the four conditions resulting from a factorial cross between hole size (small or standard) and surround type (small or large circles). The conditions were counterbalanced across participants. Before putting in each condition, the participants had to draw a circle in MS Paint that matched the apparent size of the target hole, while viewing it from the distance of 2 m.

Results

Figure 2 shows the results of Experiment 1b (top panels).

Perceived size of the hole

An analysis of variance was conducted on the perceived size of the hole (in cm), with hole size (small or standard) and surround type (small or large circles) as within-subjects variables. Overall, the participants perceived the small hole ($M = 3.53$ cm, SD = 1.08 cm) as being smaller than the standard hole ($M = 6.09$ cm, SD = 1.66 cm), $F(1, 39) = 200.70$, $p < 0.001$ ($\eta_p^2 = 0.84$). However, the Ebbinghaus visual

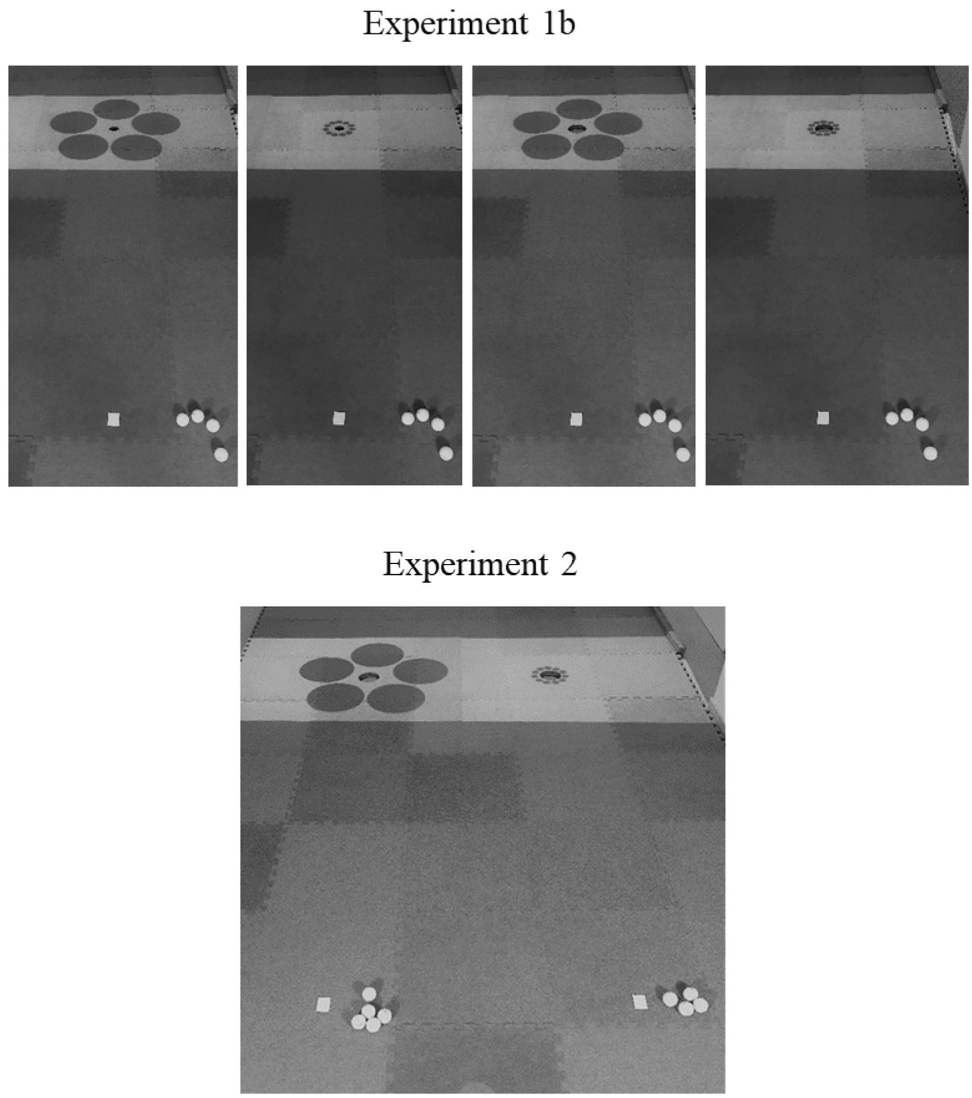

Fig. 1 Holes and surrounding circles used to create the Ebbinghaus visual illusion. In Experiment 1b, the single hole presented on the mat was either small or standard. In Experiment 2, two standard holes were presented simultaneously. The white rectangles indicate the location from which the participants putted

illusion did not influence the perceived size, $F(1, 39) < 1$ ($\eta_p^2 = 0.004$). Hole size and surround type did not interact, $F(1, 39) < 1$ ($\eta_p^2 = 0.02$).

The mean perceived size of the small hole was 3.47 cm (SD = 1.01 cm) with a small surround and 3.59 cm (SD = 1.16 cm) with a large surround. The mean perceived size of the standard hole was 6.12 cm (SD = 1.65 cm) with a small surround and 6.07 cm (SD = 1.70 cm) with a large surround.

Golf-putting performance

An analysis of variance was conducted on the mean number of successful putts (out of 10), with hole size and surround type as within-subjects variables. There were more successful putts when the hole was standard ($M = 2.14$ putts, SD = 1.60 putts) than when it was small ($M = 0.51$ putts, SD = 0.83 putts), $F(1, 39) = 71.18$, $p < 0.001$ ($\eta_p^2 = 0.65$). Neither the main effect of surround, $F(1, 39) < 1$ ($\eta_p^2 = 0.002$), nor the hole size x surround type interaction, $F(1, 39) < 1$ ($\eta_p^2 = 0.005$), were significant.

The mean number of successful putts toward the small hole was 0.53 putts (SD = 0.82 putts) with a small surround and 0.50 putts (SD = 0.85 putts) with a large surround. The mean number of successful putts toward the standard hole was 2.08 putts (SD = 1.75 putts) with a small surround and 2.20 putts (SD = 1.45 putts) with a large surround.

Discussion

This experiment closely followed Witt et al.'s (2012) procedure but with a shorter putting distance, thus permitting novice participants to succeed in the task, at least occasionally. However, we did not detect any significant effect of the surrounds on the perceived size of the hole, irrespective of whether it was small or standard. Similarly, Witt et al. also

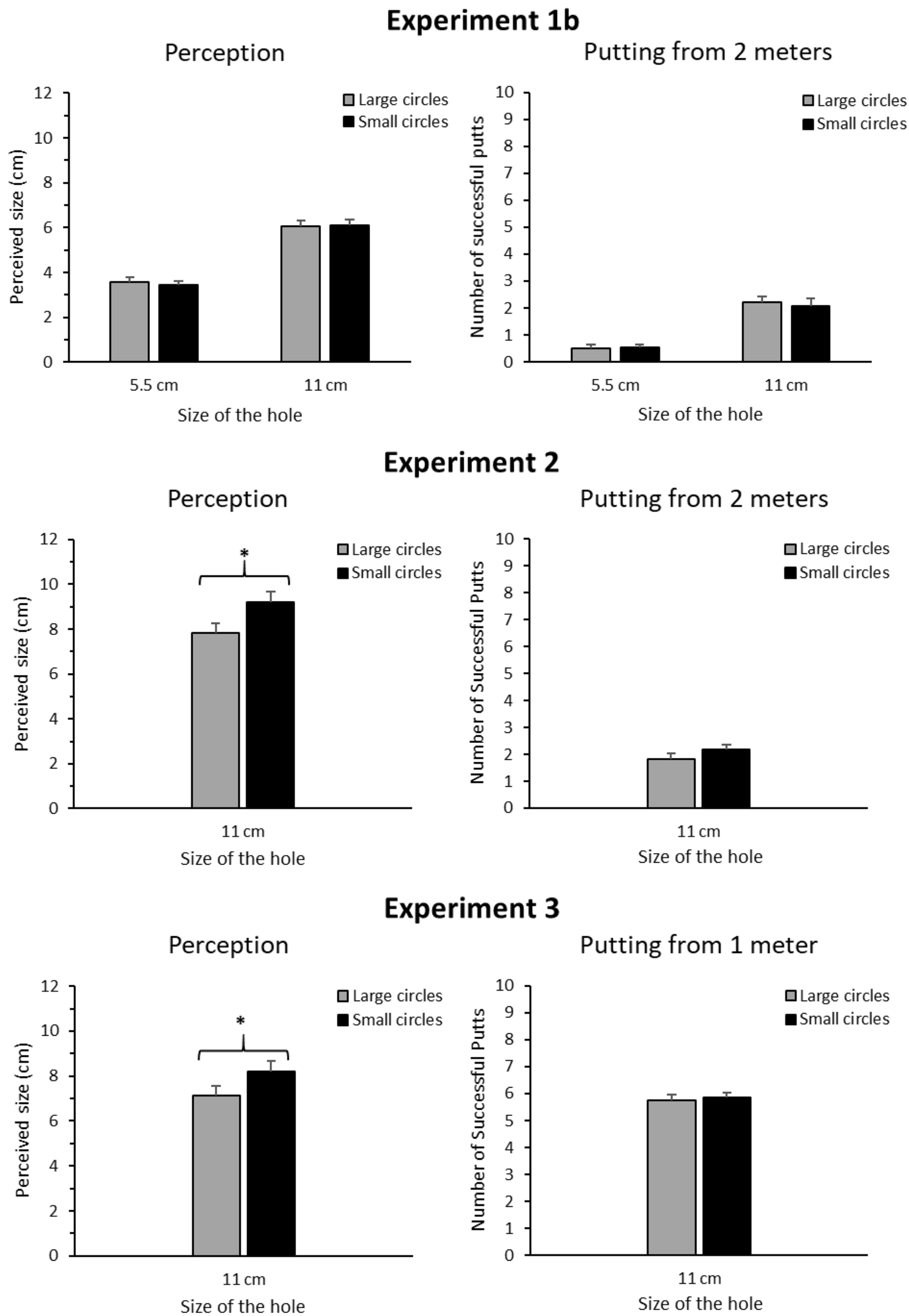

Fig. 2 Perceived size of the hole and mean number of successful putts as a function of the diameter of the hole (small, large) and of the size of the surrounding circles in Experiments 1b, 2, and 3. Error bars represent the standard error of the mean. $*p < 0.001$

did not detect any significant effect when the hole was of standard size. The failure to observe an Ebbinghaus illusion in the present study (as well as in Witt et al.'s study) is problematic since it does not make it possible to evaluate whether the visual illusion can influence golf putting. One explanation of this absence of illusion may be that the surrounding circles genuinely had no effect on perception. Alternatively, our size estimation procedure (drawing a circle that matched the apparent size of the hole) might not have been sufficiently sensitive. A third possibility is that presenting only one version of the Ebbinghaus visual illusion on the mat (as Witt et al. did) undermines the powerful effect of the illusion. Whatever the reasons why the Ebbinghaus illusion did not influence perception, Experiment 1b was not a good test for assessing the validity of Witt et al.'s findings.

It is important to highlight that the motor tasks were indisputably more difficult in Witt et al.'s experiment than in our Experiment 1b. For instance, Witt et al.'s (2012) participants putted from the distance of 3.5 m toward a 5.08-cm hole, whereas the participants in Experiment 1b putted from the distance of 2 m toward a 5.5-cm hole. Despite this, the mean number of successful putts was larger for Witt et al.'s participants (0.9 successful putts with a large surround and 1.75 successful putts with a small surround) than for the novice participants in Experiment 1b (0.51 putts on average). This leads us to conjecture that, unlike our participants, Witt et al.'s participants were actually quite skilled at putting (even though Witt et al. appear not to have noticed this).

The next experiments were designed to encourage the emergence of effects of the Ebbinghaus illusion on visual perception. To do this, we presented both versions side-by-side (as recommended by most psychology textbooks) to test the robustness of the effects of the illusion on putting.

Experiment 2

In this experiment, we presented the two holes simultaneously on the mat, with one surrounded by small circles and the other by large circles (see Fig. 1, bottom panel). By doing so, we wished to place our participants in a situation that allowed them to compare the two versions of the visual illusion presented simultaneously, thus augmenting their experience of the visual illusion. Because of the poor performance in the small hole condition observed in Experiment 1 (less than 1 successful putt on average), we focused on the standard hole to increase the sensitivity of the dependent variable.

Method

Except where noted, the procedure was the same as that used in Experiment 1b.

Participants

Forty-two new undergraduate students participated.

Material

Two standard holes were positioned side-by-side on the putting mat, separated by a distance of 95 cm. One hole was surrounded by a ring of 11 small circles and the other by a ring of 5 large circles, displayed by means of two downward-facing projectors.

Procedure

The participants performed two blocks of putts toward each of the two holes in each of the two illusion conditions, with 10 putts per block being made in succession at a distance of 2 m. The conditions were counterbalanced across participants using an ABBA or BAAB presentation order. Before performing each of the first two blocks, the participants were asked how the sizes of the two holes compared with one another. They then had to evaluate the size of the hole by drawing a circle in MS Paint while viewing the hole at a distance of 2 m.

Results

The results of Experiment 2 are shown in Fig. 2 (intermediate panels).

Perceived size of the hole

A one-tailed paired-samples t test was conducted with surround type as a within-subjects variable. In line with the Ebbinghaus visual illusion, the standard hole was perceived as larger when surrounded by small circles ($M = 9.19$ cm, SD = 3.13 cm) than by large circles ($M = 7.82$ cm, SD = 2.89 cm), $t(41) = 6.74$, $p < 0.001$, Cohen's $d = 1.040$.

Golf-putting performance

A one-tailed paired-samples t test was conducted with surround type as a within-subjects variable. The mean number of successful putts did not differ significantly when the hole was perceived as larger ($M = 2.18$ putts, SD = 1.28 putts) than when it was perceived as smaller ($M = 1.83$ putts, SD = 1.35 putts), $t(41) = 1.59$, $p = 0.12$, Cohen's $d = 0.245$. According to the null hypothesis (H_0), there should be no difference in putting performance between the two types of surrounds. However, according to the alternative hypothesis (H_1), putting performance should be influenced by the type of surround. To ascertain the absence or presence of an effect of the type of surround on putting performance, we conducted a Bayesian paired-samples *t* test (using the open-source statistical software JASP; JASP Team, 2019) and found, more specifically, $BF_{01} = 1.882$, which means that the data are approximately 2 times more likely to occur under H_0 than under H_1. According to a standard scale of interpretation (Jeffreys, 1961), Bayes factors between 1 and 3 are considered to be weak or inconclusive.

Discussion

The simultaneous presentation of the two visual displays successfully modified the apparent size of the hole: it was perceived as being 14.91% larger on average when surrounded by small than by large circles and, indeed, 88.1% of the participants said that the hole looked bigger when surrounded by small than by large circles. Even though the Ebbinghaus visual illusion (i.e., an effect on perception) was indeed observed, it did not significantly influence putting performance. However, the Bayesian analysis suggests that we cannot definitively conclude that the visual illusion has no effect on putting performance. The experimental design may have made it impossible to discriminate between H_0 and H_1, perhaps because of the floor effect found in putting performance. Indeed, the number of successful putts was relatively low: out of 10 trials, the mean number of successful putts was only 1.83 with a surround of large circles or 2.18 with a surround of small circles.

Experiment 3

The floor effect on motor performance observed in the previous experiment may have prevented the effect of the Ebbinghaus illusion from being reflected to any great extent in action. For instance, it is possible that the illusion caused the participants to modify their motor planning but that this was not reflected in their motor output (due to the difficulty of the task as reflected by the floor effect), with the result that the phenomenon was not observed. Alternatively, poor motor performance may have obscured any effect of increased confidence induced by the Ebbinghaus illusion, which would have increased the apparent size of the hole, thus making the aiming task subjectively easier (for empirical evidence consistent with this idea, see Chauvel et al., 2015; for a meta-analysis showing the relative importance of the level of confidence in the relationship between perception and action, see Woodman & Hardy, 2003). We therefore conducted another experiment similar to Experiment 2 but with the much shorter putting distance of 1 m (instead of 2 m in Experiment 2), thus allowing our participants to achieve better putting performances.

Method

The procedure was the same as that used in Experiment 2, except that forty-three new undergraduate students participated and were asked to putt from a distance of 1 m. They also had to evaluate the size of the hole while viewing it at a distance of 1 m.

Results

The results of Experiment 3 are shown in Fig. 2 (bottom panels).

Perceived size of the hole

In line with the Ebbinghaus visual illusion, the standard hole was perceived as being larger when surrounded by small circles ($M = 8.18$ cm, $SD = 3.29$ cm) than by large circles ($M = 7.13$ cm, $SD = 3.16$ cm), $t(42) = 5.31$, $p < 0.001$, Cohen's $d = 0.810$.

Golf-putting performance

The mean number of successful putts did not differ significantly when the hole was perceived as larger ($M = 5.84$ putts, $SD = 1.71$ putts) than when it was perceived as smaller ($M = 5.74$ putts, $SD = 1.45$ putts), $t(42) < 1$, Cohen's $d = 0.055$. The Bayes factor tends to favor H_0; more specifically, $BF_{01} = 5.696$, which means that the data are 5.7 times more likely to occur under H_0 than under H_1. According to a standard scale of interpretation (Jeffreys, 1961), this indicates moderate evidence in favor of H_0.

Discussion

As in Experiment 2, we found an effect of the Ebbinghaus visual illusion on perception. The simultaneous presentation of the two versions of the illusion modified the apparent size of the hole: it was perceived as being 12.8% larger on average when surrounded by small than by large circles and, indeed, 76.7% of the participants said that the hole looked bigger when surrounded by small than by large circles. We also made it easier for our participants to succeed in the putting task by reducing the putting distance to 1 m. Despite this, the illusion had no detectable influence on putting performance. A Bayesian analysis provides evidence that the data are 5.7 times more likely to occur under the null hypothesis (i.e., the Ebbinghaus illusion has no effect on golf putting) than under the alternative hypothesis (i.e., the illusion has an effect on golf putting).

General discussion

The aim of the present study was to evaluate whether the beneficial effects of the Ebbinghaus visual illusion on a ballistic sports action (Chauvel et al., 2015; Witt et al., 2012; Wood et al., 2013; for beneficial effects but in the opposite direction with a marble-shooting task, see Cañal-Bruland et al., 2016) are a robust phenomenon. As demonstrated in Experiment 1a, the motor task used by Witt et al.—putting toward a hole from the distance of 3.5 m—was not a viable task for participants with no golf expertise (i.e., they were rarely able to sink even a single putt out of 10 attempts from that long distance). We therefore shortened the putting distance in Experiment 1b, while closely following Witt et al.'s method (i.e., same number of trials per condition, presentation of only one hole at time, surrounding circles of the same diameter) in an attempt to replicate their findings. The results were straightforward: the small or large surrounding circles influenced neither perception nor putting. In Experiment 2, we simultaneously displayed the two versions of the illusion around standard holes. This change did indeed render the participants sensitive to the Ebbinghaus visual illusion. However, the illusion had no influence on putting. In Experiment 3, we used an even easier task (i.e., putting toward standard holes from the distance of 1 m) to increase the participants' motor performance. Once again, however, no detectable effect of the visual illusion on putting was observed.

Although we sampled a range of different conditions across three experiments (Experiment 1b, Experiment 2, and Experiment 3)—displaying one hole or two holes on the putting mat, using a small or standard hole size, asking participants to putt from 2 m vs. 1 m—the results of all three suggest that surrounding the hole with small circles (to make it appear bigger) does not influence golf putting compared to surrounding it with larger circles (to make it appear smaller). When the data from all three experiments (combined $N = 125$) were pooled, the 95% confidence interval for the "benefit" of the visual illusion on golf-putting performance (i.e., the difference in the number of successful putts between the conditions with the small vs. large surrounding circles) was 0.09 ± 0.23. This means that we can rule out a small benefit. We also note that the Bayesian analyses carried out in the two experiments demonstrating an effect of the illusion on perception (i.e., Experiments 2 and 3) tend to provide some support for the null hypothesis (i.e., no effect of the illusion on putting performance). This was more obvious in Experiment 3 than in Experiment 2, which may have been impacted by a floor effect on putting performance. Overall, in novice participants, we can safely conclude that the Ebbinghaus visual illusion (applied to a golf hole) does not appear to have any robust influence on putting. Future studies may attempt to determine whether the observed dissociation between perception and action can be generalized to other types of targets (e.g., smaller golf holes) and ballistic actions (e.g., dart throwing).

It should be noted that the present study is informative with regard to the boundary conditions that permit the emergence vs. non-emergence of the Ebbinghaus visual illusion in the context of a miniature putting green. More specifically, the illusion emerged when the two conditions of the visual illusion were presented simultaneously on the mat (i.e., a hole surrounded by a ring of small circles and a hole surrounded by a ring of large circles; see Experiments 2 and 3). However, the illusion did not emerge when only one condition was presented on the mat (Experiment 1b). Witt et al.'s study (2012), in which only one condition was presented on the map, also failed to reveal any influence on the perceived size of the standard golf hole. In short, the present study strongly suggests that the Ebbinghaus visual illusion is most likely to occur when the two conditions of the illusion are displayed simultaneously on the mat.

Relationship with previous studies on visual illusions and ballistic actions

The study by Witt et al. (2012) inspired subsequent studies that have yielded conflicting results, with some reporting evidence consistent with effects of the Ebbinghaus visual illusion on putting (Chauvel et al., 2015; Wood et al., 2013), whereas another, which used a marble-shooting task, reported effects in the opposite direction (Cañal-Bruland et al., 2016). What these studies have in common is that their participants were quite experienced in performing the motor tasks. They either had to learn to perform a ballistic action in a single visual illusion condition by practicing it (Cañal-Bruland et al., 2016; Chauvel et al., 2015) or were low-skilled golfers (Wood et al., 2013). The level of expertise appears to be an important difference between previous studies and the present study, in which novice participants made only a few putts in each experimental condition (at most 10 putts in Experiment 1a or at most 20 putts in Experiments 2–3). One possible explanation of the discrepancy between the findings from the present study (i.e., no effects of the illusion on putting) and those reported by previous studies (i.e., effects of the illusion on putting) is that novice performers may not hold the images of the visual scene in their minds as well as expert golfers while executing the putt. It is possible that their greater reliance on attention to perform the golf-putting task (Chauvel et al., 2012; Chauvel, Maquestiaux, Ruthruff, Didierjean, & Hartley, 2013; Masters, 1992; Maxwell, Masters, Kerr, & Weedon, 2001) reduced the activation of the relevant visual representations (e.g., the hole and the surrounding circles) in working memory, thus causing these representations to decay, or even to disappear. Therefore, the illusion would have no effect on putting in novice performers (as in the present study) but would influence putting in the more experienced performers who took part in the previous studies (i.e., Chauvel et al., 2015; Wood et al., 2013).

Because self-efficacy can mediate motor learning (e.g., Stevens, Anderson, O'Dwyer, & Williams, 2012), another possibility is that practice increases the level of self-efficacy when the Ebbinghaus visual illusion is favorable but not (or does so only to a lesser extent) when it is unfavorable. This increase may further reduce the intrusion of explicit processes that disrupt movement in the favorable illusion condition but not in the unfavorable one (Chauvel et al., 2012). However, it is possible that the level of self-efficacy in the novice participants in the present study was such that they were not sensitive to the changes in the apparent size of the hole and that, consequently, the visual illusion had no influence on their motor performance. Clearly, methodological differences (e.g., amount of practice or experience, golf putting vs. marble shooting) make it difficult to draw comparisons between previous studies and the present one. At this point, we can safely claim that, for participants with very low levels of practice, the Ebbinghaus visual illusion does not robustly influence golf putting. Future studies are needed to investigate whether an influence of the Ebbinghaus illusion on golf putting can be found in expert participants who, by definition, predominantly rely on automatic procedures and procedural knowledge to perform the motor skill.

Implications for theory and practice

The theoretical implication of the present study is that, in the case of ballistic actions performed by novice participants, vision-for-perception and vision-for-action appear to be functionally dissociated. This dissociation, found with an unskilled ballistic action, is seemingly opposite to the pattern found with visually-guided actions such as grasping, where visual illusions influence unskilled actions but have no effect on skilled actions (Gonzalez, Ganel, Whitwell, Morrissey, & Goodale, 2008). According to Goodale and Milner's (1992), two-visual-system model of perception and action, skilled actions rely on specialized visuomotor mechanisms that are unaffected by visual illusions, in contrast to unskilled actions, which are less likely to be controlled by such specialized mechanisms. When considering the present findings with unskilled participants (i.e., no robust influence of the Ebbinghaus illusion on golf putting) and previous findings with more skilled participants (i.e., an influence of the illusion on golf putting; see Chauvel et al., 2015; Witt et al., 2012[3]; Wood et al., 2013), we conjecture that knowledge representation might be the key factor in explaining these discrepancies observed in the case of ballistic actions, such as golf putting. More specifically, unskilled participants may be unable to keep the representations of the target and the visual context active in working memory because most of their attentional resources are devoted to the processing of declarative knowledge (e.g., verbal rules on how to perform the task) and to the control of body movements. In contrast, more skilled participants may be able to actively maintain the representations of the visual scene (including that related to the surrounding circles) in working memory and integrate them in their motor plans. This is because movement generation and execution predominantly result from attention-free processes and procedural knowledge. This theoretical conjecture, which is consistent with previous studies that have reported a sizable influence of visual illusions on skilled actions such as grasping (Franz, Gegenfurtner, Bülthoff, & Fahle, 2000; Kopiske, Bruno, Hesse, Schenk, & Franz, 2016), needs be addressed in future studies.

One practical implication of the present study is that sportsmen, coaches and teachers should not rush to embrace training techniques that rely on the Ebbinghaus illusion to improve sports performance in novices, unless they are prepared to accept little or no benefit. Another practical implication is that, as teachers, we should now be more reluctant to assert that visual illusions definitively influence sports performance.

[3] As discussed in Experiment 1b, Witt et al.'s (2012) participants were somehow more skilled at putting than our participants.

Acknowledgements The authors would like to thank Florence Bailly and Julien Soichet for their help with Fig. 1.

Funding Financial support for this research was provided by an IUF Grant to François Maquestiaux.

Compliance with ethical standards

Conflict of interest Each of the six coauthors declare that she/he has no conflict of interest.

Ethical approval All the procedures performed in this study involving human participants were conducted in accordance with the standards of the Ethics Committee of the Université de Franche-Comté and with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

Cañal-Bruland, R., van der Meer, Y., & Moerman, J. (2016). Can visual illusions be used to facilitate sport skill learning? *Journal of Motor Behavior, 48*, 385–389.

Chauvel, G., Maquestiaux, F., Hartley, A. A., Joubert, S., Didierjean, A., & Masters, R. W. S. (2012). Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: evidence from golf putting. *Quarterly Journal of Experimental Psychology, 65*, 25–38.

Chauvel, G., Maquestiaux, F., Ruthruff, E., Didierjean, A., & Hartley, A. A. (2013). Novice motor performance: Better not to verbalize. *Psychonomic Bulletin & Review, 20*, 177–183.

Chauvel, G., Wulf, G., & Maquestiaux, F. (2015). Visual illusions can facilitate sport skill learning. *Psychonomic Bulletin & Review, 22*, 717–721.

Ebbinghaus, H. (1902). *Grundzüge der Psychologie volumes I and II*. Leipzig: Verlag von Viet & Co.

Franz, V. H., Gegenfurtner, K. R., Bülthoff, H. N., & Fahle, M. (2000). Grasping visual illusions: No evidence for a dissociation between perception and action. *Psychological Science, 11*, 20–25.

Gonzalez, C. L. R., Ganel, T., Whitwell, R. L., Morrissey, B., & Goodale, M. A. (2008). Practice makes perfect, but only with the right hand: Sensitivity to perceptual illusions with awkward grasps decreases with practice in the right but not the left hand. *Neuropsychologia, 46*, 624–631.

Goodale, M. A., & Milner, D. A. (1992). Separate pathways for perception and action. *Trends in Neurosciences, 15*, 20–25.

Grzeczkowski, L., Clarke, A. M., Francis, G., Mast, F. W., & Herzog, M. H. (2017). About individual differences in vision. *Vision Research, 141*, 282–292.

JASP Team. (2019). *JASP (Version 0.10) [Computer software]*. Retrieved from https://jasp-stats.org/.

Jeffreys, H. (1961). *Theory of probability*. Oxford: Oxford University Press.

Kopiske, K. K., Bruno, N., Hesse, C., Schenk, T., & Franz, V. H. (2016). The functional subdivision of the visual brain: Is there a real illusion effect on action? A multi-lab replication study. *Cortex, 79*, 130–152.

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology, 54*, 146–157.

Masters, R. S. W. (1992). Knowledge, knerves, and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*, 343–358.

Maxwell, J. P., Masters, R. S. W., Keer, E., & Weedon, E. (2001). The implicit benefit of learning without errors. *Quarterly Journal of Experimental Psychology, 54A*, 1049–1068.

Mruczek, R. E. B., Blair, C. D., Strother, L., & Caplovitz, G. P. (2015). The dynamic Ebbinghaus: Motion dynamics greatly enhance the classical contextual size illusion. *Frontiers in Human Neuroscience, 9*, 77.

Pashler, H., & Harris, C. (2012). Is the replicability crisis overblown? Three arguments examined. *Perspectives on Psychological Science, 7*, 531–536.

Ray, W. J. (1999). *Methods: Toward a science of behavior and experience*. Belmont, CA: Wadsworth/Thomson Learning.

Stevens, D., Anderson, D. I., O'Dwyer, N. J., & Williams, A. M. (2012). Does self-efficacy mediate transfer effects in the learning of easy and difficult motor skills? *Consciousness and Cognition, 21*, 1122–1128.

Witt, J. K., Linkenauger, S. A., & Proffitt, D. R. (2012). Get me out of this slump! Visual illusions improve sports performance. *Psychological Science, 23*, 397–399.

Wood, G., Vine, S. J., & Wilson, M. R. (2013). The impact of visual illusions on perception, action planning, and motor performance. *Attention, Perception, & Psychophysics, 75*, 830–834.

Woodman, T., & Hardy, L. (2003). The relative impact of cognitive anxiety and self-confidence upon sports performance: A meta-analysis. *Journal of Sports Sciences, 21*, 443–457.