

Examining Action Effects in the Execution of a Skilled Soccer Kick by Using Erroneous Feedback

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ABSTRACT. The authors examined the role of action effects (i.e., ball trajectory) during the performance of a soccer kick. Participants were 20 expert players who kicked a ball over a height barrier toward a ground-level target. The authors occluded participants' vision of the ball trajectory after foot-to-ball contact. Participants in a 1st group received erroneous feedback from a video that showed a ball-trajectory apex approximately 75 cm lower than that of their actual kick, although the ball's landing position was unaltered. Participants in a 2nd group received correct video feedback of both the ball trajectory and the landing position. The erroneous-feedback group showed a significant bias toward higher ball trajectories than did the correct-feedback group. The authors conclude that performers at high levels of skill use the visual consequences of the action to plan and execute an action.

Keywords: expertise, feedback, soccer kick, vision

Researchers believe that during practice, performers acquire general and task-specific perception–action representations that guide the planning and production of actions (Adams, 1971; Proteau, 1992; Schmidt, 1975, 1976). Researchers have also found that the sensory effects of the action, especially those external to the performer, form an important part of those representations (e.g., Koch, Keller, & Prinz, 2004). In this study, we provided skilled performers with erroneous feedback to examine the importance of the visual effects of the action (i.e., ball trajectory).

In the motor learning literature, researchers have traditionally argued that extended practice leads to the development of intrinsic error-detection mechanisms that decrease the need for feedback about the visual consequences of the action (e.g., Adams, 1971; Schmidt, 1975). More recently, however, they have found that the visual consequences of the action continue to be important across practice and that extended practice leads to stronger associations between an

action and its ensuing consequences (e.g., Elsner & Hommel, 2001; Kunde, Hoffmann, & Zellmann, 2002; Kunde, Koch, & Hoffmann, 2004; Prinz, 1997). The aforementioned researchers have also shown that the association between an action and its effect or effects is bidirectional; that is, anticipation of an action's effect facilitates the initiation and execution of the action itself (i.e., reaction time [RT]; see Kunde et al., 2002). Therefore, one would expect that skilled performers who have amassed large amounts of practice on a task will have formed strong associations between an action and its visual effects. As a consequence, they may be more reliant on viewing those visual consequences for successful initiation and execution of an action than are their less skilled counterparts.

To examine the role of action effects in the execution of a whole-body action, Ford, Hodges, Huys, and Williams (2006) occluded ball-flight information as novice, intermediate, and skilled soccer players executed a soccer-kicking action. Novices and intermediate performers depended on visual information of the ball's trajectory. Their accuracy decreased when that information was removed, irrespective of the provision of knowledge of results (KR). In contrast, the removal of visual information did not affect the skilled performers' accuracy. Kinematic analysis showed, however, that across skill levels, performers displayed a more constrained, rigid movement in the absence of ball-flight information. The data showed a decreased role of visual information at higher levels of skill, at least in terms of accuracy in target attainment. However, one cannot conclude on the

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basis of those findings alone that ball-trajectory information does not form an important part of the movement representation at higher levels of skill.

That removal of visual action-effect information did not impair target accuracy on subsequent trials does not rule out the possibility that skilled performers anticipate visual action-effect information before the action. In the experiments that Kunde and colleagues (e.g., Kunde et al., 2002) have conducted, RT in response to an action-effect prime was the typical measure of performance. Those authors demonstrated that action-effect information is active before and during the initiation of a movement (i.e., in the planning of an action). Researchers may need other measures of performance to determine how performers use that visual information during the planning and execution of more complex skills. If skilled performers have well-developed representations of the visual effects, then they may be able to vividly image the expected effects for the upcoming action without the need to view those consequences to aid in the preparation of subsequent movements (Koch et al., 2004). That would be particularly true in cases in which accuracy is high and errors are low (see Ford et al., 2006).

Furthermore, in a sport such as soccer, performers must quickly gain from the environment visual information about the movements of other players and flight of the ball. There is evidence that performers who have amassed many hours of practice under such a variety of task and sensory conditions have developed the ability to adapt flexibly to the availability or occlusion of a particular source of sensory information (e.g., Bennett, Button, Kingsbury, & Davids, 1999; Soucy & Proteau, 2001; Williams, Weigelt, Harris, & Scott, 2002). Researchers have demonstrated experts' flexible use of various sources of sensory information for accurate performance in skills such as weightlifting (Bennett & Davids, 1995), juggling (Huys & Beek, 2002), and beam walking in gymnastics (Robertson, Collins, Elliott, & Starkes, 1994; Robertson & Elliott, 1996). Investigators have suggested that the removal or occlusion of information may change how the task or skill is normally performed (see Khan, Elliott, Coull, Chua, & Lyons, 2002). Thus, the better performance of experts than less skilled performers when an information source is unavailable may reflect flexibility in movement control rather than whether performers typically use a particular information source when it is available.

To more exactly determine whether performers use a particular type of information when it is still available, researchers have examined how perturbed or erroneous information influences performance. If such information plays an important role in skill execution, then one would expect target accuracy to move in the direction of any perturbations of the visual feedback during or after the movement. If, in the present experiment, ball-trajectory information is an integral part of the sensorimotor representation that guides performers' movements, then perturbing

ball-trajectory information from its actual or expected trajectory should result in (erroneous) changes in performers' planning and execution of subsequent movements in the direction of the perturbation.

By manipulating outcome-success feedback (i.e., KR), Buekers, Magill, and Hall (1992; see also Buekers & Magill, 1995; McNevin, Magill, & Buekers, 1994; Vanvenckenray, Buekers, Mendes, & Helsen, 1999) showed that novice participants use KR to aid in performance of their actions. They falsely told participants performing an anticipation-timing task that their timing error was 100 ms later than was actually the case. Participants subsequently demonstrated a bias of -100 ms in the direction of the erroneous KR during both (a) acquisition, when KR was provided, and (b) retention, when KR was removed. Furthermore, Buekers and Magill found similar results with experienced performers at that task. Researchers believed that experienced performers have developed the intrinsic capability to detect and correct their own errors (and hence not to rely on visual feedback for error-detection purposes). However, erroneous KR affected skilled performance, although that occurred only during and directly after the trials in which that information was presented.

Our aim in the present study was to examine the use of ball-trajectory information for the successful execution of a lower-limb skilled soccer-kicking action. We compared two separate groups who received either erroneous ball-flight information after each available trial or correct feedback on the same trials as the other group. The erroneous feedback was video footage of a ball trajectory that was 75 cm lower than the trajectory that the participant achieved on that trial. For both groups, we did not alter the landing position of the ball. Thus, we controlled for the effects of KR and hence accuracy in this task. If information about the visual consequences of the action is not important for skilled performance (e.g., Adams, 1971; Schmidt, 1975), then the erroneous feedback should not affect performance. We determined that effect by comparing pretest accuracy and posttest accuracy and by comparing the correct-feedback group and the erroneous-feedback group. Alternatively, if players at high levels of skill use action-effect information to perform an action (see Keller & Koch, 2006), then this would suggest that visual information pertaining to ball trajectory has become important for skilled performance. If that information is indeed important, then the actions of participants in the erroneous-feedback group should show a bias toward higher ball trajectories (when they have underestimated ball-flight feedback) in comparison with those of participants in the correct-feedback group. Researchers have found that erroneous feedback affects the performance of experienced performers only in the trials in which it is provided and that erroneous feedback does not affect their longer-term performance (see Buekers & Magill, 1995). Therefore, if participants use that visual information, then the effects of erroneous feedback would be evident only during trial blocks in which we provided it.

Method

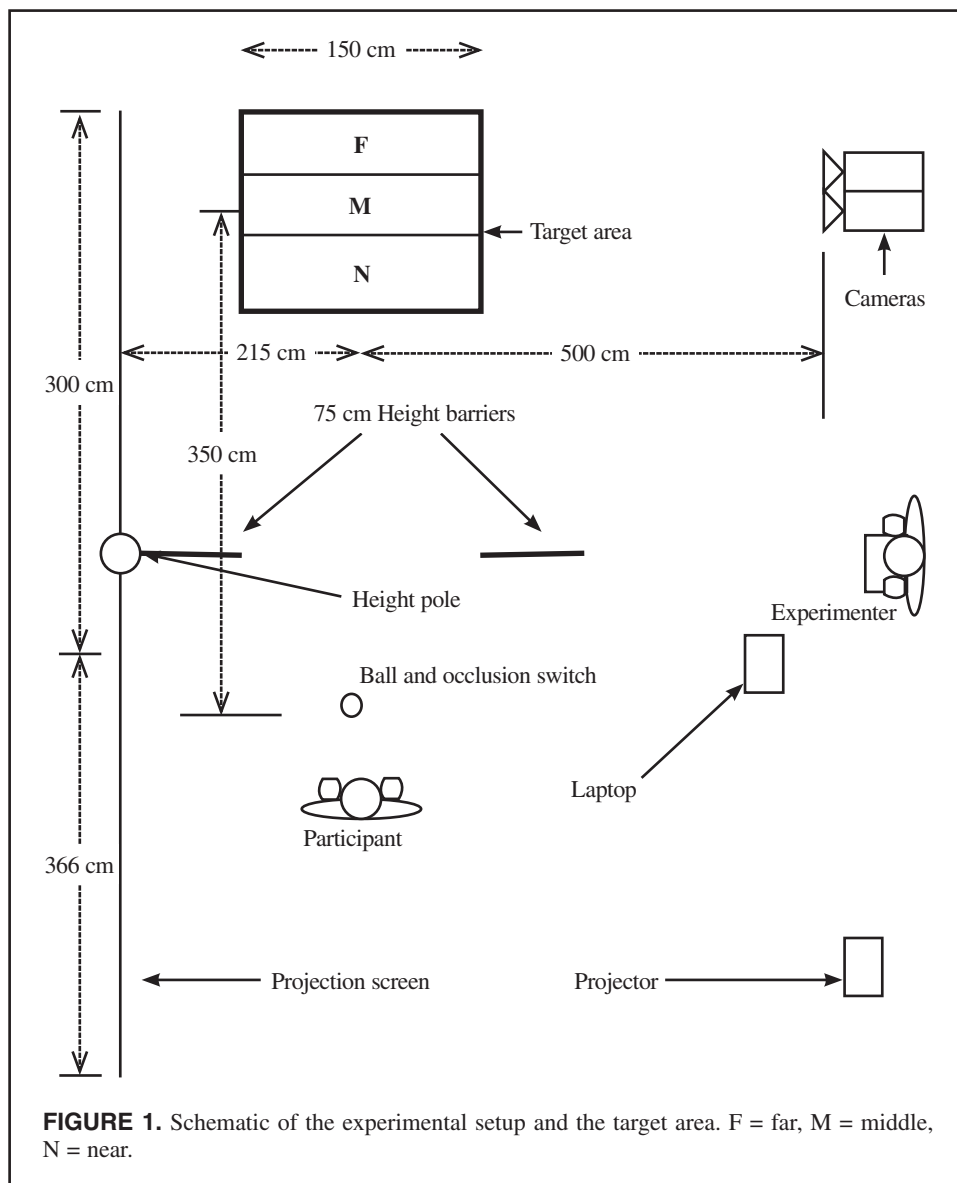
Participants

Participants were 20 skilled male soccer players whose mean age was 21.9 years (range = 18–28 years). They volunteered to participate and provided informed consent. We conducted all procedures according to the ethical guidelines of the university. We pseudorandomly allocated participants to one of two groups, with the constraint that the groups had to be approximately matched for years of competitive playing experience. We allocated participants alternately to the erroneous-feedback group and then the correct-feedback group because of the requirement to yoke participants in the latter group. The mean age of the participants in the first group, who received erroneous ball-flight feedback, was 22.6 years (range = 20–28 years), and they had been playing soccer regularly for an average of 16.2 years (range = 14–21 years). The mean age of participants in the second

group, who received unedited, correct feedback, was 21.6 years (range = 18–26 years), and they had been playing soccer regularly for an average of 14.0 years (range = 10–19 years). All participants had previously played at varsity level (i.e., the highest standard of university sports), and all but 2 (both in the correct-feedback group) had played at a professional club's youth academy or at a semiprofessional level. Participants were free to withdraw from testing at any stage.

Task and Apparatus

The experimental setup is shown in Figure 1. We required participants to kick a soccer ball (a standard size-5 Fédération Internationale de Football Association regulation ball) from its starting position on a visual-occlusion switch over a height barrier to a target area. The type of soccer kick encouraged by the setup (for a further description, see Ford et al., 2006) enables the performer to achieve target success



with relatively large variation in the height of the ball's trajectory.

We conducted the experiment indoors on a carpeted surface. The target area was a 150×150 -cm square that we marked on the floor in yellow tape. The floor switch (5-cm diameter) for manipulating vision via occlusion spectacles (Translucent Technologies, Toronto, Ontario, Canada, model PLATO P-1) was 350 cm from the center of the target area. We connected the occlusion spectacles to the floor switch with an extension cable. We constructed a height barrier by using two 1-m-long poles and two chairs. We attached one pole to one chair and the other pole to the other chair. We aligned the poles horizontally with the ground at a height of 75 cm. We placed the poles 100 cm away from the visual occlusion switch, between the switch and the target area. A 50-cm gap between the ends of the poles directly in front of the participants' starting position prevented the ball from hitting the height barrier.

We positioned a movable partition (300 cm wide, 180 cm high) to the left of the target area (215 cm from the center). We aligned the end of the partition with the far edge of the target area. We mounted a plastic pole on the back of the partition and perpendicular to the height barrier so that 1 m of the pole was visible above the partition. We marked in red tape four height zones (each 75 cm high) on the partition and the pole. Height Zone 1 (HZ1) was from floor level at 0 cm to the height barrier at 75 cm. Height Zone 2 (HZ2) was from the height barrier at 75 cm to 150 cm above floor level. Height Zone 3 (HZ3) was from 150 cm to 225 cm above floor level. Height Zone 4 (HZ4) was from 225 cm to 300 cm above floor level. We did not apprise participants of the height zones or that we would record the height of the apex of their ball trajectory.

We positioned a 366-cm-wide \times 274-cm-high projection screen (Draper Screen Co., Spiceland, IN, Cinefold model) in line with the partition to enable the provision of feedback. We used a large screen so that the height and distance of the ball could be exactly replicated in the video playback. We positioned a Dell model 2300MP video projector (Dell UK, Bracknell, England) facing the screen and to the participants' right. We mounted two Model XM2 digital video camcorders (Canon UK, Reigate, England) on tripods, posi-

tioned next to each other and to the right of the target area. The cameras recorded the trajectory and landing position of the ball. After the experiment, we replayed trials in which the determination of height zone was unclear. We could operate the ball-trajectory camera, which we connected to the video projector in the correct-feedback condition, via remote control. We positioned a Model Vaio PCG-K1155 laptop (Sony UK, Weybridge, England) on a table next to the video projector and used a cable to connect the laptop to the video projector in the erroneous-feedback condition. The experimenter was in line with the height barrier, 750 cm from the center of the target area, where he or she could record outcome attainment and operate the cameras, laptop, and projector.

Prerecorded video clips. For the group who received erroneous feedback, we produced 24 video clips of various ball trajectories. Video footage showed only the flight of the ball. We did not record any body-related cues that would allow person identification. To produce the clips, we used a skilled soccer player who performed the experimental task with the same ball as participants used in the experiment. One of the digital cameras recorded the flight of the ball, as illustrated in Figure 2. The experimenter recorded the height zone that the ball's trajectory attained at its apex. We filmed ball flight for three landing positions. We denoted those landing positions as *near*, *middle*, and *far*, corresponding to 50-cm zones within the target area (see Figure 1). We retained the video footage only for trials in which the ball traveled in a relatively straight line toward the center of the target area through one of the height zones to one of the three landing positions. We produced 2 video clips for each of the 4 (height zone: HZ1, HZ2, HZ3, HZ4) \times 3 (landing position: near, middle, far) combinations, resulting in a total of 24 video clips. During testing, we counterbalanced the provision of those 2 clips across trials for each pair of clips. We produced 2 clips for each Height Zone \times Landing Position combination to reduce the possibility that participants who viewed the same clip on repeated occasions would realize it was the same clip. Minor variations existed between pairs of clips (e.g., the position of the ball varied by a few centimeters), although the height zone and the target landing zone remained constant. We stored all footage on the laptop.



FIGURE 2. Illustration of the ball-trajectory information provided as feedback to participants via a large video screen.

Procedure

Before the experiment, we felt it was necessary to mislead participants as to our purpose in the experiment to avoid their suspicion that we had distorted the feedback. We told participants that we had designed the experiment to investigate the effects of feedback provision that was either body related or ball related and that the provision of feedback would be either coach-selected or self-selected. Then we told all participants that they were in the coach-selected group and that they would receive ball-related feedback. At the end of the experiment, we explained the true purpose of the experiments to participants.

We told participants that we would provide feedback in the form of a video of their ball flight projected onto a screen. We said that their task was to kick the ball from its starting position on the visual occlusion switch, over a height barrier, to land in the target area. The experimenter demonstrated an appropriate kick before the start of testing. Participants first completed six familiarization pretest trials under normal-vision conditions. Participants then completed six occluded-vision pretest trials in which they wore the visual occlusion spectacles and foam earplugs to block out audible feedback. When the ball was on the switch, the spectacles were transparent. When the participants kicked the ball, the spectacles became opaque, occluding participants' vision of the ball's flight and its landing position. After pretest trials, the participants completed a total of 30 experimental trials. Participants wore the visual occlusion spectacles and earplugs in the feedback trials. During those trials, one group of participants received erroneous feedback of their ball trajectory on selected trials, and the other group received feedback of their actual ball trajectory. The experimenter recorded outcome attainment (i.e., the height zone achieved, whether the ball landed in the target area, and whether the ball had landed in the center line of the target area in either the near, middle, or far areas). After those experimental trials, participants completed 6 posttest trials under occluded-vision conditions and then 6 posttest trials under normal-vision conditions.

We set no limit on the number of trials in which feedback could be given to the erroneous-feedback group during the experimental trials. We balanced the number of trials across groups. We had produced only a limited number ($n = 24$) of

prerecorded video clips (in which the ball trajectory passed through a designated height zone and landed in a relatively straight line in the target area) for the erroneous-feedback group. First, we gave no feedback on trials in which the ball landed in the target area and the ball veered to the left or right of the center. Second, we gave no feedback on trials in which the apex of the ball's trajectory appeared to be split between two height zones or in which the ball landed on a line denoting the target area zones. Third, we gave no feedback on trials in which one of two errors occurred: The ball landed outside the target area (i.e., either short, long, left, or right of the target area) or hit the height barrier. We provided feedback on just under one third of all trials (see Tables 1 and 2 for means corresponding to the number of feedback trials and types of errors, respectively). Participants wore the visual occlusion spectacles and earplugs in the feedback trials.

Erroneous-feedback group. For the erroneous-feedback group, we connected the laptop to the video projector. Only one camera actually recorded outcome attainment during the trials. In the experimental trials, we provided erroneous feedback only when the ball landed in the target area and the ball flew in a straight line. We always showed members of the erroneous-feedback group video footage of a ball trajectory that reached its apex one height zone lower than that reached by their actual ball trajectory. The actual landing position of the ball remained unchanged. For example, when a participant kicked the ball in a straight line through HZ3 to the middle landing position, we showed them footage of a ball trajectory that went in a straight line through HZ2 to the middle landing position.

Correct-feedback group. We yoked each member of the correct-feedback group to a member of the erroneous-feedback group to provide them with feedback on the same trials as the ones on which their yoked partner had received feedback. For the correct-feedback group, we connected one of the cameras to the video projector and operated it by remote control. Participants in the correct-feedback group received feedback of their own ball trajectory and landing position only when the ball landed in the target area and when it flew in a relatively straight line. On trials in which feedback was scheduled and one of the aforementioned anomalies occurred, we provided feedback on the next available trial.

TABLE 1. Mean and Between-Participants Standard Deviation of Number of Trials in Which Feedback Was Given, as Function of Trial Block

Feedback	Trial block									
	1		2		3		4		5	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Erroneous	2.90	0.99	2.60	0.84	2.40	1.65	1.70	1.34	1.60	1.07
Correct	2.60	0.52	2.70	1.25	2.00	1.41	2.10	1.91	1.80	1.32

TABLE 2. Mean and Between-Participants Standard Deviation of Number and Type of Target Misses

Feedback	Type of error									
	Long		Short		Left		Right		Hit barrier	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>No-vision pretest</i>										
Erroneous	1	1	0	0	0	0	0	0	0	0
Correct	0	0	1	1	0	0	0	0	0	0
<i>Experimental trials</i>										
Erroneous	9	7	1	1	1	1	0	0	0	1
Correct	1	2	3	2	1	2	0	0	0	0
<i>No-vision posttest</i>										
Erroneous	3	3	0	0	0	0	0	0	0	0
Correct	0	0	1	1	0	0	0	0	0	0

On trials in which we provided feedback, the delay between the *action itself* (defined as when the participant touched the ball) and the provision of feedback was approximately 45 s. The delay between the provision of feedback and the start of the next action was also approximately 45 s. On trials in which we did not provide feedback, the intertrial delay was approximately 30 s. At the end of the experimental trials, participants in both groups completed six occluded-vision, no-feedback posttest trials in which they wore the visual occlusion spectacles and earplugs. Those experimental trials were then followed by six normal-vision posttest trials.

Data Analysis

The two measures of performance were target success (i.e., hit or miss, scored as a 0 or 1, respectively) and height zone (1–4). For data analysis, we calculated mean values on the basis of 6-trial blocks for the 12 pretest trials (normal vision, occluded vision), the 30 experimental trials, and the 12 posttest trials (normal vision, occluded vision). We calculated mean values for target success and ball-trajectory apex for each trial block as a function of group. Data for participants' success in hitting the target area were nominal, and we determined deviations in normality by using a Kolmogorov–Smirnov test. Therefore, we transformed the data by using Bartlett's modified arcsine transformation (Bartlett, 1937, discussed in Zar, 1996). The underlying distributions of the resultant data were nearly normal. We performed two separate factorial analyses of variance (ANOVAs) on each data set to examine both the immediate effects of the feedback and any remaining effects once feedback was withheld. That partitioning resulted in a 2 (group: erroneous, correct) \times 5 (block: 1–5) mixed ANOVA with repeated measures on the last factor and a 2 (group) \times 2

(test block: pretest, posttest) \times 2 (vision: normal, occluded) mixed ANOVA with repeated measures on the last two factors. We report partial eta-squared (η_p^2) values as a measure of effect size. We corrected violations to sphericity by using Greenhouse–Geisser procedures. We followed skill and interaction effects with Tukey honestly significant difference post hoc procedures. For all tests, we set the alpha required for significance at $p < .05$.

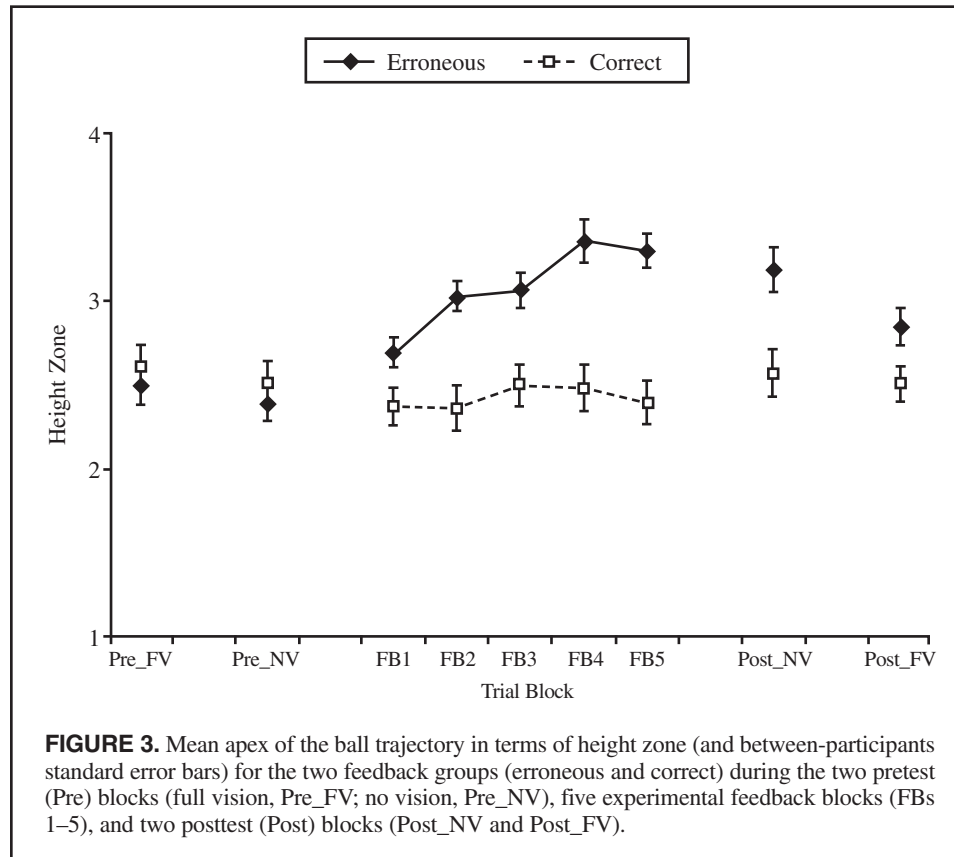
Results

For both groups, we provided feedback on 112 out of 300 experimental trials (mean = 11.2 trials per participant, range = 7–16 trials/per participant). Table 1 shows the number of trials in which feedback was given as a function of trial block. For the erroneous-feedback group, most of the trials in which we gave erroneous feedback were those in which the ball peaked in HZ3 (the erroneous feedback was therefore that the ball was in HZ2; $M = 7.2$ trials, range 3–12 trials). The ball trajectory was in HZ2 on an average of 3.2 trials (range 0–8 trials; thus, the erroneous feedback was that the ball was in HZ1). The ball peaked in HZ4 in only 0.8 of the trials (range 0–3 trials). For the correct-feedback group, there were 27 occasions in the 112 trials in which an error or abnormality in the ball's trajectory meant that participants did not receive feedback on the same trial as had their yoked partner in the erroneous-feedback group.

Feedback Trials

Height Zone

The mean ball-trajectory apex for each group, expressed as a function of the height zone, is shown in Figure 3. We observed a significant group effect, $F(1, 18) = 24.03$, $p < .01$, $\eta_p^2 = .57$. The apex of ball trajectory for the erroneous-feedback group was significantly higher than the apex of



ball trajectory for the correct-feedback group. There was a significant main effect for block, $F(2.54, 45.77) = 7.70$, $p < .01$, $\eta_p^2 = .30$, and block interacted with group, $F(2.54, 45.77) = 4.96$, $p < .01$, $\eta_p^2 = .22$. Post hoc tests showed that on trial blocks 2–5, the erroneous-feedback group achieved a higher height zone than the correct-feedback group did.

Erroneous-feedback trials in which participants received feedback showing the ball apex in HZ2 or HZ3 (i.e., the ball cleared the height barrier) occurred twice as often ($n = 80$) as did trials in which participants received feedback showing the ball apex in HZ1 (i.e., perceived failure to clear the height barrier, $n = 32$). On the trial after the provision of erroneous feedback showing the ball apex in HZ2 or HZ3, the apex of the ball trajectory was in a zone higher than the one achieved in the previous trial on 90% of occasions. On the trial after feedback of the ball in HZ1, the ball apex was in a zone higher than achieved on the previous trial on 100% of occasions. Those findings demonstrate that the erroneous-feedback group used the ball-trajectory information to alter and raise their ball trajectory on the trial after feedback regardless of whether they perceived that the ball had cleared the height barrier.

Target Success

The mean percentages of trials in which the target area was hit are shown in Figure 4. There was a significant group effect, $F(1, 18) = 7.99$, $p < .05$, $\eta_p^2 = .31$. The correct-

feedback group was significantly more successful than the erroneous-feedback group at hitting the target area. A significant main effect for block was observed, $F(4, 72) = 2.86$, $p < .05$, $\eta_p^2 = .14$, and group interacted with block, $F(4, 72) = 4.58$, $p < .01$, $\eta_p^2 = .20$. Post hoc tests showed no difference between the target successes of the two feedback groups for the first two blocks. For the final three trial blocks, the erroneous-feedback group was less successful than the correct-feedback group at hitting the target.

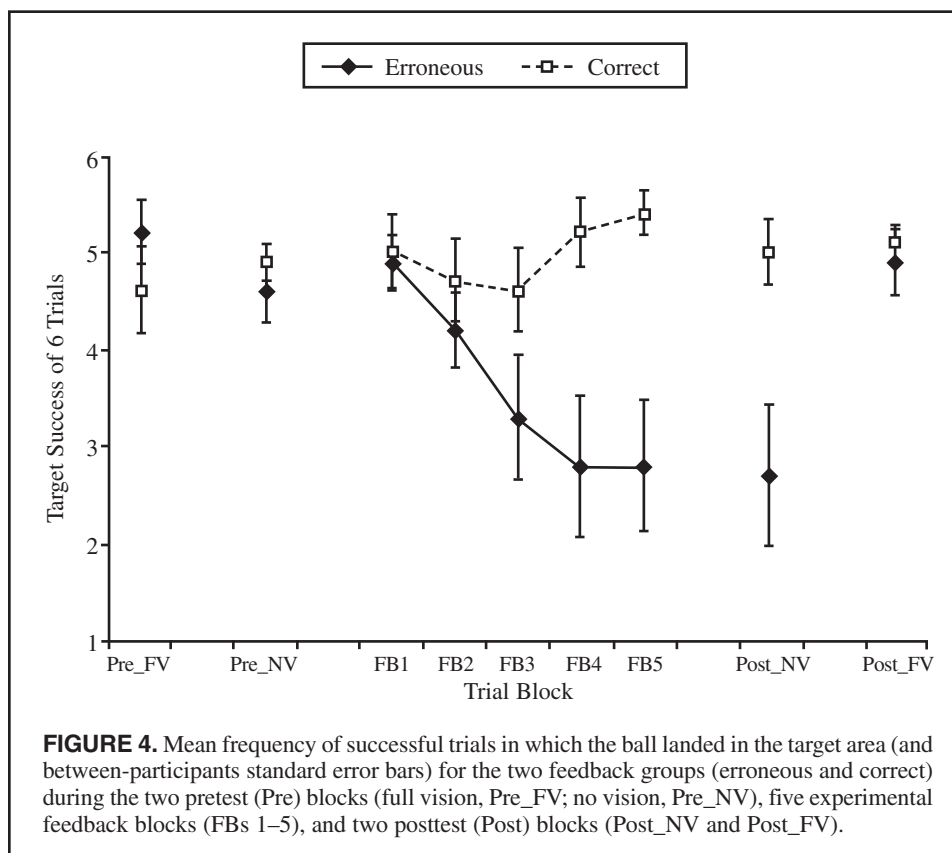
Errors

The types of errors that occurred as a function of feedback group are shown in Table 2. In the 30 experimental trials, the erroneous-feedback group ($M = 9$ trials, range = 0–18 trials) overshot the target area more often than the correct-feedback group did ($M = 1$ trial, range = 0–6 trials). Participants in the correct-feedback group undershot the target on an average of 3 trials (range = 0–6 trials), whereas participants in the erroneous-feedback group undershot the target on an average of 1 trial (range = 0–4 trials). All other error types (i.e., target miss to the left or right, barrier hit) occurred on an average of only 1 trial or fewer per participant.

Pretest to Posttest

Height Zone

The height-zone data are presented in Figure 3. There was no significant group effect, $F(1, 18) = 2.51$, $p = .13$, $\eta_p^2 =$



.12. There was a main effect of test block, $F(1, 18) = 8.01, p < .05, \eta_p^2 = .31$, and a Group \times Test Block interaction, $F(1, 18) = 9.26, p < .01, \eta_p^2 = .34$. Post hoc tests showed that there was no difference in the apex of ball trajectory for the two feedback groups in the pretest trial blocks. However, the ball-trajectory apex of the erroneous-feedback group was significantly higher than that of the correct-feedback group in the posttest trial blocks. We observed no main effect for vision, $F < 1$. There was a significant interaction between test block and vision, $F(1, 18) = 9.61, p < .01, \eta_p^2 = .35$. Post hoc tests showed that under normal-vision conditions, there was no difference in the ball-trajectory apex between the pretest and posttest. Under occluded-vision conditions, however, the ball-trajectory apex was significantly higher in the posttest than in the pretest. There was no three-way Group \times Test Block \times Vision interaction, $F(1, 18) = 2.21, p = .16, \eta_p^2 = .11$. However, there was a trend toward higher ball trajectories for the erroneous-feedback group than for the correct-feedback group in the posttest, occluded-vision condition.

Target Success

Figure 4 shows the mean number of trials in which the target area was hit. The group effect was not significant, although it approached conventional levels, $F(1, 18) = 4.10, p = .06, \eta_p^2 = .19$. The correct-feedback group tended to be more successful than the erroneous-feedback group at hitting the target area. We observed no significant main effect for test block, $F(1, 18) = 3.57, p = .08, \eta_p^2 = .13$.

.17. However, there was a significant Group \times Test Block interaction, $F(1, 18) = 7.98, p < .05, \eta_p^2 = .31$. Post hoc tests showed that there were no differences in the target success of the two feedback groups in the pretest trial blocks, but the target success of the erroneous-feedback group was significantly lower than that of the correct-feedback group in the posttest trial blocks. There was a main effect for vision, $F(1, 18) = 7.35, p < .01, \eta_p^2 = .29$, and a significant Group \times Vision interaction, $F(1, 18) = 9.76, p < .01, \eta_p^2 = .35$. Post hoc tests showed no difference in the target success of the two feedback groups under normal-vision conditions, but the target success of the erroneous-feedback group was significantly worse than that of the correct-feedback group under occluded-vision conditions. We observed a significant interaction between test block and vision, $F(1, 18) = 6.22, p < .05, \eta_p^2 = .26$. Target success was significantly worse in the posttest than in the pretest only under occluded vision conditions. There was no three-way Group \times Test Block \times Vision interaction, $F(1, 18) = 2.68, p = .12, \eta_p^2 = .13$.

Discussion

We examined the importance of ball-trajectory information for skilled participants' execution of a lower-limb soccer-kicking action. We provided participants with either erroneous or correct feedback pertaining to the flight of the ball, although we held KR constant. Researchers have traditionally believed that visual feedback has a reduced role to

play as skill is acquired, regardless of whether that feedback provides information about outcome success or about how the movement was achieved (e.g., Adams, 1971; Schmidt, 1975). However, other researchers have provided evidence that has led them to question whether the role of visual feedback about an action and its consequences diminishes as a function of practice experience (e.g., Kunde, 2001; Proteau, 1992).

Ford et al. (2006) found little evidence of an increased dependence on visual information among skilled participants when ball-trajectory information was occluded. In comparison, we expected that perturbing visual information would be a more effective manipulation for determining whether skilled performers use that information because it is still available for use. We predicted that visual information pertaining to ball trajectory would be an important part of the sensorimotor representation that guides skilled soccer-kicking actions (e.g., Keller & Koch, 2006). In the current experiment, a bias in the skilled, erroneous-feedback group's actions toward higher ball trajectories in comparison with those of the skilled, correct-feedback control group demonstrated the importance of ball-trajectory information. We observed that bias both during feedback trials and from pretest to posttest (when erroneous feedback was no longer presented). In the pretest, the ball-trajectory apex of the erroneous-feedback group was not different from that of the correct-feedback group. In the posttest, the apex of the ball trajectory for the erroneous-feedback group was significantly higher than that of the correct-feedback group.

The erroneous-feedback group's increase in the apex of the ball trajectory from pretest to posttest was coupled with a decrease in target accuracy from pretest to posttest, which resulted from a tendency to overshoot the target area (see Table 2). We believe that as a result of the feedback pertaining to the ball trajectory, those participants tried to hit the ball either with more force or at a different angle to try to further elevate or lift the ball, resulting in overshooting of the target area. That finding demonstrates that the erroneous-feedback group used the ball-trajectory information to aid in skill execution. It is possible that as a result of the perceived discrepancy between expected and actual feedback, participants in the erroneous-feedback group kicked the ball more forcefully because of their frustration. In future investigations, the addition of a group that is shown ball trajectories higher than expected would help researchers to show whether those errors result from participants' increased force because of frustration or from their attempt to change the ball flight on the basis of erroneous feedback.

We found that test block interacted with vision condition. Under normal-vision conditions, there was no difference in either ball-trajectory apex or target success between the pretest and posttest. Under occluded-vision conditions, the ball trajectory was higher and the target success was lower in posttest than in pretest. Although those effects were more noticeable for the erroneous-feedback group than for the correct-feedback group, the three-way interactions were

not significant. These findings show that the effects of erroneous feedback were still apparent when it was no longer provided, but only under conditions in which correct feedback was not available (i.e., normal vision). The erroneous feedback affected only the skilled participants' short-term performance and not their longer-term performance (see Buekers & Magill, 1995).

Data from the feedback trials further supported our prediction that visual information pertaining to ball trajectory is an important part of the representation guiding skilled actions. The erroneous-feedback group showed a bias toward higher ball trajectories in the last four feedback trial blocks (M height zone = 3.2) than in the first trial block (M height zone = 2.7). We did not observe that bias for the correct-feedback group. Skilled participants were using the erroneous ball-trajectory feedback to adjust their actions on subsequent trials in a manner previously demonstrated in erroneous-KR studies (e.g., Buekers et al., 1992). However, because target success could still be (and was) achieved in the trials in which we provided erroneous feedback, that information played more than an error-detecting role (as in previous KR studies). The actual ball-trajectory apex for participants in the erroneous-feedback group occurred most frequently in HZ3 so that they received erroneous feedback showing an apex in HZ2. Under those conditions, participants achieved both height and target success, yet participants in the erroneous-feedback group still increased their ball-trajectory apex on the trial after feedback provision. We suggest that the skilled performers had an expectation of what the ball flight should look like (i.e., an internally driven anticipation of the visual consequences). When visual feedback did not match the skilled performer's expectations, they modified the action on subsequent attempts. Other researchers have shown that the role of representations of action effects is not only to evaluate and correct an action (cf. Adams, 1971) but also to facilitate or generate an action (Koch et al., 2004).

In a previous experiment (Ford et al., 2006), skilled performers were able to compensate for the occlusion of visual information and continue to perform the task successfully, perhaps by vividly imagining the expected action effect (Koch et al., 2004), relying on other sources of information to help with successful execution of their actions (e.g., proprioceptive control; see Robertson & Elliott, 1996), or doing both. We replicated that finding in the present experiment for the correct-feedback group, which maintained target success even in trials in which visual feedback was not provided.

In conclusion, we examined the role of ball-trajectory information in the performance of a skilled soccer-kicking task. Skilled performers used ball-trajectory information to execute movements. Compared with presentation of correct feedback, provision of erroneous feedback caused a significant bias toward higher ball trajectories and more target failures. Skilled performers who have developed through extended practice the ability to plan and control

their actions on the basis of other sources of sensory information when vision is unavailable (e.g., Ford et al., 2006) use the visual consequences of the action to aid in action execution.

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