The Role of External Action-Effects in the Execution of a Soccer Kick: A Comparison Across Skill Level

Paul Ford, Nicola J. Hodges, Raoul Huys, and A. Mark Williams

The importance of action-effects for the performance of a soccer kick was examined. Novice, intermediate, and skilled players performed a soccer chip task with the intention of getting the ball over a height barrier to a near or far ground-level target under three conditions: full vision, no vision following ball contact with and without knowledge of results (KR). The removal of vision of the ball trajectory resulted in increased radial error, irrespective of the presence or absence of KR but in a skill-level and target dependent manner. At the near target, novice participants relied on ball trajectory information. Intermediate performers were affected by its removal across both target conditions, whereas skilled participants were not affected by the removal of ball vision. Variability in knee-ankle coordination significantly decreased when vision of the ball trajectory was removed, irrespective of KR and skill level. Although across skill level there was evidence that action-effects information is used to execute the action when it is available, only at the lower levels of skill did this information aid outcome attainment. There was no evidence to suggest that with increasing skill the dependence on this information increases.

Key Words: expertise, vision, feedback, motor control

The acquisition of expertise results from many hours of deliberate practice over several years of participation (for a motor-skills review, see Ward, Hodges, Williams, & Starkes, 2004). During this extended practice period, performers are believed to acquire general and task-specific perception-action representations that can guide the planning and production of actions (Adams, 1971; Schmidt, 1975, 1976; Proteau, 1992). It has been suggested that there is a commonality between the representations underlying perception and action such that actions may be generated by anticipation of their perceptual consequences (see Hommel, Müsseler, Aschersleben & Prinz, 2001). In this article, we examine how action-effects...
affect execution of a lower-limb soccer kicking action performed by participants with differing levels of skill.

There is evidence that with extensive practice a performer’s reliance on sensory information, such as response-produced visual feedback, decreases. This is proposed to be due to changes in the way the movement is controlled, typically visual to proprioceptive control (e.g., Fleishman & Rich, 1963; Henderson, 1975), or the development of motor programs enabling open-loop control (e.g., Schmidt & McCabe, 1976; Schmidt, 1975). It has also been suggested that with increasing skill the type of information important for action becomes more specific and relevant to action success, such that some researchers have suggested that learning is a process of attuning to specific sources of information, without reference to intervening representations (for a review see Beek, Jacobs, Daffertshofer & Huys, 2003). Robertson, Collins, Elliott, and Starkes (1994) found that for balance beam walking, skilled gymnasts were not affected by the removal of vision as much as novice gymnasts. Similarly, Williams, Weigelt, Harris, and Scott (2002) found that 12-year old skilled soccer player’s ability to control a soccer ball was not affected by the removal of vision, whereas the performance of the novice players was negatively affected. These findings might lead to the conclusion that visual feedback has a decreased role to play in skill execution as skill level progresses.

Similar conclusions have been drawn from research investigating the role of feedback available after the movement is completed. That is, as skill increases on a task, response-produced sensory information, what has been termed knowledge of results (KR), decreases in importance (e.g., Schmidt & McCabe, 1976). This proposal is based on the assumption that the representations which guide movement execution become more refined and specific to the task conditions so that the dependence on outcome-based information is reduced relative to early practice trials. Overall, these findings demonstrate that extensive practice leads to a decrease in the performer’s reliance on the sensory (and outcome) information that is present during and after the movement.

However, in laboratory-based uni-limb aiming tasks involving hundreds or at best thousands of practice trials (rather than years of experience), results contrary to those described above have been observed, whereby the more experienced performers have been shown to be more affected by the removal of vision (e.g., Proteau, Marteniuk, Girouard & Dugas, 1987). Similar conclusions have emerged from research investigating the role of sensory information available after the action is completed. For example, Kunde and colleagues (e.g., Kunde, 2002; Keller & Koch, 2003; Kunde et al., 2004) showed that anticipation of an action’s effect (such as a response tone) is functional during initiation of an action and that the importance of this information increases as skill is acquired. The proposal is that extended practice leads to strong associations between an action and its ensuing effects, and that this association is assumed to become bi-directional, so that once acquired, anticipation of an action’s effect leads to initiation of the action itself (see Prinz, 1997; Elsner & Hommel, 2001; Kunde, 2001; Koch & Kunde, 2002; Kunde, Hoffmann, & Zellmann, 2002; Kunde, 2003; Kunde, Koch, & Hoffmann, 2004). Action effect information is therefore important for skilled performers (see Keller & Koch, 2003; Koch, Keller, & Prinz, 2004). In contrast, novice performers lack strong links between actions and their effects, and hence action-effects might be expected to be less important for performance at low levels of skill, although not
necessarily for learning. Most of the evidence in support of this theory is based on key-press responses to artificially paired response tones, such that after practice the effect tone promotes faster initiation of the response associated with that tone (yet see Keller & Koch, 2003 who have shown similar effects in piano experts).

One explanation for the apparent discrepancy in research findings as to whether skill leads to an increase or decrease in the importance of response-produced information, has been in terms of tasks constraints. For example, Khan and Franks (2004) have suggested that skill-related changes in the use of sensory information depend on the type and demands of the task, with the modality most suited to meeting these demands progressively dominating the others. Despite the attention given to response-produced feedback in the literature, and the implications of action-effects based planning for skills that produce a distal and remote effect, there has been little examination of the importance of outcome information pertaining to the trajectory of an object such as a ball or discus. Latash (1996) and Gentile (1998) have discussed the potential importance of this information which they defined as the working point (such as the trajectory of the ball in basketball free-throw shooting) or end-point (such as the toe in clearing hurdles), respectively. Latash argued that the working point is the point with which the “central controller” is most concerned, which might be taken to suggest that this point forms part of the movement representation that guides the ensuing action. As noted earlier, action-effects have been examined in relatively artificial tasks where a response is paired to an action across a few days of practice (e.g., Kunde, 2002). These effects provide no information as to the accuracy of the movement. In addition, the action-effects have typically been auditory, a modality which, relative to vision and proprioception, could be considered less important in the execution of most sensorimotor skills. Principles that are derived from the study of simple skills do not necessarily generalize to more complex skills (Wulf & Shea, 2002) and, as detailed, there is evidence that the type of task mediates skill-related changes in the relative importance of sensory information, as does the degree of skill level (e.g., Proteau, Marteniuk, Girouard, & Dugas, 1987; Robertson et al., 1994).

The following experiment was designed to address the role played by action-effects in the execution of a motor skill. The chosen skill is believed to be representative of motor expertise in soccer and requires the displacement of an external object (i.e., a ball) onto a target area. In this task the distal effects of the action are realistic consequences of the action and therefore we would expect that these associations are well developed in skilled performers in comparison to beginners. The relative importance of the action-effects on the performance of a constrained soccer “kicking” task was examined through the occlusion of visual information from the ball’s trajectory. The participants performed under three conditions in which, following ball contact: (1) visual information of ball flight and landing position (i.e., knowledge of results, KR) was fully available; (2) visual information of ball flight was not available, neither was KR; and (3) visual information of ball flight was not available, but KR was provided in the form of a marker indicating landing position. These three conditions enabled the direct examination of the importance of ball trajectory in soccer kicking, while controlling for the effects of KR. If visual information of the action-effects is important for performance then participants will show negative effects (i.e., increased error) following its removal.
The associations between actions and their effects are thought to take time to develop (e.g., Keller & Koch, 2003), and become embedded in the performer’s cognitive representation of the skill. If this is the case, only the intermediate and skilled performers are predicted to be able to effectively use ball flight information to aid their performance, and therefore only these performers will be negatively affected by visual occlusion of action-effects. However, because outcome information has been shown to decrease in importance as a function of skill, it might only be the novice and possibly the intermediately skilled groups who will be affected by the removal of ball trajectory information and KR (see Adams, 1971).

It is also possible to look at control strategies through analysis of movement kinematics. There is evidence that changes in coordination occur as a function of task difficulty, feedback, and practice (e.g., Vereijken, van Emmerik, Whiting & Newell, 1992; Broderick & Newell, 1999; Hodges, Hayes, Horn, & Williams, 2005; Horn, Williams, Scott & Hodges, 2005). For example, Hodges et al. (2005), who used a soccer kicking action similar to the one employed in the current experiment, provided evidence that early in practice the movements of a novice were more “rigid” in appearance (as evidenced by strong couplings across hip, knee, and ankle joints of the prime effector) whereas later in practice the movements appeared more “fluid.” There have been reports of decreased variability in the kinematics of actions when vision and/or feedback is removed (e.g., Elliott, Helsen, & Chua, 2001; Robertson & Elliot, 1996), presumably because less information is available to the performer to make corrections from trial to trial. A decrease in movement variability during an action is expected to indicate that when this information is available (either ball trajectory information or KR) it is used to inform action. Since novice participants are expected to be more dependent on KR, whereas dependency on ball trajectory information might increase or decrease as a function of skill, an interaction between skill and vision condition is expected.

**Methods**

**Participants**

Twenty-seven undergraduate students (17 male, 10 female) age 21.50 years (min = 18, max = 30) volunteered to participate and provided informed consent. All procedures were conducted according to the ethical guidelines of Liverpool John Moores University. Participants were selected and divided into three groups based on soccer skill and experience level. The first group comprised nine skilled soccer players (8 male, 1 female) age 21.8 years (min = 18, max = 30). These players had 15.4 years (min = 13, max = 20) competitive soccer experience and were currently playing at semi-professional or varsity level. All had played previously at a professional club’s youth academy. The female player had 20 years soccer experience, having spent 10 of those years as a player in the top German women’s league. The second group comprised nine intermediate soccer players (8 male, 1 female) age 22.4 years (min = 18, max = 27). These players had 14.7 years (min = 9, max = 19) competitive soccer experience at an amateur standard only. The third group comprised nine novice soccer players (8 female, 1 male) age 20.4 years (min = 18,
max = 24) who had no experience of competitive football and limited experience of the sport at a recreational standard.

Performance on 12 pre-test, warm-up trials differentiated across the three skill groups. A one-way ANOVA on height success data (see Data Analysis section for further details on this measure) from all trials revealed a significant group effect \( F(2, 26) = 5.36, p < .05 \). Tukey post-hoc tests showed that the novice group \( (M = 48.15\%, SD = 30.27\%) \) were significantly less successful than both more skilled groups, but that the intermediate group \( (M = 75.93\%, SD = 16.90\%) \) did not differ from the skilled group \( (M = 80.56\%, SD = 12.50\%) \). A one-way ANOVA on radial error was also significant \( F(2, 26) = 3.62, p < .05 \). Tukey post-hoc tests showed that the skilled participants \( (M = 58.70\text{ cm}, SD = 9.70\text{ cm}) \) were significantly more accurate than both lesser skilled groups, but that the intermediate group \( (M = 79.95\text{ cm}, SD = 20.45\text{ cm}) \) did not differ from the novice group \( (M = 79.39\text{ cm}, SD = 24.13\text{ cm}) \).

Task and Apparatus

The experimental set-up is shown in Figure 1. Participants were required to kick a soccer ball from its starting position on a switch mounted on the floor over a height barrier to either a near or far target. This task was chosen as a representative measure of skill due to the degree of control required (i.e., to kick, lift, and place it accurately on a target), which represents specialized skills of players beyond merely a beginner level, and the fact that this skill is encountered during match-play, such as when making short and accurate passes or shots while overcoming an intervening obstacle such as a defender or goalkeeper. Figure 2 shows an example of the type of kick required to achieve the task goal. First, it should be noted that the action was a soccer chip and not a typical soccer-kicking action. The non-kicking leg contributed little to the action and participants were constrained to keep their arms at their sides so as not to occlude the reflective markers on the hip (see below). Second, the action was predominantly confined to the sagittal plane, thus, effectively, the chip was predominantly established through the action of the hip, knee, and ankle joint in this plane.

The experiment was conducted indoors on a carpeted surface. The target measurement grid was a 400 cm × 600 cm rectangle divided equally into a grid of 48 squares each 50 cm × 50 cm. The floor switch (5 cm diameter) for manipulating vision via occlusion spectacles was located centrally on the 400 cm side of the rectangle. A standard size 5, FIFA-regulation soccer ball was positioned on this switch and visual occlusion spectacles (model PLATO P-1, Translucent Technologies, Toronto, Canada) were connected to the floor switch via an extension cable.

Two targets were marked on the grid. The targets were located on the grid floor, one at a distance of 200 cm from the occlusion switch (i.e., “near target”), and the other at a distance of 400 cm from the occlusion switch (i.e., “far target”). The requirement to kick to two different targets in a random manner across trials was expected to increase the demands on the planning of each action and subsequently be more sensitive to action-effects related information. Under single or blocked
target conditions, it is proposed that the action plan constructed for the first target is held in working memory and used for the remaining trials to the same target (Lee & Magill, 1985). A height barrier was constructed using two 1 m long poles, each attached to a chair placed either side of the target grid so that there was a 1 m gap between the ends of the poles directly in front of the participants’ starting position, which

**Figure 1**—Experimental set-up (see text).
prevented the ball striking the barrier. The poles were horizontally aligned with the ground at a height of 70 cm and were parallel to, and 100 cm away from, the participant. A ruler was used to record error in the ball’s landing position compared to the center of the target and height success was determined by an experimenter who consistently observed from the same position. A VHS video camera (model MS5 S-VHS, Panasonic UK Ltd., Bracknell, UK) was used to aid in the recording of outcome attainment.

Three infrared cameras (model MCU1000, Qualisys, Gothenburg, Sweden) mounted on tripods (at a height of 2 m) were positioned outside the grid, located to the right of the participants. These were connected to a motion capture system (Qualisys, ProReflex, Gothenburg, Sweden). This enabled collection of three-dimensional movement kinematics data recorded at 240 Hz.

Figure 2—An illustration of the kicking action performed by a skilled individual.

Procedures

Before testing, spherical reflective markers (15 mm diameter) were placed on the right-hand side of each participant’s body at the acromion process (top of shoulder), greater trochanter (hip joint), lateral condyle of the femur (knee joint), lateral malleolus (ankle joint), and the distal head of the fifth metatarsal (little toe). Participants were instructed to kick a soccer ball from its starting position on the visual occlusion switch, over a height barrier, to a near or far target as specified by the experimenter. They were instructed to kick the ball within a 5 s window following a “go” signal. Participants first completed 12 warm-up/practice trials (in blocks of three trials to each target, starting with the near target). During these trials, the participant wore standard laboratory spectacles. Following these warm-up trials, participants completed a total of 30 trials under three viewing conditions. The 10 trials for each vision condition were subdivided into two blocks of five trials. These six vision/target blocks were ordered quasi-randomly across participants with the constraint that no more than two people performed the same order of conditions. The order of conditions was counterbalanced across participants within a group, but was the same across groups. The target condition order was randomized within each condition, but was the same for each participant.

Under full vision (FV) conditions, participants wore standard laboratory spectacles instead of visual occlusion spectacles. In the no ball vision (NV) conditions, participants wore the visual occlusion spectacles. When the ball was on the switch the spectacles were transparent. When the ball was kicked the spectacles became opaque, occluding participants’ vision of the ball’s flight and its landing position (i.e., KR). The spectacles remained opaque while the experimenter recorded whether
the ball had cleared the height barrier and measured the ball’s landing position relative to the target. In the second no vision manipulation, participants were shown the landing position of the ball on the grid after the trial (NV_KR). Following the experiment, trials in which it had been unclear if the ball had cleared the height barrier were replayed on video to facilitate judgments.

Data Analysis

**Outcome Error.** The participants’ success in clearing the height barrier as a function of condition was determined. The first trial in each condition was omitted from the calculation of height success, as performance on this trial may have been confounded by the information that was available in the last trial of the previous condition. Since the percentage data was nominal in nature and deviations in normality were determined using a Kolmogorov-Smirnov test, the data was transformed using Bartlett’s modified arcsine transformation (Bartlett, 1937, in Zar, 1996). The resultant data had an underlying distribution that was nearly normal.

Our primary measure of performance accuracy was expressed (in cm) as radial error (RE), that is, the absolute distance between the target and the ball’s landing position, calculated according to the following formula: \( RE = (x^2 + y^2)^{1/2} \). Mean values for RE, for each group under each vision × target condition were calculated. The first trial in each condition was omitted from the calculation of RE. Moreover, trials in which participants failed to clear the barrier were not included in the calculation of RE.\(^1\) When mean data from only one cell for a single participant was missing, an estimated value for RE was substituted based on each participant’s overall mean error and the mean of participants in that individual’s group for the respective target × vision condition, which occurred on two occasions out of a possible 138. If means corresponding to more than two cells were missing, the participant was not included in the analysis, which resulted in \( n = 6 \) for the novice group, \( n = 8 \) for the intermediate group, and \( n = 9 \) for the skilled group.

Secondary analysis of outcome attainment was also conducted to help explain how the error scores were obtained. Performance consistency was expressed (in cm) as variable error (VE). VE provided an index of force errors (along the \( y \)-axis) as well as directional errors (along the \( x \)-axis). Consistency was calculated for both

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\(^1\) We also conducted an analysis of the radial error (RE) data with the first trial of each condition removed, but with both height success and height failure trials included. The group effect remained. The vision effect comparing across the full vision and two no vision conditions approached conventional levels of significance (\( p = .06 \)). No interactions were significant. Generally, radial error was lower on trials in which participants failed to clear the height barrier (\( M = 65 \) vs. 61 cm), especially in the four conditions when vision of the ball was prevented (\( M = 70 \) vs 63 cm). In the height success data, there was a height success × group interaction (\( p < .05 \)), with novice participants failing to clear the height barrier on more occasions than the skilled participants. Therefore, to obtain the most valid representation of group performance radial error was based only on trials where height success was achieved.
the $x$- and $y$-axes using the population standard deviation formula (see Schmidt & Lee, 2005). Performance bias was expressed (in cm) as absolute constant error (ACE). This was calculated by using the $x$- and $y$-axes signed data to derive a mean for each participant under each vision $\times$ target condition. For group analysis only absolute deviations were analyzed to avoid possible cancelling effects as a result of within-group individual differences in the direction of error. The first trial in each condition was not included in the calculation of VE and ACE.

To explore the effects of experimental conditions on RE, VE, ACE, and height success, a separate factorial ANOVA was used on each data set to examine the effects of skill (skilled, intermediate, novice), vision (FV, NV, NV_KR), and target (near, far), with repeated measures on the last two factors. Since our predictions were specific to the vision conditions, pre-planned orthogonal contrasts were used. The first contrast allowed us to compare the control condition (i.e., full vision) to the two no vision conditions and the second contrast allowed comparison of the two no vision conditions, that is, with or without KR, to each other. Partial eta squared ($\eta^2_p$) values are reported as a measure of effect size. Skill and interaction effects were followed up with Tukey HSD post-hoc procedures. For all tests, the alpha required for significance was set at $p < .05$.

**Movement Kinematics**

As detailed earlier, the movement occurred mainly in the kicking leg, through the action of the hip, knee, and ankle joint in the sagittal plane. Joint angles in this plane were calculated based on the angle formed between two adjoining joint segments (e.g., the knee angle was calculated based on the hip, knee, and ankle coordinates using Qualisys Excel PC Reflex software, Gothenburg, Sweden). The consistency of coordination across trials was examined with respect to these angles using the NoRMS procedure proposed by Sidaway et al. (1995) in which coordination consistency is expressed as the across trial deviation of (joint) angle-angle trajectories from its mean. In view of the limited number of relevant variables in the soccer chip movement, and the requirement to explore for subtle differences across conditions, the NoRMS covariance analysis was used rather than alternative methods such as Principal Component Analysis or Range of Motion.

The joint angle data were calculated from the joint coordinate data based on the coordinates of each joint viewed in the sagittal plane. NoRMS values were calculated for the hip-knee and knee-ankle angles of eight participants from each group for all three conditions. For each selected trial, the start and end points of the movement were defined as the beginning of knee flexion in the sagittal plane immediately before ball contact and the maximal displacement of the toe in the same axis, respectively.

The kinematic data from three participants, one from each group, were not suitable for analysis due to marker occlusion. Six trials per condition were selected for analysis (three trials to the near target and three to the far target). As with radial

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2. We did conduct an analysis of range of motion (ROM) for the hip, knee, and ankle of the kicking leg for all groups as a function of vision and target. There were no skill or vision effects, although there were consistent target effects. Not surprisingly, ROM was greater at the far target compared to the near target.
error, the first trial in each condition was omitted from the kinematic analysis. The remaining six trials were selected in order until there were six trials for each condition. Both hip-knee and knee-ankle coordination variability were analyzed (in terms of NoRMS) in a three-factor ANOVA with skill (skilled, intermediate, novice) as the between-participant factor and vision (FV, NV, NV_KR) and target (near, far) as repeated measures factors. As with radial error, two pre-planned contrasts were used to examine the effects of the vision condition.

Results

Height Success

The mean percentage of trials in which the height barrier was cleared within each vision × target condition is presented in Table 1. There was a significant group effect, $[F(2, 24) = 6.75, p < .05, \eta_p^2 = 0.36]$. Post-hoc tests showed that the skilled group was significantly more successful at clearing the height barrier than the novice group, but both these groups did not differ from the intermediates. There were no significant effects involving vision (both contrast $F$s ≤ 1). There was a significant effect for target, $[F(1, 24) = 18.66, p < .05, \eta_p^2 = 0.44]$. Participants were more successful at clearing the height barrier when kicking the ball to the far target compared to the near target. The target × group interaction was not significant, $[F(1, 24) = 2.19, p = .10, \eta_p^2 = 0.15]$. 

Table 1  Percentage of Successful Trials That Cleared the Height Barrier Across the Three Vision Conditions as a Function of Group and Target

<table>
<thead>
<tr>
<th>Target</th>
<th>Near</th>
<th></th>
<th>Far</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Full vision</td>
<td>No vision with KR</td>
<td>No vision</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td></td>
<td>77.8</td>
<td>77.8</td>
<td>72.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(29.2)</td>
<td>(23.2)</td>
<td>(34.1)</td>
</tr>
<tr>
<td>Intermediate</td>
<td></td>
<td>61.1</td>
<td>61.1</td>
<td>61.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(35.6)</td>
<td>(37.7)</td>
<td>(33.3)</td>
</tr>
<tr>
<td>Novice</td>
<td></td>
<td>30.6</td>
<td>36.1</td>
<td>36.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(24.3)</td>
<td>(30.9)</td>
<td>(30.9)</td>
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</table>

Note: Values are means, with between participant SDs in brackets. KR, knowledge of results.

Radial Error

The accuracy data, expressed as radial error (RE), for each condition is shown in Figure 3. A significant group effect was observed, $[F(2, 20) = 5.97, p < .01, \eta_p^2 = 0.37]$. Post-hoc tests showed that the skilled participants were significantly more accurate than the novices, but both these groups did not differ from the intermediates. There was also a significant vision effect, $[F(1, 20) = 6.96, p < .05, \eta_p^2 =$
Removal of vision of the ball trajectory resulted in a decrease in accuracy irrespective of KR, as evidenced by a lack of difference between the two no vision conditions, \( F < 1 \). There was a significant effect for target, \( [F(1, 20) = 4.62, p < .05, \eta^2_p = 0.19] \). Radial error was lower at the near compared to the far target. Despite the predictions and the apparent lack of increase in error following the removal of vision for the skilled group in comparison to the other groups (as illustrated in Figure 3), there was no interaction between group and vision. However, the group \( \times \) vision \( \times \) target interaction was significant, \( [F(2, 20) = 3.70, p < .05, \eta^2_p = 0.25] \). This interaction was mainly due to the increase in error for the intermediate participants when vision was removed when kicking to the far target (as confirmed through post-hoc testing). Post-hoc analysis also showed that at the near target the novice participants were more accurate under FV compared to no vision conditions. At the far target, the novice participants were not affected by the vision manipulation. The accuracy of skilled participants was unaffected by the removal of vision irrespective of target condition. No other effects were significant.

**Figure 3**—Mean radial error (cm) and between participant SE bars across the three vision conditions (FV = full vision; KR = no ball vision, plus KR; NV = no vision, no KR) as a function of group and target.

### Absolute Constant Error in x-Axis

Performance bias in the x-axis, expressed as absolute constant error (ACE), for each condition is shown in Table 2. The group effect was not significant, \( [F(2, 24) = 1.93, p = .17, \eta^2_p = 0.06] \). There was a significant vision effect comparing across the full vision and the two no vision conditions, \( [F(1, 24) = 7.54, p < .05, \eta^2_p = 0.24] \). Removal of vision of the ball trajectory resulted in a tendency for participants to kick more to the right of the target than when vision was available and this was irrespective of the availability of KR. There was no group \( \times \) vision interaction, \( F(1, 24) = 1.86, p = .13 \), \( \eta^2_p = 0.13 \), and no significant target effects.
Variable Error in x-Axis

Performance consistency in the x-axis, expressed as variable error (VE), for each condition is shown in Table 2. A significant group effect was observed, \[ F(2, 24) = 3.49, p < .05, \eta^2_p = 0.23 \]. Skilled participants were generally more consistent than both the intermediate and the novice groups. There were no significant vision effects, both \( F_s < 1 \), and no group \( \times \) vision interaction, \[ F(1, 24) = 1.37, p = .26, \eta^2_p = 0.10 \]. There was a significant target effect, \[ F(1, 24) = 9.99, p < .05, \eta^2_p = 0.29 \]. Participants were more consistent when kicking the ball to the near target compared to the far target.

Table 2  Absolute Constant Error (ACE), and Variable Error (VE) in the x-Axis as a Function of Group, Target, and Condition (cm)

<table>
<thead>
<tr>
<th>Target</th>
<th>Near</th>
<th>Far</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full vision</td>
<td>No vision with KR</td>
</tr>
<tr>
<td>Skilled</td>
<td>9.36</td>
<td>12.42</td>
</tr>
<tr>
<td></td>
<td>(13.72)</td>
<td>(15.36)</td>
</tr>
<tr>
<td>Novice</td>
<td>12.06</td>
<td>19.86</td>
</tr>
<tr>
<td></td>
<td>(13.66)</td>
<td>(14.98)</td>
</tr>
</tbody>
</table>

Variable error

| Skilled | 10.55 | 12.55 | 12.54 | 15.54 | 11.63 | 14.52 |
|         | (7.13) | (8.31) | (8.17) | (9.05) | (7.87) | (7.98) |
|         | (9.26) | (9.71) | (9.59) | (14.84) | (27.84) | (13.24) |
| Novice | 15.49 | 15.39 | 13.21 | 18.32 | 25.50 | 28.57 |
|         | (9.60) | (10.33) | (5.39) | (9.32) | (14.57) | (20.40) |

Note: Values are means, with between/participant SDs in brackets. KR, knowledge of results.

Absolute Constant Error in y-Axis

Performance bias in the y-axis, expressed as absolute constant error (ACE), for each condition is shown in Figure 4 panel a. A significant group effect was observed, \[ F(2, 24) = 3.87, p < .05, \eta^2_p = 0.24 \]. Post-hoc tests showed that the novice participants showed an increased tendency to overshoot the target in comparison to the skilled group. Intermediate participants were not significantly different to the skilled or novice skill group. The vision effect comparing across the full vision and the two no vision conditions was not significant, \[ F(1, 24) = 2.01, p = .17, \eta^2_p = 0.08 \], nor
across the two no vision conditions, $F < 1$. The group × vision interaction was not significant, $[F(2, 48) = 2.33, p = .07, \eta_p^2 = 0.16]$.

**Variable Error in y-Axis**

Performance consistency in the y-axis, expressed as variable error (VE), for each condition is shown in Figure 4 panel b. A significant group effect was observed, $[F$

![Figure 4](image-url)

**Figure 4**—Mean (a) absolute constant error (and between participant SE bars) in y-axis, and (b) variable error (and between participant SE bars) in y-axis, across the three vision conditions (FV = full vision; KR = no ball vision, plus KR; NV = no vision, no KR) as a function of group and target.
The skilled group was significantly more accurate than both the intermediate and novice groups, who did not differ from each other. The vision effect comparing across the full vision and the two no vision conditions was not significant, \( F(1, 24) = 2.56, p = .10, \eta^2_p = 0.10 \). There was no difference between the two no vision conditions, \( F(1, 24) = 1.09, p > .05, \eta^2_p = 0.04 \), and no group × vision interaction, \( F < 1 \). The target effect was significant, \( F(1, 24) = 8.04, p < .05, \eta^2_p = 0.15 \). Participants were more consistent when kicking the ball to the near target compared to the far target.

**Kinematics–NoRMS Analysis**

*Hip-Knee.* The three skill groups did not differ significantly in terms of between trial variability in hip-knee coordination, \( F < 1 \). These data are plotted in Figure 5 panel a. There was a trend for participants to become less variable when ball

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**Figure 5**—Between trial variability as indicated by NoRMS in (a) hip-knee coordination and (b) knee-ankle coordination, across three vision conditions (FV = full vision; KR = no ball vision, plus KR; NV = no vision, no KR) as a function of group and target.
trajectory information was removed (irrespective of KR availability), \([F(1,21) = 2.45, p = .13, \eta^2_p = 0.10]\). Although vision did not interact with group there was a significant target × vision interaction comparing across the two no vision conditions, \([F(1,21) = 5.89, p < .05, \eta^2_p = 0.22]\). For the far target, variability increased when KR was prevented, whereas for the near target performers were more consistent in the no vision, no KR condition in comparison to the KR available condition. No other effects were significant.

**Knee-Ankle.** The three skill groups did not differ significantly in terms of between-trial variability in knee-ankle coordination, \(F < 1\), as illustrated in Figure 5 panel b. Variability in knee-ankle coordination decreased when ball trajectory information was removed (irrespective of KR availability), \([F(1,21) = 7.68, p = .01, \eta^2_p = 0.27]\). No other effects were significant.

**Discussion**

In this experiment, we examined changes in the importance of visual information relating to distal action-effects as a function of skill using a soccer kicking task. Manipulations of the sensory consequences associated with the action, specifically ball trajectory information and KR, were undertaken. Traditional motor learning theories (e.g., Adams, 1971; Schmidt, 1975) predict that the visual consequences of the action, and specifically feedback, would decrease in importance the higher the skill level (due to the development of intrinsic error-detection mechanisms). Alternatively, it might take time for the associations between actions and their effects to develop (e.g., Keller & Koch, 2003), such that only at intermediate or higher levels of skill is visual information pertaining to ball trajectory an important part of the cognitive representation guiding actions (see also Proteau, 1992).

In general, visual information pertaining to the consequences of the action was shown to affect performance across all levels of skill, although most noticeably for the intermediate and novice participants. When ball trajectory information was occluded, irrespective of the provision of KR, radial error increased (coupled with an increased tendency to hit to the right of the target, although variable error remained unchanged). A three-way interaction for radial error comparing across the full vision and no ball vision conditions for group and target demonstrated that the groups did not act in the same manner across conditions. For the near target, the novice participants showed less error under full vision conditions compared to conditions when vision of ball trajectory was prevented. At the far target, there were no differences across these two conditions. All participants were generally less successful at clearing the height barrier to the near target (57% success) compared to the far target (78% success), with the novice participants (36%) finding it particularly difficult to clear the barrier to the near target compared to the intermediate (60%) and the skilled (71%) groups. Since on each trial the goal of height barrier clearance preceded the goal of target accuracy, the difficulty the novice performers had in achieving the first goal (i.e., height barrier clearance) at the near target may have raised the importance of information related to the successful completion of this goal (i.e., ball trajectory information). At the far target, where novice participants did not find clearing the barrier as difficult, information related to the second goal (i.e., accuracy related information) became more important.
It has been shown that during the early stage of acquisition for a specific action, novice performers acquire associations between the action and its consequences, which are subsequently used to plan and control the action (Prinz, 1997; Elsner & Hommel, 2001; Kunde, 2001; Hommel et al., 2001; Kunde et al., 2002; Koch et al., 2004). Novice performers showed evidence that they were in the process of acquiring these associations by virtue of the fact that they were negatively affected by the removal of either KR or ball trajectory information depending on what was currently the most difficult task goal.

As predicted, the radial error scores of the intermediate participants increased when ball trajectory information was removed, especially for the far target. These participants were more successful at clearing the height barrier at the far (84%) compared to the near target (60%), suggesting they may have traded height success for accuracy at the near target. These findings for radial error and height success support the proposal that intermediate participants had already acquired associations between the action and its effects and were subsequently using these to plan and control the action.

The radial error scores for skilled participants did not appear to be affected by the removal of visual action-effects information or KR. These findings are congruent with traditional theories of learning (e.g., Adams, 1971; Schmidt, 1975, 1976) showing that as skill progresses, either executive structures are developed that enable the control of action without the need for KR or other such information, or that performers are using additional on-line sources of feedback (e.g., proprioception) to control the action. An online source of feedback, such as proprioception, will have been well calibrated to action-effects in the past, but can now operate independently of these effects (see Proteau, 1992). This does not rule out the possibility that actions are planned by anticipation of their end-effects at higher levels of skill, rather, feedback about the end-effects or sensory consequences of the action is not needed to accurately plan and execute movements. As suggested by Koch et al. (2004), if skilled participants have well developed representations of these end-effects then they might be able to vividly image the expected effects for the upcoming action without the need for feedback about the last action to aid in preparing the movement.

When vision of ball trajectory was removed, the general decrease in radial error especially for the novice and intermediate groups was accompanied by a decrease in between-trial movement variability, although only significantly so for knee-ankle coordination (see also Robertson & Elliott, 1996). The movements of participants were generally less variable across trials under no vision conditions. The absence of feedback only affected movement variability for the far target, which, as detailed above, is more constrained by accuracy information in terms of distance rather than necessarily height success. Variation across trials when vision was available suggests that performers in all groups were attempting to use ball trajectory information to plan and perform subsequent actions.

In the present experiment, we provided some evidence, in terms of radial error and movement variability, that action-effects are being used to help in action execution although we were unable to provide evidence to indicate that actions are directly planned by anticipation of their effects. Providing this evidence is not an easy task, since anticipatory cognitive representations cannot be directly observed, but must be inferred through behavioral data (Kunde et al., 2004). Manipulation of
the sensory consequences of the action and associated measurement of performance as a result of these manipulations may not be sufficient to allow clear conclusions about their role in action selection and initiation. It is also possible that performers use a different strategy to plan their actions when they have prior knowledge that vision will be occluded (see Khan & Franks, 2004). We have begun experiments to address these points and to more directly manipulate the planning process through instruction manipulations that emphasize the planning of the upcoming action either in terms of body movements or in terms of ball flight (see Ford, Hodges, Huys & Williams, submitted; Hodges, Hayes, Eaves, Horn & Williams, in press).

In conclusion, we have provided a first attempt at examining the role of ball trajectory information in performance of a skill where the action-effects are more than incidental consequences of the action, but are naturally paired and provide a potential source of feedback about how the action was performed. Evidence has been provided that performers across skill level, but particularly at the lower levels of skill, use this information to execute a movement and/or aid in outcome attainment. Novice performers in particular appeared to differentially use the action-effect information depending on the main task constraint and consequently the emphasis on a certain action-effect. Skilled performers, irrespective of the target, did not appear to be reliant on ball trajectory information to achieve target success. As a result of extended practice and exposure to the task, it is suggested that they have developed alternative ways to plan and control their actions which might involve anticipation of the end-effects to aid in action selection and accurate execution.

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References


