Skill in Sport:

The Role of Action-effect Representations

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Contents

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Thesis abstract

Five experiments were conducted to examine the role of ball trajectory information in the planning, execution, and evaluation of a complex motor skill as a function of skill. This sensory information source could either be predicted to become either more (Koch *et al.*, 2004) or less (Schmidt, 1975) important as skill is acquired. In Experiments 1, 2, and 3 the importance of ball trajectory information in the execution of a soccer kick to a target as a function of skill was examined using visual occlusion (Exp 1 and 2) and perturbation (Exp 3) techniques. Skilled performers were able to maintain accuracy when vision of ball trajectory was occluded, although they were shown to use this information when it was available but perturbed. The accuracy of less-skilled performers decreased when vision of ball trajectory was occluded. Across skill groups, variability in knee-ankle coordination also decreased under these conditions. Although these finding was taken as evidence that across skill levels 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. In Experiments 4 and 5 the importance of ball trajectory information in the planning of a soccer kick to a target as a function of skill was examined. Skilled and novice soccer players were instructed to plan the action in terms of the ball's trajectory or in terms of the body movements. There was little evidence that actions are more effectively planned by anticipation of their effects or that the ability to do so is skill-dependent (Koch *et al.*, 2004). However, there was some evidence that a body-related focus was detrimental to performance in comparison to control conditions when feedback was removed (McNevin *et al.*, 2003). Although ball trajectory information does not seem to be critical for task success, there was evidence that it is used to plan and perform actions across skill levels. Skilled performers were shown to be less reliant on this information compared to less skilled.

Chapter 1

Skill in sport: the role of action-effect representations.

Expert performance is achieved after extended practice over many years of participation. During this practice individuals acquire domain-specific adaptations that underpin their superior performance. Almost all of the elements of the human body are adaptable following extended practice, with the exception of some basic physical characteristics such as height (Ericsson, 2003a, 2003b). One such adaptation that is critical for performance in most motor tasks is the relative contribution to motor control of the body's various sensory sources, which has been a topic of debate in the literature for many years (for a motor skills review, see Khan & Franks, 2004). At one end of the spectrum, sensory information is thought to become less important for motor control as skill is acquired (e.g., Schmidt, 1975). At the other end of the spectrum it is thought to become more important (e.g., Koch, Keller, & Prinz, 2004; Proteau, 1992). This sensory information can occur during or after an action, and provides feedback about the correctness of the action. In this way sensory feedback facilitates the detection of errors and the subsequent correction of these errors either during the movement itself or in further attempts at that action (Schmidt & Lee, 2005).

Researchers have recently demonstrated that sensory information also plays a role in the planning of actions. Kunde and colleagues (e.g., Kunde, 2001) have provided evidence that the sensory consequences of an action are anticipated before the action and that this anticipation facilitates action initiation. There is some preliminary evidence (e.g., Drost, Rieger, Brass, Gunter, & Prinz, 2005), that the planning and initiating of actions by anticipation of their effects is also dependent on skill (Koch & Kunde, 2003). In addition to the type of sensory information that is available to performers (i.e., vision/proprioception), they can be selective in directing their attention to specific features of the movement (e.g., the foot in kicking, see Ford, Hodges, & Williams, 2005) or to particular features of the external environment (e.g., the racket or ball in sports such as tennis, see Wulf, Lauterbach, & Toole, 1999). There is also evidence that the relative importance of these various features changes as a function of skill (see Beilock & Carr, 2001).

In experiments examining the role of sensory information *during* actions, researchers have demonstrated task- and skill-based differences in its relative importance. For example, when performance is examined in relatively simple tasks (e.g., Proteau, Marteniuk, Girouard, & Dugas, 1987) vision has been shown to increase in importance as practice is amassed. For more complex skills this dependency on one information source has not been observed (e.g., Robertson & Elliott, 1996). In this research, sport-settings have provided the opportunity to look at experts performing whole-body motor skills, such as gymnasts performing balance beam walking. These experts have typically acquired many years of practice in a domain. When these experts are compared to novice performers who have accumulated little or no practice strong conclusions can be drawn about how sensory information increases or decreases in importance as a function of practice. Although there has been considerable interest in how the various sources of sensory information change in their importance as a function of practice there has been little examination of sensory information pertaining to an action's effect, such as the trajectory of a ball in kicking and throwing. This information is an action effect that provides information to the performer as to how an action goal was achieved. This action-effect information has also been shown (e.g., Kunde, 2001) to form an important part of the representation for that action during initiation, even though it is distally removed from the movements themselves.

The associations between an action and its effects that form the representation for action have been shown (e.g., Elsner & Hommel, 2001) to become stronger as more practice is acquired. Thus, expert performers are likely to show more dependence on this information and a better ability to plan their actions in terms of the anticipated action-effect. This information also provides an important feedback role in error detection and correction, and thus is a form of knowledge of results (KR). Since there is evidence showing that KR becomes less important as skill is acquired (e.g., Schmidt & McCabe, 1976), expert performers might also be expected to have become less dependent on this action-effect information. In this thesis the relative importance of sensory information (i.e., the action effect) for the effective planning, execution and evaluation of an expert sport action is examined.

Expertise and the importance of practice

Many researchers have shown that expert performers in a domain acquire the skills that differentiate them from non-experts through years of dedicated practice (for a motor-skills review, see Ward, Hodges, Williams, & Starkes, 2004). Practice was recently referred to in a review by Janelle and Hillman (2003) as the common denominator in the development of expertise. Experts across domains, including athletes (e.g., Helsen, Hodges, & Starkes, 1998), musicians (Ericsson, Krampe, & Tesch-Römer, 1993) and scholars (Simonton, 1999, 2000), progress to that stage through extensive practice over several years of participation. This extended practice in a domain leads to biological and cognitive adaptations, which underpin superior performance. Although researchers are some way from detailing causal accounts between types of practice activities undertaken and the associated adaptations to the performer, others have demonstrated the existence of these adaptations using the expert-novice paradigm (Ericsson, 2003a).

The pioneering research in this area, conducted by de Groot (1965) and Simon and Chase (1973), focused on differences between expert and non-expert chess players. Simon and Chase hypothesised that experts did not differ from non-experts in terms of their mental "hardware", such as short-term working memory capacity, but that the performance advantage of experts could be attributed to vast domain-specific knowledge structures. In a series of studies they presented a chess board to these players with either structured representative chess situations or unstructured randomly positioned chess pieces. In the unstructured condition, skill-based differences in recall did not emerge, whereas in the structured condition, expert players could recall 25 to 30 pieces compared to non-experts who could only recall 4 to 6 pieces. Simon and Chase concluded that the expert advantage in a domain is due to domain-specific cognitive knowledge structures acquired through years of practice in that domain. Since this seminal work many researchers have demonstrated that the various systems of the human body (including short-term working memory, Ericsson & Kintsch, 1995) are amenable to extended practice, with the exception of some basic physical characteristics such as height (Ericsson, 2003a, 2003b). In subsequent studies examining expert-novice differences in sport, adaptations in experts have been shown in their perceptual-cognitive skills (e.g., decision making and memory, McPherson, 2000; visual search behaviour and anticipation, Williams & Davids, 1998; psychological skills, Gould & Dieffenbach, 2002) and physical capacities (e.g., maximum oxygen uptake, Reilly, Bangsbo, & Franks, 2000). These adaptations interact to underpin the expert's superior performance, and although all contribute to expert performance, the remainder of this thesis will concentrate on the sensory adaptations that occur during practice.

Sensory adaptations as a result of practice

Sensory information and the on-line control of movements.

Vision plays an integral role in coordinated movements and actions, not least by interacting with the other sensory sources, such as proprioception, to provide response produced feedback about the control and success of action (Williams, Davids, &

Williams, 1999; Williams & Weigelt, 2002). Feedback can occur during (i.e., online) or after (i.e., offline) an action, providing information about the correctness of the action. This information can be used to detect errors in performance and subsequently, to correct the action and any further attempts at that action. It can be internally generated through the performers' own sensory sources, which is termed response-produced or intrinsic feedback. It can also be provided from an external source, which it typically referred to as augmented feedback, (see Schmidt & Lee, 2005). Early behaviourists (e.g., Thorndike, 1931) thought feedback served a motivational role in that actions that were rewarded were repeated, whereas those that were punished (or not rewarded) were not. Researchers have since (e.g., Adams, 1971) shown that feedback actually plays an informational role alerting the performer to errors in outcome (termed *knowledge of results, KR*) and performance (termed *knowledge of performance, KP*). This process involves both error detection and correction processes. It is thought that sensory sources of feedback are compared to a reference of correctness or an environmental goal enabling the evaluation and correction of actions on-line (i.e., during the movement) and on subsequent movement attempts (Schmidt & Lee, 2005).

The relative importance of the various sensory sources of information during the acquisition and performance of skilled actions has been a source of some debate in the literature. This debate centres on whether adaptations to sensory sources as skill is acquired makes the source more (e.g., Proteau, 1992) or less important (e.g., Schmidt, 1975) for the *online* control of actions. Alternatively, other researchers hold that during extensive practice a shift occurs from the importance of one sensory source to another (Adams, 1971 Fleishman & Rich, 1963), or that experts develop the ability to adapt and use different sources of information in a flexible manner depending on the current situation (e.g., Robertson, Collins, Elliott, & Starkes, 1994; Robertson & Elliott, 1996).

Some researchers have shown that for novices, early in practice, the processing of response-produced feedback for movement accuracy is important, whereas for practised performers the importance of this information has diminished (e.g., Schmidt, 1975). It is proposed that more skilled performers are able to pre-program their movements so that they are able to control their movements without the need to monitor feedback. Researchers have provided evidence to suggest that learned movements can still be performed successfully following accidental (Lashley, 1917) or experimental deafferentation (i.e., the elimination of sensory input into the spinal cord by destroying afferent nerve fibres, leaving efferent fibres intact) (Polit & Bizzi, 1978). However, the accuracy of movement is affected under these perturbation conditions and it is possible that total deafferentation is not achieved. The decrease in the reliance on this information across practice is believed to be accompanied by the development of motor programs that enable open-loop control of actions without the need for feedback (e.g., Schmidt, 1975, 1976).

Other researchers have suggested that the importance of sensory information for movement control does not decrease with practice, but that a shift occurs from the importance of one sensory source to another, typically from visual to proprioceptive control (e.g., Fleishman & Rich, 1963, Adams, 1971, Henderson, 1975). Data supporting this later proposal was provided by Fleishman and Rich (1963) in an experiment designed to examine the acquisition of a two-handed coordination task. The task required participants to attempt to follow a target by manipulating two crank handles that move a pointer. Fleishman and Rich demonstrated that vision was more important in the early compared to the later stages of acquisition, whereas proprioception became more important as skill was acquired. Although this account differs to that proposed by Schmidt (1975), in terms of the contribution of sensory feedback for movement control, both views lead to the conclusion that vision becomes less important as skill progresses.

Despite these conclusions there is also counter evidence that expert performer's reliance on the available sources of sensory information increases with practice. Proteau and colleagues (e.g., Proteau *et al.*, 1987; Proteau & Cournoyer, 1990; Proteau, 1992; Proteau, Tremblay, & DeJaeger, 1998) propose that with practice the source of sensory information that is most suited to ensure optimal performance on that task progressively dominates the others (Proteau *et al.,* 1998). This has been termed the *specificity of practice* hypothesis. Support for this hypothesis has been provided by Proteau *et al.* (1987) who had four groups of participants practice a manual aiming task for 200 trials (moderate practice) or 2000 trials (extensive practice) under normal vision or vision of target only conditions. Knowledge of results (KR) was provided after each trial. Following the practice period, all four groups transferred to a vision of target only condition with no KR. The groups who had practiced with normal vision showed a larger increase in error in transfer compared to those who had practiced without, and this effect was greater for the group who had accrued more practice. Proteau, Marteniuk, & Levesque (1992) have used the same paradigm to show that the addition of vision, after moderate or extensive practice without vision can result in increased error in proportion to the amount of practice amassed. These studies have been taken as evidence that practice leads to a reliance on the sensory conditions available during practice so that a change in these conditions is detrimental to performance, especially if the amount of practice in these specific conditions increases.

In the studies of Proteau and associates (e.g., Proteau *et al.*, 1987) laboratory-based aiming tasks were practiced during carefully controlled practice phases that provided consistent sensory feedback conditions across hundreds or at best thousands of practice trials. For these tasks, when the sensory conditions in practice are held constant, visual information is typically most suited to ensure optimal performance, and when participants practice with vision it remains the most important information source for performance. In natural sporting domains, however, where tasks are relatively complex and acquisition phases last many years, the task itself and its practice /performance conditions present the performer with the need to use different or many sources of sensory information. For example, soccer players practice dribbling the ball extensively under conditions in which vision cannot be directed to the limbs because there is a need to monitor other players in the playing environment. Variability in these conditions during practice or performance is likely to encourage performers to be able to adapt to various sensory conditions. This means that they do not become dependent on one source of sensory information when the context does not allow that. This flexibility in the ability to use different sources of sensory information to perform the task accurately has been shown to be a characteristic of expertise (e.g., Bennett & Davids, 1995; Robertson *et al.*, 1994; Robertson & Elliott, 1996; Soucy & Proteau, 2001).

In a study designed to examine the relative contribution of the sensory sources in gymnastics balance beam crossing as a function of skill, Robertson *et al.* (1994) demonstrated that expert gymnasts were less reliant on visual feedback compared to novices. Specifically, for expert gymnasts, movement time to cross a balance beam was not affected when vision of the environment was removed using occlusion spectacles, whereas for novice gymnasts, movement time increased significantly. Moreover, although the number of form errors increased for both groups, the increase was greater for novices. These findings were taken as evidence that expertise in this domain was characterized by the ability to use proprioceptive feedback to perform the task rather than, or at least not exclusively, vision. Further evidence in support of this proposal was provided by Bennett and Davids (1995) who examined the effect of skill level on the role of vision during a power lift squat. Skilled, intermediate, and novice lifters performed power lift squats under three vision conditions that provided full vision (i.e., facing a full-length mirror), ambient vision (i.e., focusing on a fixed point overhead), and no vision (i.e., blindfolded). The spatiotemporal performance of the skilled lifters was not affected by these visual conditions, whereas the performance of the less skilled lifters decreased when vision was removed. Bennett and Davids suggested that for this task performers might have come to rely on or have developed the ability to switch to other sources of sensory information, such as proprioception.

The findings in these two studies could be taken to suggest that as skill is acquired a shift occurs from the importance of visual to proprioceptive control (e.g., Adams, 1971). However, Robertson and Elliott (1996) provided support for the alternative prediction that experts develop the ability to switch to other sources of sensory information when vision is not available. They had expert and novice gymnasts cross a balance beam as quickly as possible under conditions in which vision was perturbed. Perturbation to vision was caused when participants wore 25 diopter prism spectacles, which displaced the visual field by approximately 15 degrees to the left or right. Although expert performance would be expected to be less disrupted by this perturbation if a shift had occurred from visual to proprioceptive control, both novice and expert gymnasts crossed the beam slower and with a high number of attempts to obtain success under perturbed conditions compared to normal vision control conditions. This was taken as evidence that when vision is available both expert and novice performers use it, although the studies of Robertson *et al.* (e.g., Robertson *et al.*, 1994; Robertson & Elliott, 1996) also demonstrate that when vision is unavailable expert gymnasts are able to make use of alternative feedback sources for the online control of actions. It has been suggested by some researchers (e.g., Newell, 1986; Gibson, 1988) that learning is a process of progressively attuning to the many relevant sources of perceptual information for the task, without reference to intervening representations. Although researchers debate the mechanisms underlying sensory dependence, if this attuning to the various relevant sources of sensory information for the action has occurred, skilled performers are less affected by the removal of one source in comparison to novices (for a sports-related review, see Williams *et al.*, 1999).

Sensory information and interceptive actions.

Similar arguments and conclusions to those just discussed have occurred regarding the skill-dependent changes in the role of vision and proprioception in interceptive tasks (for a review, see Williams & Weigelt, 2002). Interceptive actions are activities that require an actor (or the limbs of the actor) to move or intercept an object. These activities are common in everyday life, such as shaking hands or sitting down on a chair, as well as in sports, such as catching a baseball or using a racket to hit an incoming tennis ball (Davids, Savelsbergh, Bennett, & Van der Kamp., 2002). Typically, researchers have investigated skill-based differences in the use of vision and proprioception in catching using either the screen paradigm, in which an opaque screen occludes vision of the limb, or the 'catching in the dark' paradigm, in which only the ball is illuminated. The general conclusion from this research is the same as that drawn from research investigating the role of sensory information in the on-line control of movements (see previous section). Expert performers have developed the capability to make use of alternative feedback sources when vision is not available (Williams & Weigelt, 2002).

An example of data supporting this 'flexibility' prediction in catching was provided by Fischman and Schneider (1985) who used the screen paradigm to demonstrate expert-novice differences for softball players at one-hand catching. The ability of expert softball players to position the limb and grasp the ball was only minimally affected under screen conditions, whereas screen conditions disrupted novice limb positioning considerably. Although this was taken as evidence that experts have developed the ability to use alternative feedback sources when vision is not available, some researchers have failed to replicate these skill-effects (e.g., Davids & Stratford, 1989). In their review of the role of vision and proprioception in interceptive actions, Williams and Weigelt (2002) have cited methodological differences (e.g., variability in occlusion periods, spatio-temporal accuracy requirements) between studies as the main cause of these discrepancies. Although these discrepancies mean the empirical evidence is not conclusive, the general consensus remains that expert performers make more effective use of alternative sources of sensory information to perform the task when vision is unavailable (Williams & Weigelt, 2002). Since this ability also underlies expert performance in the online control of actions, it might also underlie the use of action-effect sensory information by expert performers.

Sensory information and the off-line control of movements.

Vision also plays a role after action execution (i.e., offline) as an enriched form of KR that enables error detection and adjustment to subsequent actions (Khan & Franks, 2004). In a similar vein to the on-line control of movements, there is debate as to whether this *offline* sensory information becomes more (e.g., Kunde, 2001) or less important (e.g., Schmidt & McCabe, 1976) as skill is acquired. Traditionally, in motor learning, it has been thought that extended practice leads to the development of intrinsic error-detection mechanisms which decrease the need for feedback about the visual consequences of the action to adjust subsequent actions (e.g., Schmidt & McCabe, 1976). This proposal is based on the assumption that the representations that 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. For example, in an experiment designed to examine how the use of feedback changes across practice, Schmidt and McCabe (1976) had participants perform a coincidence barrier knockdown task for 200 trials on each of five days. This task required participants to knock down a barrier at the moment a clock which had started at 0-sec reached 2-sec using a movement lasting 750-msec (i.e., if the movement is 750m-sec, then the initiation should occur when the clock reaches 1.25-sec). Knowledge of results was not provided, but the clock stopped as soon as the barrier had been knocked down providing visual outcome KR. Across practice there was an increase from a moderate to a high correlation between the movement initiation time and the time difference between the subject's movement end time and the clock's arrival at 2-sec. In other words, in the early stages of practice, if a participant started the movement late, they would arrive early, late, or on time. At the late stages of practice, if a participant started the movement late they would also finish it late. This was taken as evidence for decreased use of feedback processes and increased reliance on open-loop processes or reflex-based corrections as practice progressed.

Despite this conclusion recent evidence from studies investigating offline processing of sensory information has demonstrated that the consequences of an action are important for accurate performance even after extended practice, although not necessarily for error detection. In a series of studies investigating the planning of actions, Kunde, Koch and co-workers (see Prinz, 1997; Elsner & Hommel, 2001; Kunde, 2001; Koch & Kunde, 2002; Kunde, Hoffmann, & Zellmann, 2002; Kunde, 2003; Kunde, Koch, & Hoffmann, 2004; Schack, 2004) have demonstrated that extended practice leads to strong associations between an action and its ensuing effects. These associations are believed to become bi-directional, so that once acquired, anticipation of an action's effect leads to initiation of the action itself. Since practice at a task is predicted to lead to strong bi-directional action-effect associations it is assumed that skilled performers plan their actions by anticipation of their effects, and by inference that these effects are important for them in facilitating skill execution (Koch *et al.*, 2004). For domain novices, who have undertaken few, if any, hours of task-specific practice, the reverse may be true. Their lack of experience at a task means they are unlikely to have formed associations between specific actions and those action's consequences. Therefore, they are unlikely to be able to use this information to aid action initiation, although it may be important for action evaluation.

Data supporting these proposals were presented by Keller and Koch (in press) who demonstrated that response-effect compatibility increases as a function of the stage of skill acquisition the performer has reached. Participants with varying musical experience were required to perform short music-like sequences in which mappings between response key location (e.g., top, middle, bottom) and effect tone pitch (e.g., high, medium, low) were either compatible (e.g., top key activated high tone pitch) or incompatible (e.g., top key activated low tone pitch). Reaction times to initiate the sequence were quicker in compatible trials compared to incompatible, and were quicker with the more years of musical training that the performer had undertaken. Koch *et al.* (2004) suggested that 'practice at a skill makes the performer more sensitive to the produced action effects, so that they can imagine and anticipate these effects more vividly as well' (p.371). Although Keller and Koch used expert performers who had amassed many years of practice to evaluate their hypothesis (see also Drost *et al.*, 2005), this has been the exception in the research. Most of the research has been conducted with participants who have only undergone hundreds of practice trials. Furthermore, the typical response required in these studies has been a key-press, which has little accuracy or coordination requirements in comparison to whole-body tasks, such as kicking. Also, the action effects in these experiments provide no information about the correctness of the movements.

Schack and colleagues (e.g., Schack, 2004; Schack & Mechsner, 2006) have provided further evidence supporting the proposal that the representation for action adapts during practice. They investigated the nature of the long-term memory structures underpinning complex athletic skills as a function of expertise. To explore this issue, they had skilled and novice athletes group together pictures of the sub-movements of a complex action (e.g., tennis serve, Schack & Mechsner, 2006) into their perceived functional order. Skilled athletes represented the sub-movements (termed basic action concepts, BACs) in a relatively consistent and hierarchical manner. Their representation closely matched the sub-movements to functional demands (e.g., leg swing back to generate force for kicking). In contrast, the representations of novice athletes were organised less hierarchically, with greater variability between persons, and were less matched to the functional demands of the skill. These studies have revealed the nature of the usually implicit motor representations underlying skilled performance in complex sport tasks.

Attentional focus.

Researchers investigating the attentional focus of performers have also provided evidence for the importance of action effect information. Wulf and colleagues (e.g., Wulf, Höß & Prinz, 1998; Wulf, Lauterbach & Toole, 1999; Wulf & Weigelt, 1997; Wulf & Prinz, 2001) have shown that instructions or feedback which direct a performers' attention to their movements (i.e., internal-focus) are less effective for learning than instructions which direct their attention to the effects of their movement on the environment (i.e., external-focus). These attentional effects have been suggested to be consistent irrespective of the skill level of the performer, following observations by Wulf, McConnel, Gärtner, and Schwarz (2002) that volleyball serves were more accurate across expertise levels under external- compared to internal-focus conditions. However, manipulations to attention during skill execution in complex tasks such as soccer dribbling, golf putting and baseball batting (e.g., Beilock & Carr, 2001; Beilock, Wieringa, & Carr 2002; Beilock, Carr, McMahon, & Starkes, 2002; Ford *et al.*, 2005; Gray, 2004; Perkins-Ceccato, Passmore, & Lee, 2003) have generally shown skill-dependent attention effects. Specifically, at high levels of skill a focus of attention on features external to the skill facilitates performance, whereas at lower levels of skill performers either show detrimental effects when asked to focus on external features (e.g., Perkins-Ceccato *et al.*, 2003) or are not affected (Beilock *et al.*, 2002). Manipulations to the attentional focus of performers during skill execution have also been shown to impact on the movement kinematics. Instructions that induce a focus of attention onto body movements are predicted to actively intervene in the control of those movements, causing a reduction in the body's active degrees of freedom (see Wulf, McNevin and Shea, 2001). This is thought to be desirable for novice performers who are expected to be in the process of discovering a functional movement pattern for the action (e.g., Newell, 1986).

The visual consequences of an action usually comprise multiple sources of information for the performer (e.g., limbs, ball, other players), the relative importance of which may also change across skill acquisition. Researchers have shown that certain visual consequences of the action are more beneficial for skill acquisition and performance than others. There is evidence that a focus on an external-effect (such as the ball leaving the racket in tennis) rather than a general external cue (such as the ball approaching the racket) is more beneficial for skill acquisition (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000), and that a distal, external cue is better than a proximal, external cue for balance-related tasks (McNevin, Shea & Wulf, 2003). However, Wulf *et al.* (2000) showed that learners benefited more from a focus on the club in golf than a focus on the trajectory of the ball. This result may be limited to situations where an implement, rather than the foot or hand, is required to exert force, which awaits further investigation.

Thesis Rationale

It has been thought that extended practice leads to a decrease in the need for feedback about the visual consequences of the action (e.g., Schmidt & McCabe, 1976). However, there is evidence (e.g., Kunde *et al.*, 2002) that practice leads to stronger associations between an action and its ensuing effects, such that this information might become more important for action initiation and execution. This research has been predominately limited to simple laboratory-based tasks involving uni-limb actions and acquisition phases of hundreds of practice trials. There is no research to date examining the importance of these visual consequences for the successful execution of more complex, real-world tasks involving multi-limb actions. One of the central issues for theories of motor control is to account for how humans constrain the many degrees of freedom (i.e., independent dimensions of the body that are free to vary, such as joints, muscles) of the motor system to produce these complex actions (Bernstein, 1967). Similarly, each complex action contains many sub-movements that are matched to the functional demands of the action (i.e., BACs, Schack & Mechsner, 2006). These units are organised into a functional representation of the action as expertise increases.

Initiating complex actions by anticipation of their sensorial effects has been forwarded as a simple and economic way to automatically constrain the muscles etc. into organised voluntary action (see Kunde *et al.*, 2004; Mechsner, 2004). Complex tasks often have naturally available external action-effects that provide error information that can be used to update subsequent attempts. Task related differences in the use of sensory information have been shown in previous research investigating the online control of motor skills. In these studies, the relative contribution of the sensory sources differs between simple tasks acquired during acquisition phases with consistent sensory conditions, where vision becomes the source of sensory information that is most suited to ensure optimal performance, and more complex, real-world tasks, in which vision is required for purposes other than monitoring limb movement.

The aim of this thesis was to examine the relative contribution of action-effect information (i.e., ball trajectory) for the successful planning and execution of a complex, real-world task as a function of skill. The task used was a lower-limb soccer-kicking task, which has ball trajectory as its action effect. 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). The task requires specialised skills of players beyond merely a beginner level, and 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. The advantage of using a real world task is that it is possible to examine and compare performers who have accrued many hours of domain-specific practice across several years of participation (i.e., experts) against those who have little or no domain experience (i.e., novices). In five experiments, participants were required to kick a ball to clear a height barrier and land on ground level targets.

The relative importance of the action effects (i.e., ball trajectory) for the planning and performance of a soccer-kick across various levels of skill was examined.

In Chapter 2, two experiments are reported in which the importance of action effects for the performance of a soccer kick was examined through the occlusion of visual information of the ball's trajectory. In Experiment 1, skilled players performed a soccer kick task, the intention of which was to kick the ball over a height barrier to a near or far ground-level target under three conditions: full vision, occluded vision following ball contact with and without KR. In Experiment 2, novice, intermediate, and skilled players performed the same task under the same vision conditions but this time the order of target conditions was varied in an effort to increase the demands on action planning. In Chapter 3, the role of ball trajectory information for the successful execution of a lower-limb soccer kicking action performed by skilled participants was further examined through ball trajectory perturbations. Two separate groups of skilled soccer players were compared who following performance either received erroneous ball flight information or received unedited, correct feedback. For both groups the landing position of the ball was unaltered. In Chapter 4, two experiments are presented where an attempt was made to directly influence the planning of the action through effects-related or body-related instruction. In Experiment 1, skilled and novice soccer players performed a kicking task to clear a height barrier to a near or far target under four conditions: planning in terms of body movements or in terms of ball trajectory, either with or without visual feedback. In Experiment 2, skilled and novice soccer players performed the task under the same planning conditions, but in the absence of vision and KR.

If the visual consequences of the action are important for performance then participants will show negative effects (i.e., increased error) following its occlusion or perturbation, and positive or neutral effects (in comparison to control conditions) when their attention is directed towards this information. Ball trajectory information and landing position (i.e., KR) form an important part of the visual feedback following an action, and it expected that their role in action execution will change as a function of skill. The associations between actions and their effects are thought to take time to develop (e.g., Keller & Koch, in press) and become embedded in the performer's cognitive representation of the skill. If this is the case only the skilled performers are predicted to be able to effectively use ball flight information to aid their performance. Therefore, only these performers will be negatively affected by visual occlusion or perturbation of action-effects, and only these performers will have become highly proficient at planning actions by anticipation of their effects. For novice performers, since they have not amassed many hours of practice at the task, they would be expected to have weak associations between actions and their effects. If this were so, then removal of action effect information would not be expected to affect their performance, especially if outcome information (i.e., KR) is unaltered. Perkins-Ceccato *et al.* (2003) have also shown that novice performers are more consistent under performance conditions that encourage attention to the movements rather than the effects of the action, which is opposite to expert performers.

Chapter 2

The role of external action-effects in the execution of a soccer kick: A comparison across skill level

Abstract

The importance of action effects for the performance of a soccer chip was examined. Skilled soccer players (Exp. 1) and novice, intermediate and skilled soccer players (Exp. 2) 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 KR. In Experiment 1, skilled participants performed as accurately when visual information of the ball's trajectory was withheld compared to when it was provided. In Experiment 2, the removal of vision of the ball trajectory resulted in increased radial error in a skill-level and target dependent manner. At the near target, novice participants relied upon ball trajectory information for target accuracy. The accuracy of intermediate performers was affected by the removal of ball trajectory across both target conditions. The accuracy of skilled participants was 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). In this paper 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), 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. For example, Schack and colleagues (e.g., Schack & Mechsner, 2006) have shown that the representation for complex actions becomes more consistent and hierarchical in nature, such that it more closely matches the functional structure of the complex skill, as a function of expertise. Other researchers have suggested that skill acquisition 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 the 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. 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, with acquisition phases of hundreds or at best thousands of practice trials (rather than years of experience), results contrary to those described above have been observed. In these studies 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 in the planning of actions. For example, Kunde and colleagues (e.g., Kunde, 2002; Keller & Koch, in press; Kunde, Koch, & Hoffmann, 2004) showed that anticipation of an action's effect (such as a response tone) occurs 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 *et al.*, 2004). Therefore, action effect information is thought to be important for skilled performers (see Keller & Koch, in press; 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 tasks in which responses are artificially paired to effect tones. With these tasks, following practice the effect tone promotes faster initiation of the response associated with that tone (yet see Keller & Koch, in press, 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. This is a simple and economic way for the human system to control complex actions, which have many degrees of freedom (Bernstein, 1967) and many representational units (Schack, 2004). 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. Additionally, 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 sensori-motor skills. Principles that are derived from the study of simple skills do not necessarily generalise 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 experiments were designed to address the role played by action effects in the execution of a complex 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. Skilled soccer players (Exp. 1) and novice, intermediate and skilled soccer players (Exp. 2) performed under three conditions in which, following ball contact: (i) visual information of ball flight and landing position (i.e., knowledge of results, KR) was fully available; (ii) visual information of ball flight was not available, neither was KR; and (iii) 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 and become embedded in the performer's cognitive representation of the skill (e.g., Proteau *et al.,* 1987). 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).

Experiment 1

In the following experiment the relative importance of the skill's action effects on the performance of a soccer-kicking task performed by domain experts was examined, through the occlusion of visual information of the ball trajectory. Participants were required to kick a soccer ball over a height barrier, to either a near or far floor target. The participants performed under three conditions in which, following ball contact: (i) visual information of ball flight and landing position (i.e., knowledge of results, KR) was fully available; (ii) visual information of ball flight was not available, neither was KR; and (iii) visual information of ball flight was not available, but KR was provided in the form a marker indicating landing position. These three conditions enabled the direct examination of the importance of ball trajectory in soccer kicking, whilst controlling for the effects of KR.

Methods

Participants

Nine skilled soccer players aged 20.22 yr (*Min* = 19 yr, *Max* = 25 yr) who were also undergraduate students in the U.K. volunteered to participate and provided informed consent. All procedures were conducted according to the ethical guidelines of Liverpool John Moores University. The participants had an average of 13.78 yrs (*Min* = 10 yr, *Max* = 18 yr) competitive soccer experience and they were currently playing at Varsity or semi-professional level.

Task and Apparatus

The experimental set-up is shown in Figure 2.1. 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 specialised 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.

The experiment was conducted indoors on a carpeted surface. The target measurement grid was a 400 cm x 600 cm rectangle divided equally into a grid of 48 squares each 50 cm x 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, F.I.F.A. regulation soccer ball was positioned on this switch and visual occlusion spectacles (Translucent Technologies, Toronto, Canada, Model PLATO P-1) were connected to the floor switch via an extension cable.

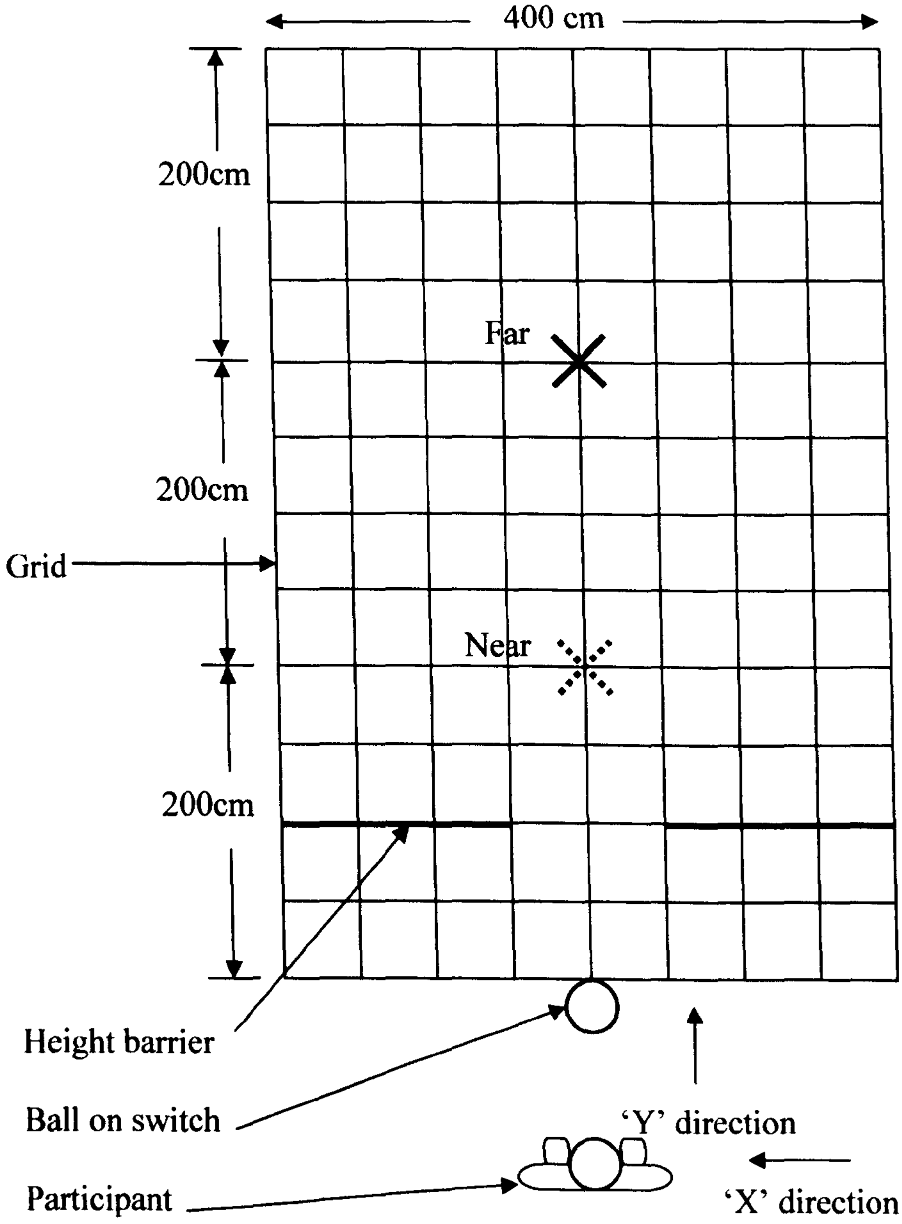

Figure 2.1. Experimental set-up (see text).

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'). 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 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 centre of the target and height success was determined by an experimenter who consistently observed from the same position. A VHS Video Camera (Panasonic UK Ltd., Bracknell, United Kingdom, Model MS5 S-VHS) was used to aid in the recording of outcome attainment.

Procedures

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. Participants first completed eight warm-up/practice trials (in blocks of 2 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 ten trials for each vision condition were subdivided into two blocks of five trials, pertaining to the two different targets (near and far). 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.

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 judgements.

Data analysis

The participant's 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 according to $p' = (360/2\pi)\arcsin\left(\sqrt{(c+3/8)/(n+3/4)}\right)$, with n = number of trials (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) [1], 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 x Target condition were calculated. The first trial in each condition was omitted from the calculation of RE, as performance in this trial would have been confounded by the information that was available in the last trial of the previous condition. Moreover, trials in which participants failed to clear the barrier were not included in the calculation of RE. 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. When means corresponding to more than two cells were missing for two participants the data from these participants were not included in analysis of radial error.

To explore the effects of experimental conditions on RE and height success, a repeated-measures ANOVA was used on each data set to examine the effects of vision (FV, NV, NV_KR), and target (Near, Far). 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 (μ_p^2) values are reported as a measure of effect size. For all tests, the alpha required for significance was set at $p < .05$.

Results

Height success

The mean percentage of trials in which the height barrier was cleared within each Vision × Target condition is presented in Table 2.1. There were no significant effects involving vision (both contrast F's < 1). There was also no significant effect for target, $F(1, 8) = 2.53$, $p > .05$, $\mu_p^2 = 0.24$. The Vision x Target interaction was not significant, $F < 1$.

Table 2.1. Percentage of successful trials (and between participant SDs) that cleared the height barrier across the three vision conditions as a function of target.

Target	Near			Far	
Full vision	No vision with KR	No vision	Full vision	No vision with KR	No vision
69.4 (42.9)	63.9 (37.7)	69.4 (46.4)	77.8 (26.4)	77.8 (36.3)	75.0 (37.5)

Table 2.2. Mean radial error in cm (and between participants SD) across the three vision conditions as a function of target.

Target	Near			Far		
	Full vision	No vision with KR	No vision	Full vision	No vision with KR	No vision
	58.30 (29.02)	53.28 (16.89)	44.65 (14.81)	56.59 (19.94)	58.51 (15.15)	51.20 (17.59)

Radial error

The accuracy data, expressed as radial error (RE), is displayed in Table 2.2. There were no significant effects involving vision (both contrast F's < 1). The participants were as accurate on trials where vision of ball flight and KR were not available as they were on trials where it was. There was also no significant difference between targets, F < 1, and no Target × Vision condition interaction, $F(2, 12) = 1.17$, $p > .05$, $\mu_p^2 = 0.16$.

Discussion

In this experiment we examined changes in the importance of visual information relating to distal action-effects for a skilled soccer-kicking task. Manipulations were undertaken of the sensory consequences associated with the action, specifically ball trajectory information and KR. Traditionally in motor learning it has been thought (e.g., Adams, 1971; Schmidt, 1975) that the visual consequences of the action, and specifically feedback, would no longer be important at a high skill level (due to the development of intrinsic error-detection mechanisms). Alternatively, the associations between actions and their visual effects may become stronger with practice, such that at high levels of skill visual information pertaining to ball trajectory is an important part of the representation guiding actions (see Proteau, 1992; Schack & Mechsner, 2006).

The radial error and height success scores for skilled participants were not affected by the removal of visual action-effects information or KR. These findings support traditional theories of learning (e.g., Adams, 1971; Schmidt, 1975, 1976) showing that at high skill levels, either performers are using additional on-line sources of feedback (e.g., proprioception) to control the action, or that executive structures are developed that enable the control of action without the need for KR or other such information. This does not rule out the possibility that actions are planned by anticipation of their end-effects at higher levels of skill. 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. However, in the current experiment only one skill level was examined and hence no general conclusions can be made about the role of ball trajectory information as a function of skill. According to Adams' (1971), external feedback becomes less important as skill progresses. Although a number of researchers have examined this notion with respect to KR and even on-line visual feedback, little attention has been paid to the role of trajectory of the end effect (i.e., action effects that are not directly controlled).

Experiment 2

In Experiment 1, skilled participants were able to perform accurately when visual information of the ball's trajectory was withheld. To examine whether this is a skill-dependent ability, in the present experiment, the importance of action-effects as information for the attainment of accuracy on a soccer-kicking task was examined across three different stages of skill (skilled, intermediate, and novice soccer players). Including a third 'intermediate' group enabled the examination of the way in which the relative importance of sensory information changes across the skill acquisition process. Participants performed under the same three vision conditions examined in Experiment 1 (see above).

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 and become embedded in the performer's cognitive representation of the skill (e.g., Proteau *et al.*, 1987). If this is the case then only the intermediate and skilled performers are predicted to be able to effectively use ball flight information to aid their performance. 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 similar soccer kicking action 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 effecter) whereas later in practice the movements appeared more 'fluid'. Changes in coordination as a function of practice on this task were most noticeable at the hip, knee, and ankle joints of the kicking leg. 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 females) aged 21.50 yr (*Min* = 18 yr, *Max* = 30 yr) 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 9 skilled soccer players (8 males, 1 female) aged 21.8 yr (*Min* = 18 yr, *Max* = 30 yr). These players had 15.4 yr (*Min* = 13 yr, *Max* = 20 yr) competitive soccer experience and were currently playing at semi-professional or Varsity level (i.e., inter-university soccer). 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 9 intermediate soccer players (8 males, 1 female) aged 22.4 yr (*Min* = 18 yr, *Max* = 27 yr). These players had 14.7 yr (*Min* = 9 yr, *Max* = 19 yr) competitive soccer experience at an amateur standard only. The third group comprised 9 novice soccer players (8 females, 1 male) aged 20.4 yr (*Min* = 18 yr, *Max* = 24 yr) 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 the three skill groups. A one-way ANOVA on height success data (i.e., percentage of successful height barrier clearances, which was transformed using Bartlett's modified arcsine transformation as per Bartlett, 1937, in Zar, 1996) from all 12 pre-test, warm up 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 from all 12 pre-test, warm up trials also revealed a significant group effect, $F(2, 26) = 3.62$, $p < .05$. Tukey post-hoc tests showed that the skilled participants (M = 58.70 cm, SD = 9.70 cm) were significantly more accurate than both lesser skilled groups, but that the intermediate group (M = 79.95 cm, SD = 20.45 cm) did not differ from the novice group (M = 79.39 cm, SD = 24.13 cm).

Task and Apparatus

The task and apparatus was the same as for Experiment 1. In Experiment 2 movement kinematics data was also recorded. Figure 2.2 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 sagital plane, thus, effectively, the chip was predominantly established through the action of the hip, knee, and ankle joint in this plane. Three infrared cameras (Qualisys, Gothenburg, Sweden, Model MCU1000) 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.

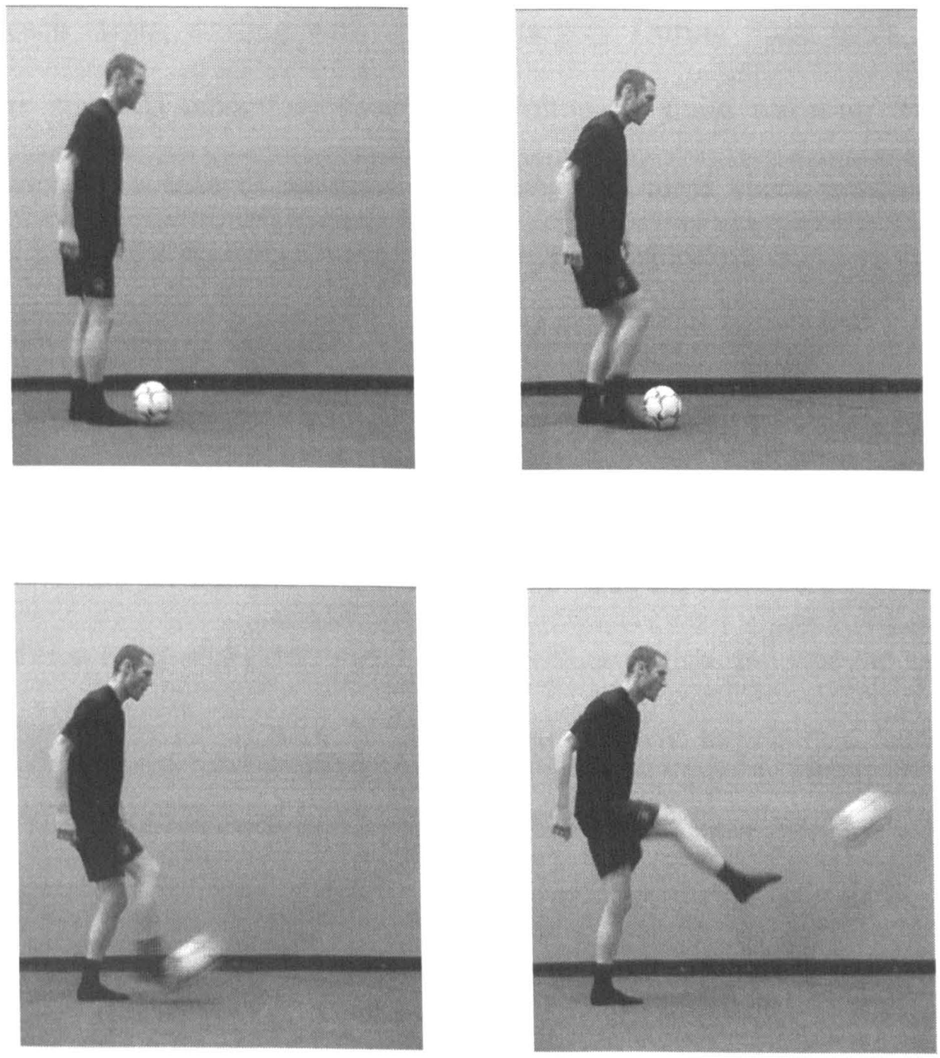

Figure 2.2. An illustration of the kicking action performed by a skilled individual.

Procedures

Before testing, spherical reflective markers (15mm 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 informed to kick the ball within a 5 s window following a 'go' signal. Participants first completed twelve warm-up/practice trials (in blocks of 3 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 the same three vision conditions examined in Experiment 1 (see above). The ten 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. 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. In contrast, 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).

Data analysis

Outcome error.

As with Experiment 1, the participant's 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 according to $p' = (360/2\pi)\arcsin\left(\sqrt{(c+3/8)/(n+3/4)}\right)$, with n = number of trials (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 x 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 [2]. 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 x Vision condition, which occurred on 2 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 the x- and y-axis 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-axis signed data to derive a mean for each participant under each Vision x 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 (μ_p^2) 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 sagital 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 [3].

The joint angle data were calculated from the joint co-ordinate data based on the coordinates of each joint viewed in the sagital 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 point of the movement were defined as the beginning of knee flexion in the sagital 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 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. Partial eta squared (μ_p^2) was used as a measure of effect size. The alpha required for significance for all tests was set at .05.

Results

Height success

The mean percentage of trials in which the height barrier was cleared within each Vision × Target condition is presented in Table 2.3. There was a significant group effect, $F(2, 24) = 6.75$, $p < .05$, $\mu_p^2 = 0.36$. 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, $F(1, 24) = 18.66$, $p < .05$, $\mu_p^2 = 0.44$. Participants were more successful at clearing the height barrier when kicking the ball to the far target compared to the near target. The Target x Group interaction was not significant, $F(1, 24) = 2.19$, $p = .10$, $\mu_p^2 = 0.15$.

Radial error

The accuracy data, expressed as radial error (RE), for each condition is shown in Figure 2.3. A significant group effect was observed, $F(2, 20) = 5.97$, $p < .01$, $\mu_p^2 = 0.37$. 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 a significant effect for target, $F(1, 20) = 4.62$, $p < .05$, $\mu_p^2 = 0.19$. Radial error was lower at the near compared to the far target. There was a significant vision effect comparing across the full vision and the two no vision conditions, $F(1, 20) = 6.96$, $p < .05$, $\mu_p^2 = 0.26$. There was no difference between the two no vision conditions, $F < 1$. 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 2.3), there was no interaction between Group and Vision. However, the Group × Vision × Target interaction was significant, $F(2, 20) = 3.70$, $p < .05$, $\mu_p^2 = 0.25$. 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).

Table 2.3. Percentage of successful trials (and between participant SDs) that cleared the height barrier across the three vision conditions as a function of group and target.

Target	Near			Far		
Group	Full vision	No vision with KR	No vision	Full vision	No vision with KR	No vision
Skilled	77.8 (29.2)	77.8 (23.2)	72.2 (34.1)	88.9 (25.3)	80.6 (32.5)	83.3 (21.7)
Intermediate	61.1 (35.6)	61.1 (37.7)	61.1 (33.3)	91.7 (12.5)	83.3 (17.7)	83.3 (25.0)
Novice	30.6 (24.3)	36.1 (30.9)	36.1 (30.9)	72.2 (31.7)	61.1 (33.3)	58.3 (35.4)

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.

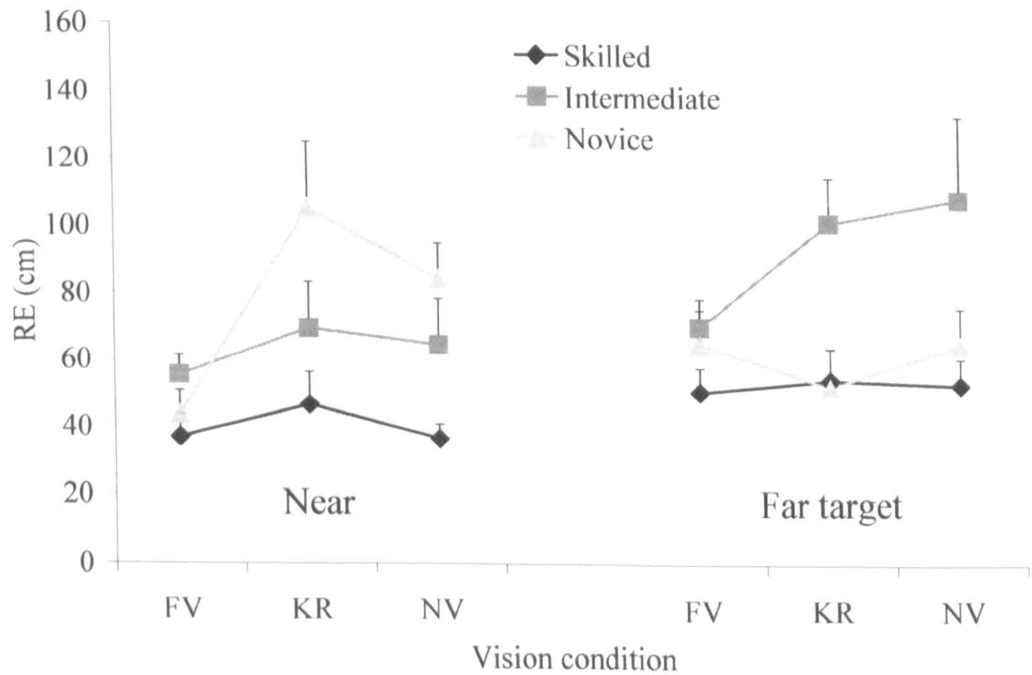

Figure 2.3. Mean radial error (cm) and between participant SE bars across the three vision conditions (FV = full vision; KR = No ball vision, plus KR; NV = No vision, no KR) as a function of group and target.

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 2.4. Deviations to the left were scored negatively and deviations to the right were scored positively. The group effect was not significant, F (2, 24) = 1.93, p =.17, μ_p^2 = 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, μ_p^2 = 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 x Vision interaction, F (1, 24) = 1.86, p =.13, μ_p^2 = 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 2.4. A significant group effect was observed, F (2, 24) = 3.49, p <.05, μ_p^2 = 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 x Vision interaction, F (1, 24) = 1.37, p =.26, μ_p^2 = 0.10. There was a significant target effect, F (1, 24) = 9.99, p <.05, μ_p^2 = 0.29. Participants were more consistent when kicking the ball to the near target compared to the far target.

Table 2.4. Mean (and SD) absolute constant error (ACE) and variable error (VE) in the x-axis as a function of group, target and condition (cm)

Target	Near			Far		
Group	Full vision	No vision with KR	No vision	Full vision	No vision with KR	No vision
Absolute constant error						
Skilled	9.36 (11.18)	12.42 (11.33)	14.94 (14.63)	6.61 (9.14)	15.89 (14.40)	23.22 (13.87)
Intermediate	23.42 (13.72)	22.47 (15.36)	21.81 (13.09)	18.11 (14.25)	25.67 (22.27)	14.22 (18.54)
Novice	12.06 (13.66)	19.86 (14.98)	14.36 (9.12)	20.53 (27.06)	20.11 (15.45)	32.25 (22.48)
Variable error						
Skilled	10.55 (7.13)	12.55 (8.31)	12.54 (8.17)	15.54 (9.05)	11.63 (7.87)	14.52 (7.98)
Intermediate	16.55 (9.26)	16.51 (9.71)	13.97 (9.59)	21.92 (14.84)	30.13 (27.84)	15.40 (13.24)
Novice	15.49 (9.60)	15.39 (10.33)	13.21 (5.39)	18.32 (9.32)	25.50 (14.57)	28.57 (20.40)

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 2.4a. A significant group effect was observed, F (2, 24) = 3.87, p <.05, μ_p^2 = 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. There was no significant vision effect comparing across the full vision and the two no vision conditions, F (1, 24) = 2.01, p =.17, μ_p^2 = 0.08. There was no difference between the two no vision conditions, F < 1. The Group × Vision interaction was not significant, F (2, 48) = 2.33, p =.07, μ_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 2.4b. A significant group effect was observed, F (2, 24) = 6.18, p <.05, μ_p^2 = 0.34. The skilled group was significantly more accurate than both the intermediate and novice groups, who did not differ from each other. There was no significant vision effect comparing across the full vision and the two no vision conditions, F (1, 24) = 2.56, p =.10, μ_p^2 = 0.10. There was also no difference between the two no vision conditions, F (1, 24) = 1.09, p > .05, μ_p^2 = 0.04. There was no Group x Vision interaction, F < 1. The target effect was significant, F (1, 24) = 8.04, p <.05, μ_p^2 = 0.15. Participants were more consistent when kicking the ball to the near target compared to the far target.

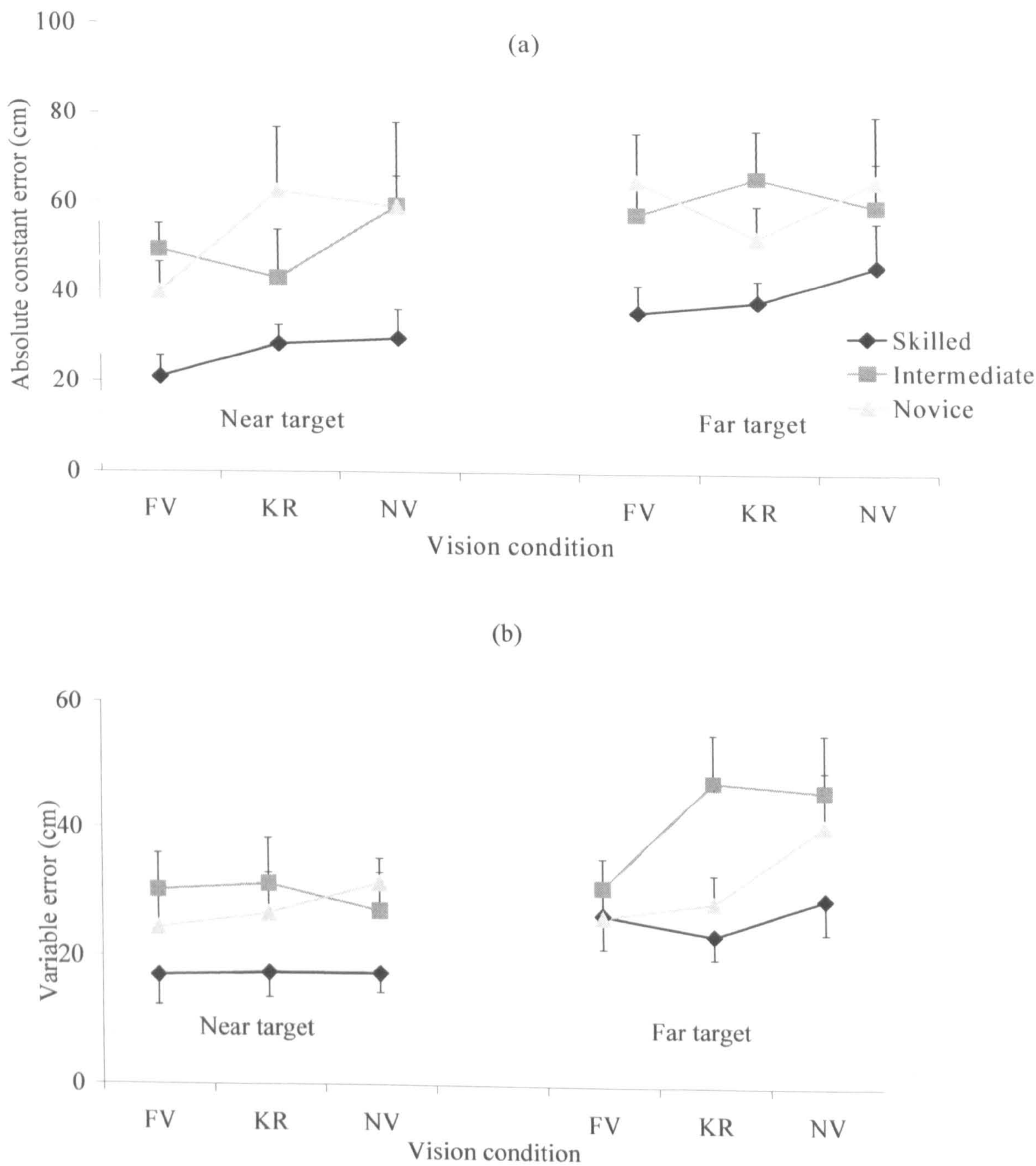

Figure 2.4. Mean (a) absolute constant error (and between participant SE bars) in *x*-axis, and (b) variable error (and between participant SE bars) in *x*-axis, across the three vision conditions (FV = full vision; KR = No ball vision, plus KR; NV = No vision, no KR) as a function of group and target.

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 2.5a. There was a trend for participants to become less variable when ball trajectory information was removed (irrespective of KR availability), $F(1,21) = 2.45$, $p = .13$, $\mu_p^2 = 0.10$. Although vision did not interact with group there was a significant Target × Vision interaction comparing across the two no vision conditions, $F(1,21) = 5.89$, $p < .05$, $\mu_p^2 = 0.22$. 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 2.5b. Variability in knee-ankle coordination decreased when ball trajectory information was removed (irrespective of KR availability), $F(1,21) = 7.68$, $p = .01$, $\mu_p^2 = 0.27$. No other effects were significant.

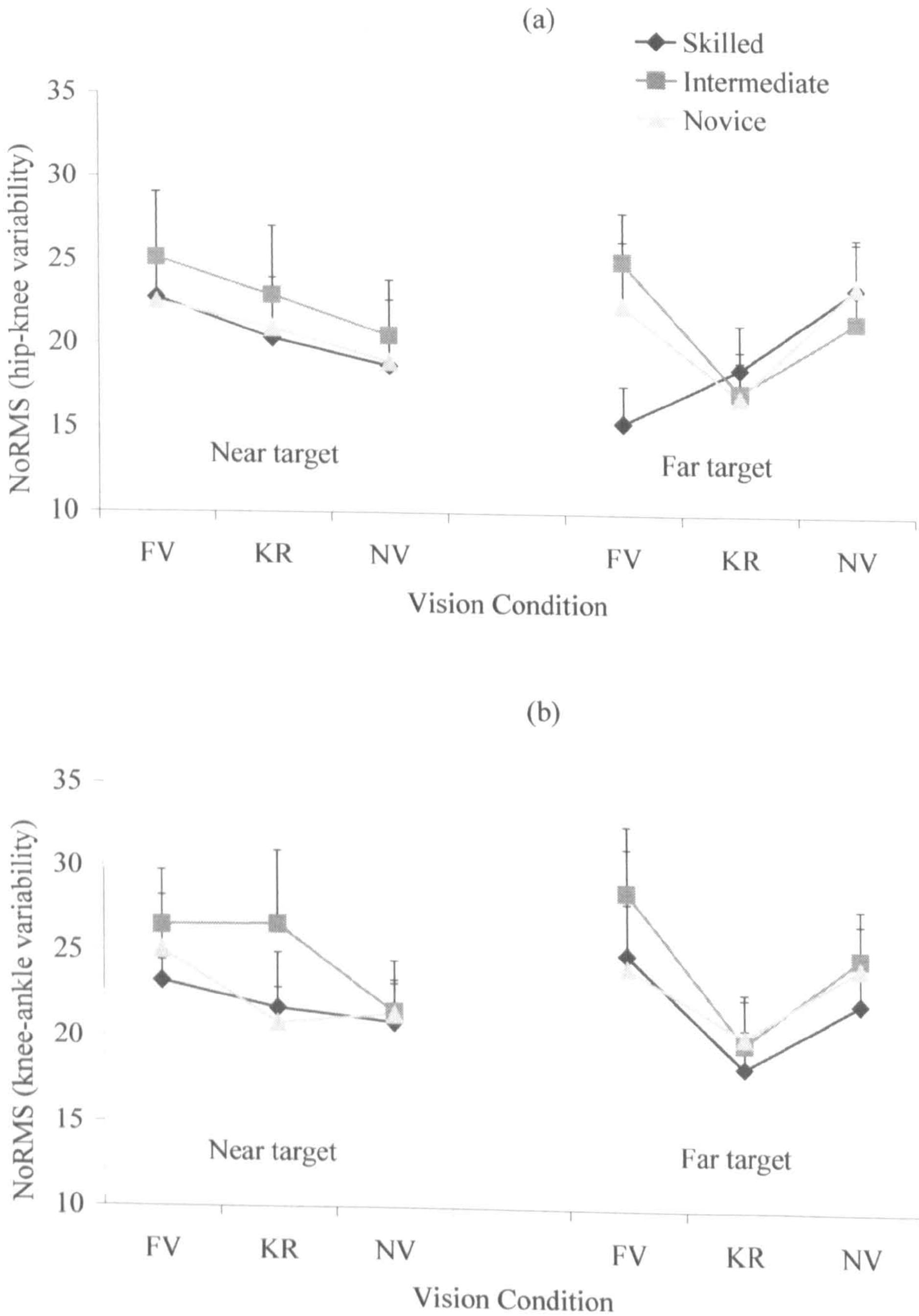

Figure 2.5. Between trial variability as indicated by NoRMS in (a) hip-knee coordination and (b) knee-ankle coordination, across three vision conditions (FV = full vision; KR = No ball vision, plus KR; NV = No vision, no KR) as a function of group and target.

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. Proteau *et al.*, 1987), 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 Proteau, 1992; Schack & Mechsner, 2006).

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, there was 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. For these performers, at the far target there were no differences across these three conditions. All participants were generally less successful at clearing the height barrier to the near (57 % success) target 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 (see Figure 2.4 and Table 2.4). 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 view 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, there was 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. 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.

General Discussion

The aim of these two experiments was to examine the importance of the visual consequences of an action as a function of skill at a soccer-kicking task. Participants were required to kick a soccer ball over a height barrier to either a near or far target. In this task, the external action effects were ball trajectory information and information pertaining to outcome attainment (i.e., KR), which were additionally feedback sources. These two sources of information were subsequently manipulated in three conditions in which, following ball contact: (i) visual information of ball flight and landing position (i.e., knowledge of results, KR) was fully available; (ii) visual information of ball flight was not available, neither was KR; and (iii) visual information of ball flight was not available, but KR was provided in the form a marker indicating landing position. In Experiment 1, skilled soccer players were examined, whereas participants in Experiment 2 were skilled, intermediate and novice soccer players.

In Experiment 1, no evidence was found that visual information pertaining to the ball trajectory was important for performing a skilled soccer kick to both near and far targets. In Experiment 2, in which three skill levels were examined and the order of target conditions was varied in an effort to increase the demands on movement planning, there was evidence that visual information of external action-effects was important at the novice and intermediate stage of learning, whereas at the more skilled stage, this information was again not important for skill execution, supporting the findings from Experiment 1. Together, these findings demonstrate changes across the skill acquisition continuum in the information used to plan and execute a soccer-kick.

Across the two experiments, under both blocked and random practice orders, skilled participants performed as accurately under conditions where the visual consequences of the action were withheld as they did under conditions where this information was available. It is assumed skilled performers were able to compensate for the occlusion of visual information, perhaps by vividly imagining the effect (Koch *et al.*, 2004) or by switching to alternative sources of sensory information, such as proprioception. However, a change in the movement kinematics following the removal of ball trajectory information demonstrated that all participants' coordination patterns were less variable when visual feedback of ball trajectory was withheld. This finding suggests that even at high levels of skill, ball trajectory information is used to adjust actions from trial to trial, although doing so did not affect skilled accuracy. Even though intrinsic error-detection capabilities had been developed that enabled accurate movements in the absence of response-produced feedback, this was evidence that this ball trajectory information was being used when it was available to update the action plan across trials (see Robertson *et al.*, 1994).

It has been shown that during the early stage of acquisition for a specific action, 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). In Experiment 2, novice performers, who were at the earliest stage of learning, showed evidence that they were in the process of acquiring associations between action and effects. Evidence for this was provided by their reliance on different sources of visual information (i.e., KR, ball trajectory) depending on what was currently the most difficult task goal. For trials to the far target, where height barrier clearance was not a major constraint, the addition of KR improved accuracy performance (see Figure 2.3). For trials to the near target, where height barrier clearance was the major constraint (as evidenced by a lower percentage of successful barrier clearances at this target), ball trajectory information was important, as this was the most important information source for improving success in height barrier clearance. For the intermediate performers, their reliance on ball trajectory information for successful performance, as evidenced by increased error when this information was removed, demonstrates they had already acquired associations between the action and its effects, and were subsequently using these to plan and control actions for both targets. These findings support the view that visual information plays a role in the cognitive representations that precede and govern action (Proteau *et al.*, 1987). This may still be the case at the skilled stage of acquisition, although the evidence in the present experiments, at least for outcome accuracy, does not support this argument. Skilled participants may still be able to see, visualise and anticipate the action effects more vividly than their lower skilled counterparts (Koch *et al.*, 2004), but they are not reliant on this information for successful performance.

Evidence has been presented in these experiments to suggest that action-effect associations are established, and that in terms of ball trajectory, they are used as a source of feedback to aid in movement accuracy. There has been no evidence to indicate that actions are planned by anticipation of their effects. Since anticipatory cognitive representations cannot be directly observed providing evidence for them is not an easy task, but must be inferred through behavioural data (Kunde *et al.*, 2004). Assessment of accuracy data and movement form alone through manipulation of the sensory consequences may be insufficient to make any clear conclusions about their role in action selection and initiation. In experiments to date where the action-effects hypothesis has been examined, speed (i.e., RT) rather than accuracy of the movements has been the primary measure of performance and examination of this hypothesis has been restricted to relatively simple movements typically involving only a key-press response (see Kunde *et al.*, 2004). We have begun experiments during which attempts are made 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 the 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. Some 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.

Footnotes

1. In Experiment 1, 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). Performance bias was expressed (in cm) as absolute constant error (ACE). This was calculated by using the x- and y-axis signed data to derive a mean for each participant under each Vision x Target condition. The first trial in each condition was not included in the calculation of VE and ACE. There were no significant main effects for vision or target, and no significant Vision x Target interactions. This data was omitted from the text for the sake of brevity.

2. 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 ($\underline{M} = 65$ vs 61 cm), especially in the four conditions when vision of the ball was prevented ($\underline{M} = 70$ vs 63 cm). In the height success data, there was a Height Success x 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.

3. 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.

Chapter 3

Examining action-effects in the execution of a skilled soccer kick through erroneous feedback

Abstract

The role of action effects (i.e., ball trajectory) during performance of a soccer kick was examined. Skilled players were required to kick a ball over a height barrier to a ground-level target area. Vision of the ball trajectory was occluded after ball contact. One group received erroneous ball trajectory feedback via video that showed a ball trajectory apex approximately 75 cm lower than their actual kick, while landing position was unaltered. A second group received correct video feedback of both ball trajectory and landing position. The erroneous feedback group showed a significant bias toward higher ball trajectories in comparison to the correct feedback group. These differences were observed not only in trials when erroneous feedback was presented, but also in trials when visual feedback was prevented. It was concluded that the visual consequences of the action are used to plan and execute an action even at high levels of skill.

Key words: *Expertise, vision, feedback, motor control*

During practice, performers are believed to acquire general and task-specific perception-action representations that guide the planning and production of actions (Adams, 1971; Schmidt, 1975, 1976; Proteau, 1992; Schack, 2004). The sensory effects of the action, especially those external to the performer, are thought to form an important part of these representations, such that actions may be generated by anticipation of their perceptual consequences (e.g., Koch, Keller, & Prinz, 2004). In this paper we provide skilled performers with erroneous feedback in order to examine the importance of the visual effects of the action (i.e., ball trajectory).

In the motor learning literature it has traditionally been thought that extended practice leads to the development of intrinsic error-detection mechanisms which decrease the need for feedback about the visual consequences of the action (e.g., Adams, 1971; Schmidt, 1975). More recently, however, research has shown that this information continues to be important across practice and there is evidence that extended practice leads to stronger associations between an action and its ensuing effects (e.g., Prinz, 1997; Elsner & Hommel, 2001; Kunde, 2001; Koch & Kunde, 2002; Kunde, Hoffmann, & Zellmann, 2002; Kunde, 2003; Kunde, Koch, & Hoffmann, 2004). This information is believed to be important for both action execution and initiation, where it has been shown that anticipation of an action's effect facilitates initiation of the action itself (i.e., RT, see Kunde *et al.*, 2002). Therefore, skilled performers who have amassed large amounts of practice on a task are expected to have formed strong associations between an action and its visual effects. As a consequence, they might be more reliant on viewing the visual consequences for successful initiation and execution of an action than their less skilled counterparts.

In an effort to examine the role of action effects in the execution of a whole-body action, Ford, Hodges, Huys, and Williams (in press) occluded ball flight information during the execution of a soccer kicking action. There was evidence that novice and intermediate level performers were dependent on visual information of the ball's trajectory, such that accuracy decreased when it was removed, irrespective of the provision of knowledge of results (KR). In contrast, the accuracy of the skilled performers was not affected by the removal of this information, although analysis of kinematics showed that across skill levels a more constrained, rigid movement was displayed in the absence of ball flight information. At least in terms of accuracy in target attainment, these data showed a decreased role for this information at higher levels of skill. However, on the basis of these findings alone it cannot be concluded that ball trajectory information does not form an important part of the movement representation at higher levels of skill.

In laboratory experiments conducted by Kunde and colleagues (e.g., Kunde *et al.*, 2002), the typical measure of performance has been RT in response to an action-effect prime. These authors have demonstrated that action-effect information is active before and during the initiation of a movement, such that it is used in the planning of an action. The fact that removal of this information does not impair target accuracy on subsequent trials does not rule out the possibility that this information is anticipated before the action and that more subtle measures of performance may be necessary to examine how this information is used during the planning and execution of the skill. If skilled participants have well developed representations of this end-effect then they might be able to vividly image the expected effects for the upcoming action without the need to view these consequences to aid in the preparation of subsequent movements (Koch *et al.*, 2004). This would be particularly true in those cases where accuracy is high and hence errors are low (see Ford *et al.*, in press).

Furthermore, in a sport such as soccer, visual information must be quickly gained from the environment about the movements of other players in addition to the flight of the ball. There is evidence that performers who have amassed many hours of practice under various task and sensory conditions have developed the ability to adapt in a flexible manner to the availability or occlusion of a particular source of sensory information (e.g., Bennett, Button, Kingsbury, & Davids, 1999; Soucy & Proteau, 2001). This flexible use of various sources of sensory information for accurate performance has been demonstrated among experts 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).

In the past, attempts to determine what information is used to aid movement control have been achieved through perturbation methods. When information is removed or occluded it has been suggested that this might change the way the task or skill is normally performed (see Khan, Elliott, Coull, Chua, & Lyons, 2002). It has been shown that experts are able to use different information sources in a flexible manner (e.g., Robertson *et al.*, 1994; Bennett *et al.*, 1999). Hence, under occluded conditions better performance in comparison to the less skilled might reflect flexibility in movement control, rather than enlighten as to whether a certain information source is typically used when it is available. Therefore, to more exactly determine whether a particular type of information is used when it is still available, researchers have examined how perturbed or erroneous information influences performance. If the information plays an important role in skill execution then it is expected that target accuracy will be adversely affected in the direction of any perturbations to the sensory feedback available during or after the movement. In the present experiment, if ball trajectory information is an integral part of the sensori-motor representation that guides movements, when this information is perturbed so that it deviates from its actual or expected trajectory, this should result in (erroneous) changes in the planning and execution of subsequent movements.

Manipulations to outcome success feedback (i.e., knowledge or results, KR) by Buekers, Magill, and Hall, (1992; see also Buekers & Magill, 1995; McNevin, Magill, & Buekers, 1994; Vanvenckenray, Buekers, Mendes, & Helsen, 1999) have shown that novice participants use this information to perform their actions as evidenced by performance biases in the direction of the erroneous KR. In an anticipation-timing task when participants were falsely told that their timing error was 100 ms later than it actually was, these participants subsequently demonstrated a bias of -100 ms during both acquisition, when KR was provided, and in retention, when KR was removed. Furthermore, Buekers and Magill (1995) showed similar findings with experienced performers at this task who are believed to have developed the intrinsic capability to detect and correct their own errors (and hence not rely on visual feedback for error detection purposes). However, erroneous KR only affected performance during and directly after the trials in which this information was presented.

The aim of this study was to examine the use of ball trajectory information for the successful execution of a lower-limb soccer kicking action performed by skilled participants. Two separate groups were compared who either received erroneous ball flight information after each available trial or received unedited, correct feedback. Erroneous feedback was video footage of a ball trajectory that was 75 cm lower than that achieved on the previous trial, although for both groups the landing position of the ball was unaltered, thus controlling for the effects of KR and hence 'accuracy' in this task. If information about the sensory consequences of the action is not important for skilled performance (e.g., Adams, 1971; Schmidt, 1975) then the erroneous feedback will not affect performance for this group. This will be determined through comparisons of pre- and post-test accuracy, as well as through comparison of the correct and erroneous feedback group. Alternatively, if action-effect information is being used to perform an action at high levels of skill (see Keller & Koch, in press), such that visual information pertaining to ball trajectory has become important for skilled performance, then participants in the erroneous group will show a bias in their actions towards higher ball trajectories (when ball flight feedback is underestimated) compared to participants in the correct feedback group. Since erroneous feedback has been shown only to affect the performance of experienced performers when it is provided, and not their long-term performance (see Buekers & Magill, 1995), if participants use this information then the effects of the erroneous feedback are expected only during the trial blocks in which erroneous feedback is provided.

Methods

Participants

Twenty skilled, male soccer players aged 21.9 years (*range* = 18-28 yr) volunteered to participate and provided informed consent. All procedures were conducted according to the ethical guidelines of Liverpool John Moores University. Participants were pseudo-randomly allocated into one of two groups with the constraint that these groups were approximately matched for years of competitive playing experience and that participants were allocated in an alternate fashion to the erroneous group then the correct group, due to the requirement to yoke participants in this latter group. The first group who received erroneous ball flight feedback had a mean age of 22.6 (range 20-28 yrs) years and had been playing soccer regularly for an average of 16.2 (range 14-21 yrs) years. The second group that received unedited, correct feedback, had a mean age of 21.6 (range 18-26 yrs) years and had been playing soccer regularly for an average 14.0 (range 10-19 yrs) years. All participants had previously played at Varsity level, and all but two had played at a professional club's youth academy or at a semi-professional level. Participants were free to withdraw from testing at any stage.

Task and Apparatus

The experimental set-up is shown in Figure 3.1. Participants were required to kick a soccer ball (a standard size 5, F.I.F.A. 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 enables the performer to achieve target success with relatively large variation in the height of the ball's trajectory. The experiment was conducted indoors on a carpeted surface. The target area was a 150 x 150 cm square marked on the floor in yellow tape. The floor switch (5 cm diameter) for manipulating vision via occlusion spectacles (Translucent Technologies, Toronto, Canada, Model PLATO P-1) was located 350 cm from the centre of the target area. The occlusion spectacles were connected to the floor switch via an extension cable. A height barrier was constructed using two 1 m long poles, with each being attached to a chair placed either side of the target grid so that there was a 50 cm gap between the ends of the poles directly in front of the participants starting position. The poles were horizontally aligned with the ground at a height of 75 cm and were parallel to, and 100 cm away from, the participant's starting position so that the ball would not hit the height barrier.

A moveable partition (300 cm wide, 180 cm high) was positioned to the left of the target area (215 cm from the centre). The end of the partition was aligned with the far edge of the target area. A plastic pole was mounted on the back of the partition and perpendicular to the height barrier, so that 1 m of the pole could be seen above the partition. Four height zones (each 75 cm high) were marked on the partition and pole in red tape. 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. Importantly, participants were not made aware of the height zones or that the height of the apex of their ball trajectory would be recorded.

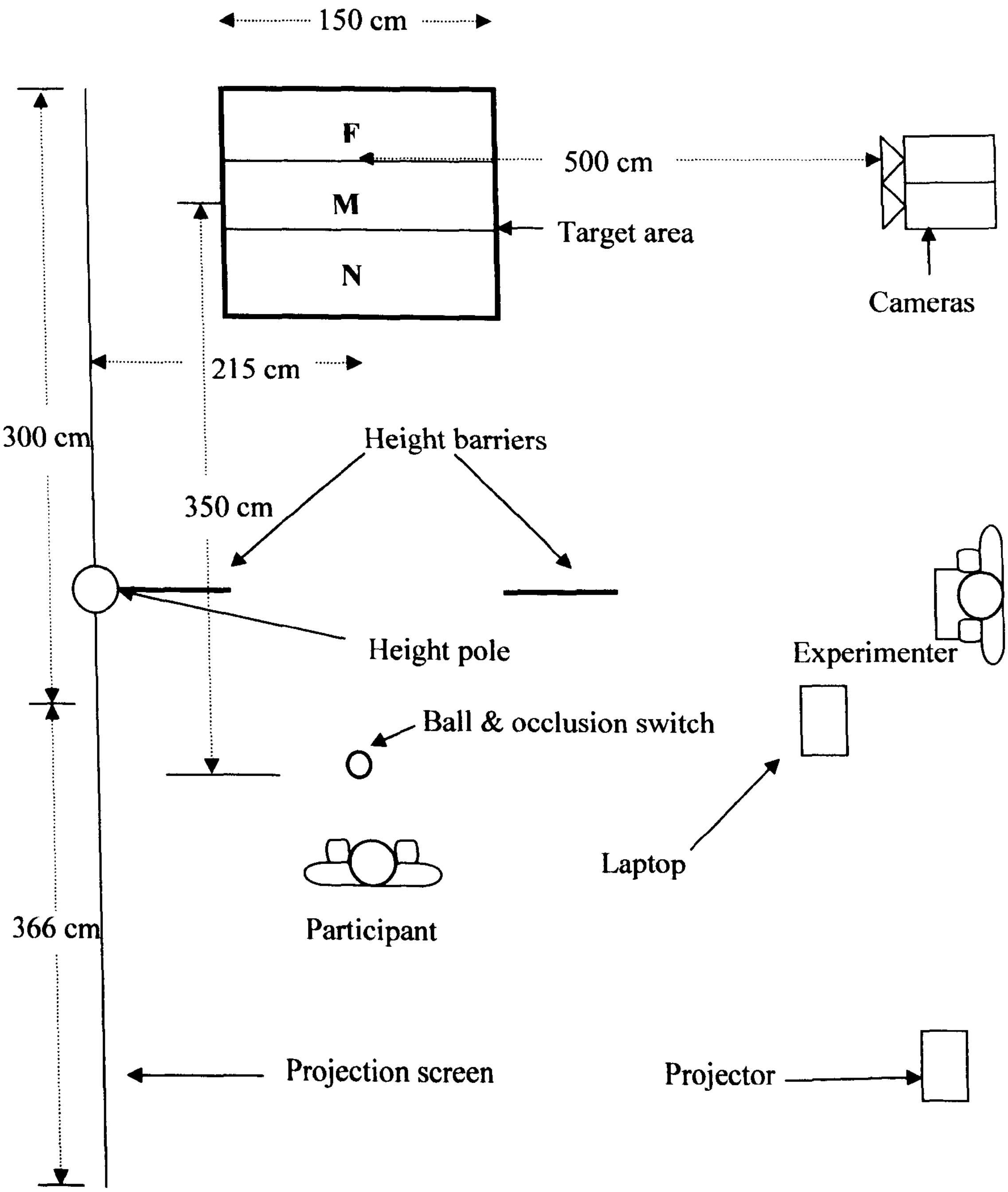

Figure 3.1. The experimental set-up and target area (F = far, M = middle, N = near).

A projection screen (Draper Screen Co., Indiana, USA, Model Cinefold, 366 cm wide, 274 cm high) was positioned in line with the partition to enable the provision of feedback. A large screen was used so that the height and distance of the ball could be exactly replicated in the video playback. A video projector (Dell U.K. Ltd., Bracknell, United Kingdom, Model 2300MP) was positioned facing the screen, to the right of the participant. Two digital video camcorders (Canon U.K. Ltd., Reigate, United Kingdom, Model XM2) were mounted on tripods, positioned next to each other and to the right of the target area. These cameras recorded the trajectory and landing position of the ball. Following the experiment, trials in which the determination of height zone was unclear were replayed. The ball trajectory camera was connected to the video projector in the correct feedback condition and could be operated via remote control. A laptop (Sony U.K. Ltd., Weybridge, U.K., Model Vaio PCG-K1155) was positioned on a table next to the video projector and a cable connected the laptop to the video projector in the erroneous feedback conditions. The experimenter was positioned in line with the height barrier, 750 cm from the centre of the target area where he could record outcome attainment and operate the cameras, laptop, and projector.

Pre-recorded video clips.

For the group who received erroneous feedback, twenty-four video clips of various ball trajectories were produced. Video footage pertained only to the flight of the ball, no body-related cues which could allow person identification were recorded. To produce the clips, a skilled soccer player performed the experimental task using the same ball as used in the experiment. One of the digital cameras recorded the flight of the ball as illustrated in Figure 3.2. This view of the ball trajectory was shown to participants as the visual feedback. The experimenter recorded the height zone attained at the apex of the ball's trajectory. Ball flight for three landing positions was filmed.

These landing positions were denoted 'near, middle, and far' corresponding to 50 cm zones within the target area (see Figure 3.1). Only in trials where the ball travelled in a relatively straight line towards the centre of the target area was the video footage retained. Two video clips were produced for each of the 4 height zones (HZ1, HZ2, HZ3, & HZ4) x 3 landing positions (Near, Middle, or Far) combinations, resulting in a total of twenty-four video clips. During testing the provision of these two clips was counter-balanced across trials for each pair of clips. Two clips were produced for each height zone x landing position to reduce the possibility that participants who viewed the same clip on repeated occasions would realise it was the same clip. This was confirmed through pilot testing. There were very minor variations between pairs of clips (e.g., the position of the ball varied by a few centimetres), although the height zone and target landing zone remained constant. All footage was stored on the laptop.

Procedures

Before the experiment, participants were misleadingly told that the experiment was designed to investigate the effects of feedback provision that was either body- or ball-related and that the provision of this information would be either "coach-selected" or "self-selected". The experimenter felt it necessary to mislead the participant in this way to avoid them suspecting that the feedback was not their own ball trajectory. All participants were then told that they were in the "coach–selected" group and that they would receive ball-related feedback. At the end of the experiment, the true purpose of the experiment was explained to participants. Participants were instructed that feedback would be provided in the form of video of their ball flight projected onto a screen. They were told 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 the kick before the start of testing. Participants first completed six familiarisation/pre-test trials under normal vision conditions. Participants then completed six occluded vision pre-test trials in which they wore the visual occlusion spectacles, as well as foam earplugs to block out audible feedback. 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. The spectacles remained opaque while the experimenter recorded outcome attainment. This included information regarding whether the target area was reached, the height zone, and whether the ball had landed in the middle of the target area in either the near, middle, or far landing area. Following the pre-test trials, participants completed a total of 30 experimental trials in which one group received erroneous feedback of their ball trajectory on selected trials and the other group received feedback of their own ball trajectory. Following these experimental trials, participants completed six post-test trials under occluded vision conditions and then six post-test trials under normal vision conditions. There was no limit set on the number of trials in which feedback could be given to the erroneous feedback group during the experimental trials. The number of trials across groups was balanced. No feedback was given on trials when the ball landed in the target area and the ball had veered to the left or right of the centre. It was also not given on trials in which the apex of the ball's trajectory appeared to be split between two height zones or on trials where the ball landed on a line denoting the target zones. Feedback was also not given on trials in which one of two errors occurred: the ball landed outside of the target area (i.e., either short, long, left, or right of the target area) or hit the height barrier. This resulted in feedback on just under one third of all trials (see Table 3.1). Participants wore the visual occlusion spectacles and earplugs in the feedback trials.

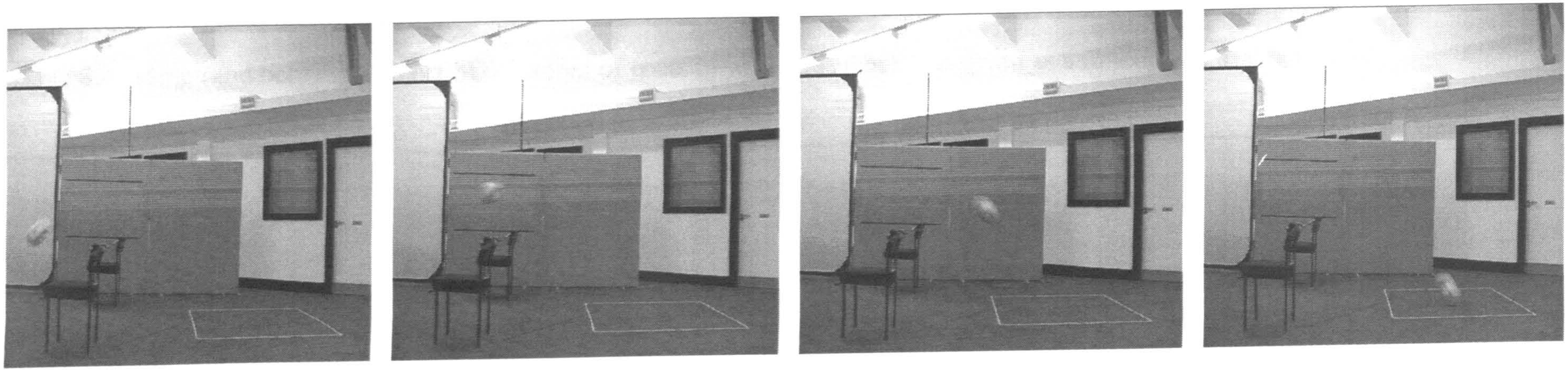

Figure 3.2. An illustration of the ball trajectory information provided as feedback to participants via a large video screen.

Table 3.1: Mean (and between-subject SD) number of trials in which feedback was given as a function of trial block.

	B1	B2	B3	B4	B5
Erroneous feedback	2.90 (0.99)	2.60 (0.84)	2.40 (1.65)	1.70 (1.34)	1.60 (1.07)
Correct feedback	2.60 (0.52)	2.70 (1.25)	2.00 (1.41)	2.10 (1.91)	1.80 (1.32)

Erroneous feedback group.

For the erroneous feedback group, the laptop was connected to the video projector. A cable was positioned so as to appear to the participants that it was connected to the laptop. Only one camera actually recorded outcome attainment during the trials. In the experimental trials, only when the ball landed in the target area and the ball flew in a straight line was erroneous feedback provided. The erroneous feedback was always shown video footage of a ball trajectory that reached its apex one height zone lower than their actual ball trajectory had reached. The actual landing position of the ball remained unchanged. For example, when a participant kicked the ball in a straight line through Height Zone 3 to the middle landing position, they were shown footage of a ball trajectory that went in a straight line through Height Zone 2 to the middle landing position. On trials in which one of the errors specified earlier occurred, feedback was not provided.

Correct feedback group.

Each member of the correct feedback group was yoked to a member of the erroneous group such that an attempt was made to provide feedback on the same trials as their yoked partner. For the correct feedback group, one of the cameras was connected to the video projector and operated via a remote control. The correct feedback group received feedback of their own ball trajectory and landing position. As with the erroneous feedback group, participants in this group only received feedback 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 errors specified earlier occurred, feedback was provided on the next available trial.

On trials where feedback was provided, 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 where feedback was not provided, the inter-trial delay was approximately 30 s. At the end of the experimental trials, participants in both groups completed six occluded vision, no feedback, post-test trials, in which they wore the visual occlusion spectacles and earplugs. This was then followed by six normal vision, post-test trials.

Data analysis

The two measures of performance were target success (i.e., hit or miss scored as a 0 or 1) and height zone (1-4). For data analysis, mean values were calculated based on 6 trial blocks for the 12 pre-test trials (normal vision, occluded vision), the 30 experimental trials, and the 12 post-test trials (normal vision, occluded vision). Mean values for target success and ball trajectory apex were calculated for each trial block as a function of group. Since data for the participant's success in hitting the target area was nominal 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 underlying distributions that were nearly normal. Two separate factorial ANOVAs were performed on each data set to examine both the immediate effects of the feedback and any remaining effects once feedback was withheld. This resulted in a 2 Group (Erroneous, Correct) x 5 Block (1-5) mixed ANOVA with repeated measures on the last factor and a 2 Group x 2 Test block (Pre, Post) x 2 Vision (Normal, Occluded) mixed ANOVA with repeated measures on the last two factors. Partial eta squared (μ_p^2) values are reported as a measure of effect size. Violations to sphericity were corrected using Greenhouse-Geisser procedures. Skill and interaction effects were followed up with Tukey HSD post hoc procedures. For all tests, the alpha required for significance was set at $p < .05$.

Results

For both groups, feedback was provided on a total of 112 experimental trials (M= 11.2 trials per participant, range = 7-16 trials) out of a total of 300 experimental trials (see Table 3.1). For the erroneous feedback group, the majority of the trials where erroneous feedback was given were when the ball peaked in Height zone 3 (such that the erroneous feedback was in Height zone 2; M = 7.2 trials, range = 3-12). The ball trajectory was in Height zone 2 on an average of 3.2 trials (such that the erroneous feedback was in Height zone 1; range = 0-8). The ball peaked in Height zone 4 on only 0.8 of the trials (range = 0-3). For the correct feedback group, there were a total of 27 occasions out of these 112 trials where an error or abnormality to the ball's trajectory meant that feedback was not received on the same trial as 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 3.3. A significant group effect was observed, $F\ (1, 18) = 24.03$, $p < .01$, $\mu_p^2 = 0.57$. 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 trial block, $F\ (2.54, 45.77) = 7.70$, $p < .01$, $\mu_p^2 = 0.30$, and Block interacted with Group, $F\ (2.54, 45.77) = 4.96$, $p < .01$, $\mu_p^2 = 0.22$. Post-hoc tests showed that on trial blocks 2-5 the erroneous feedback group achieved a higher height zone than the correct feedback group.

Erroneous feedback trials in which participants received feedback showing the ball apex in Height Zone 2 or 3 (i.e., ball cleared the height barrier) occurred twice as often (n = 80) as trials in which participants received feedback showing the ball apex in Height Zone 1 (i.e., perceived failure to clear the height barrier, n = 32). On the trial following the provision of erroneous feedback showing the ball apex in Height Zone 2 or 3 the apex of the ball trajectory was in a zone higher than achieved in the previous trial on 90% of occasions. On the trial following feedback that showed the ball apex in Height Zone 1 the ball apex was in a zone higher than achieved on the previous trial on 100% of occasions. These findings demonstrate that the erroneous group used the ball trajectory information to alter and raise their ball trajectory on the trial following feedback regardless of whether they perceived the ball had cleared the height barrier.

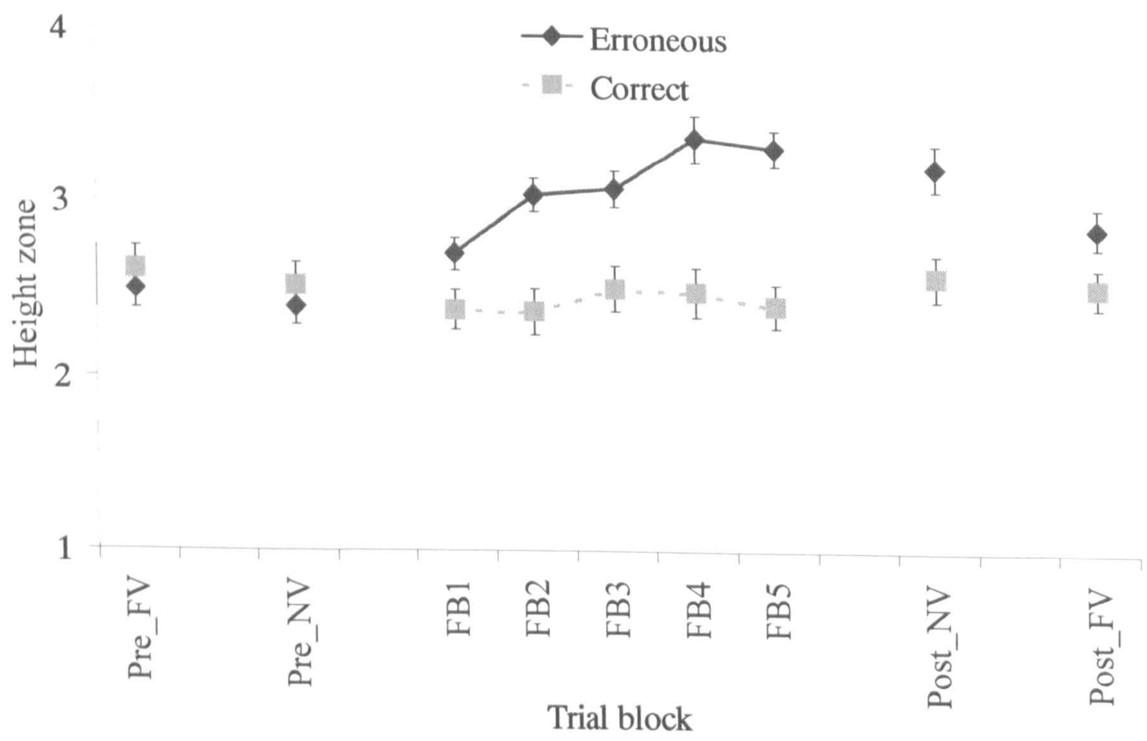

Figure 3.3. Mean apex of ball trajectory (and between participant SE bars) in terms of height zone for the 2 pre-test blocks, 5 experimental blocks, and 2 post-test blocks, across the two feedback groups (erroneous and correct).

Target success.

The mean percentage of trials in which the target area was hit is shown in Figure 3.4. There was a significant group effect, F (1, 18) = 7.99, $p < .05$, $\mu_p^2 = 0.31$. The correct feedback group was significantly more successful at hitting the target area than was the erroneous feedback group. A significant main effect for trial block was observed, F (4, 72) = 2.86, $p < .05$, $\mu_p^2 = 0.14$, and this interacted with Group, F (4, 72) = 4.58, $p < .01$, $\mu_p^2 = 0.20$. Post-hoc tests showed that there was no difference between the target success of the two feedback groups for the first two blocks, but in the final three trial blocks the erroneous feedback group were less successful at hitting the target than were the correct feedback group.

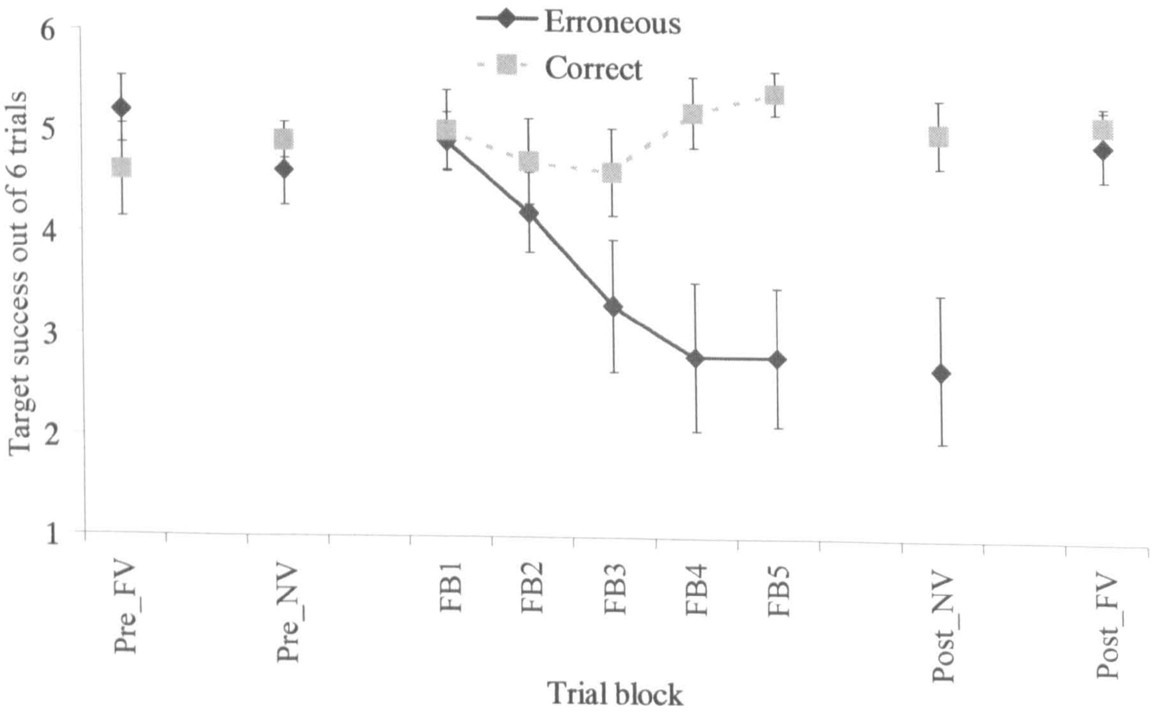

Figure 3.4. Mean frequency of successful trials in which the ball landed in the target area (and between participant SE bars) for the 2 pre-test blocks, 5 experimental blocks, and 2 post-test blocks, across the two feedback groups (erroneous and correct).

Errors.

The types of errors that occurred as a function of feedback group are shown in Table 3.2. 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 (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, to the right, barrier hit) only occurred on an average of 1 trial or less per participant.

Table 3.2. Mean (and between-subject SD) number and type of target misses.

	Long	Short	Left	Right	Hit Barrier
NV Pre-test					
Erroneous feedback	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
Correct feedback	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)
Experimental trials					
Erroneous feedback	9 (7)	1 (1)	1 (1)	0 (0)	0 (1)
Correct feedback	1 (2)	3 (2)	1 (2)	0 (0)	0 (0)
NV Post-test					
Erroneous feedback	3 (3)	0 (0)	0 (0)	0 (0)	0 (0)
Correct feedback	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)

Pre- to post-test

Height zone.

These data are presented in Figure 3.3. There was no significant group effect, F (1, 18) = 2.51, p = .13, μ_p^2 = 0.12. There was a main effect for trial block, F (1, 18) = 8.01, $p < .05$, μ_p^2 = 0.31, and this interacted with Group, F (1, 18) = 9.26, $p < .01$, μ_p^2 = 0.34. Post-hoc tests showed that there was no difference in the apex of ball trajectory for the two feedback groups in the pre-test trial blocks. However, the ball trajectory apex of the erroneous feedback group was significantly higher than that of the correct feedback group in the post-test trial blocks. No main effect for vision was observed, F < 1. There was a significant interaction between Block and Vision, F (1, 18) = 9.61, $p < .01$, μ_p^2 = 0.35. Post-hoc tests showed that under normal vision conditions there was no difference in the ball trajectory apex between the pre- and post-test, but under occluded vision conditions the ball trajectory apex was significantly higher in the post-test compared to the pre-test. Despite the trend towards higher ball trajectories for the erroneous feedback group in the post-test, occluded vision condition, in comparison to the correct feedback group, there was no three-way Group x Block x Vision interaction, F (1, 18) = 2.21, p = .16, μ_p^2 = 0.11.

Target success.

The mean number of trials in which the target area was hit is shown in Figure 3.4. The group effect was not significant, although it approached conventional levels, F (1, 18) = 4.10, p = .06, μ_p^2 = 0.19. The correct feedback group tended to be more successful at hitting the target area than was the erroneous feedback group. No significant main effect for trial block was observed, F (1, 18) = 3.57, p = .08, μ_p^2 = 0.17. However, there was a significant Group x Block interaction, F (1, 18) = 7.98, $p < .05$,

μ_p^2 = 0.31. Post-hoc tests showed that there was no difference in the target success of the two feedback groups in the pre-test trial blocks, but the target success of the erroneous feedback group was significantly lower than that of the correct feedback group in the post-test trial blocks. There was a main effect for vision, F (1, 18) = 7.35, $p < .01$, μ_p^2 = 0.29, and a significant Group x Vision interaction, F (1, 18) = 9.76, $p < .01$, μ_p^2 = 0.35. Post-hoc tests showed that there was 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. A significant interaction between Block and Vision was observed, F (1, 18) = 6.22, $p < .05$, μ_p^2 = 0.26. Only under occluded vision conditions was target success significantly worse in the post-test compared to the pre-test. There was no three-way Group x Block x Vision interaction, F (1, 18) = 2.68, p = .12, μ_p^2 = 0.13.

Discussion

We examined the importance of ball trajectory information for the execution of a lower-limb soccer kicking action performed by skilled participants. Participants were provided with either erroneous or correct feedback pertaining to the flight of the ball while KR was held constant. Traditionally, it has been believed that visual feedback has a reduced role to play as skill is acquired, whether this is information about outcome success or about how the movement was achieved (e.g., Adams, 1971; Schmidt, 1975). However, there has been evidence which serves to question this diminished role for visual feedback about an action and its consequences as a function of practice experience (e.g., Kunde, 2001; Proteau, 1992). We have previously seen little evidence of an increased dependence on this information among skilled participants when we have occluded ball trajectory information (Ford *et al.*, in press). In comparison, perturbing this information was expected to be a more effective manipulation for determining whether this information is used (when available) by skilled performers. In the current experiment, the importance of ball trajectory information was evidenced in the skilled, erroneous feedback group by a bias in their actions towards higher ball trajectories in comparison to the skilled correct feedback control group. This bias was observed both during practice and in the post-test (when erroneous feedback was no longer presented) compared to the pre-test.

These findings provide evidence that visual information pertaining to ball trajectory is an important part of the sensori-motor representation guiding skilled soccer kicking actions (e.g., Keller & Koch, in press). Skilled participants were using the erroneous ball trajectory feedback to plan and execute their movements even though the corresponding results were still judged to be correct (i.e., the ball landed in the desired target area). This increase in the apex of the ball trajectory for the erroneous group was coupled with a decrease in target accuracy from pre- to post-test that resulted in a tendency to overshoot the target area (see Table 3.2). We believe that the feedback pertaining to the ball trajectory resulted in participants attempting to hit the ball either with more force or at a different angle to get it higher, which resulted in overshooting of the target. This finding demonstrates that the erroneous feedback group used the ball trajectory information to aid in skill execution. However, pre- to post-test under normal vision conditions there were no differences in the ball trajectory apex or in the target success data. Only under occluded vision conditions was the ball trajectory higher and the target success lower in the post-test compared to the pre-test. Although this effect was more noticeable for the erroneous feedback group in comparison to the correct group, the three-way interactions were not significant. These findings show that the effects of the erroneous feedback were still apparent when it was no longer provided, but only under conditions where correct feedback was not available (i.e., normal vision) and hence the erroneous feedback only affected short-term performance, and not the skilled participant's longer-term performance of the skill (see also Buekers & Magill, 1995).

The prediction that visual information pertaining to ball trajectory is an important part of the representation guiding skilled actions was further supported by the data from the feedback trials. The erroneous feedback group showed a bias towards higher ball trajectories in the last four feedback trial blocks (*M* height zone = 3.2) compared to the first trial block (*M* height zone = 2.7). This change was not observed 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, since target success could (and was) still achieved in the trials where erroneous feedback was provided this information played more than an error-detecting role (as in previous KR studies). The actual ball trajectory apex for participants in the erroneous group occurred most frequently in Height Zone 3, so that they received erroneous feedback showing an apex in Height Zone 2. Under these conditions, both height and target success were achieved yet the erroneous group still increased their ball trajectory apex on the trial following feedback provision. It is our suggestion that the skilled performers had an expectation of what the ball flight should look like (i.e., an internally driven anticipation of the sensory consequences) and that when this did not match the skilled performer's expectations, the action was modified on subsequent attempts. Other researchers have shown that the role of these 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; Kunde, 2001).

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) and/or relying on other sources of information to help with successful execution of their actions (such as proprioceptive control, see Robertson & Elliott, 1996). This finding was replicated in the present experiment for the correct feedback group who maintained target success even in trials in which visual feedback was not provided.

In conclusion, we have 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. The presentation of erroneous feedback caused a significant bias toward higher ball trajectories and target failures compared to correct feedback. As a result of extended practice and exposure to the task, skilled performers who have also developed the capability to plan and control their actions using 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.

Chapter 4

Focus of attention in the planning of a soccer kick: A comparison across skill level

Abstract

There is evidence that actions are planned by anticipation of their distal effects (e.g., Kunde, 2001). This ability requires the prior acquisition of action-effect associations, the strength of which is dependent on the amount of practice. Expert performers therefore are expected to plan actions in this way. In Experiment 1, skilled and novice soccer players performed a kicking task to clear a height barrier to a near or far target under four conditions: planning in terms of a distal action effect (i.e., ball trajectory) or in terms of body movements, either with or without visual feedback. In Experiment 2, new skilled and novice soccer players performed the same task under the same planning conditions, but under no vision conditions throughout (to remove any potential confounding effects of feedback). Although there were significant group effects in both experiments, accuracy was not affected by the planning focus. In Experiment 2, correlations across body joints were generally higher for body rather than ball planning, suggesting that this focus acted to produce more constrained movements. Across two experiments, there was little evidence that planning movements in terms of their distal action-effects was beneficial for performance or differentiated across skill.

Key words: action effects, expertise, motor skill, imagery.

Practice at a task is generally believed to lead to the development of cognitive representations that precede and govern that task (e.g., Elsner & Hommel, 2001; Schack, 2004). Recent evidence has led to the suggestion that these representations are bi-directional, so that once acquired the performer can intentionally recruit an action by anticipating its effects (for reviews, see Hoffmann, Stoecker, & Kunde, 2004; Koch, Keller, & Prinz, 2004). Typically, the existence of these anticipatory action effect-based representations has been demonstrated using reaction time methods in experiments involving simple, discrete tasks (e.g. key presses, Kunde, 2001), where artificial stimuli have been used as effects (e.g. tones, Kunde, Hoffman, & Zellmann, 2002). In this paper, we extend this research to a complex, real-world, multi-limb action with distal effects that are realistic consequences of the action.

Recent data presented by Kunde, Koch, and colleagues (Prinz, 1997; Elsner & Hommel, 2001; Kunde, 2001; Koch & Kunde, 2002; Kunde, Hoffmann, & Zellmann, 2002; Kunde, 2003; Kunde, Koch, & Hoffmann, 2004) has provided evidence that during practice associations are acquired between an action and its effects Once this association is acquired an action can be intentionally selected and initiated by anticipation of its effects. This can be contrasted to more traditional accounts of motor control, which have action selection and initiation being mediated by a motor program containing patterns of muscle activity (e.g., Schmidt, 1975). Since expert performers in motor domains have amassed large amounts of practice at specific motor skills (e.g., Helsen, Hodges, & Starkes, 1998), it is assumed that they would have built up strong associations between their actions and sensory consequences (or action-effects). If this is so, anticipation of the action effects is expected to be the defining or preferred way of planning actions (see Koch *et al.*, 2004). Novice performers are not expected to have developed strong links between actions and their effects and consequently the planning of actions at low levels of skill is expected to be different. Elsner and Hommel (2001) discuss two distinct yet overlapping stages to this process. Early in practice response-effect associations are established and later in practice these effects serve to elicit the response that brings about the effect. We have presented evidence in favour of this proposal where we showed that less skilled individuals on a kicking task were reliant on visual information about the actions' effects to help execute their actions in comparison to more skilled performers (Ford, Hodges, Huys, & Williams, 2006).

Evidence that skilled performers have established strong links between their actions and their effects has been presented by Keller and Koch (2006). They used the response effect compatibility paradigm (see Hoffman *et al.*, 2004) to show that skill-based differences exist in the strength of the association between an action and its effect(s). They also demonstrated that expert performers are better able to anticipate action effects when selecting and initiating that action. Participants with varying musical experience were required to respond as quickly as possible to four arbitrary colour stimuli by producing 'music-like' sequences. The sequences consisted of three taps on three vertically aligned keys. The location of these response keys were mapped to effect tones in either a compatible (e.g., top key activated high tone pitch), incompatible (e.g., top key activated lower tone pitch), or neutral (e.g., all keys activated same tone pitch) fashion. Reaction times to initiate a sequence were quicker in compatible trials compared to incompatible or neutral trials and this effect was magnified among skilled musicians (see also Drost, Reiger, Brass, Gunter, and Prinz, 2005).

Researchers investigating the anticipated action-effects hypothesis have tended to employ simple, laboratory-based key press tasks. In these tasks the distal effect is usually an artificial and an incidental consequence of the action response. It has been typical to examine 'skilled' performance following only hundreds of practice trials (rather than years of practice). There is no research to date examining this hypothesis for the successful initiation of more complex, real-world tasks involving multi-limb actions. Initiating complex actions by anticipation of their sensorial effects has been forwarded as a simple and economic way to automatically constrain the many degrees of freedom (Bernstein, 1967) and sub-movements (Schack & Mechsner, 2006) of the motor system. In research investigating the relative importance of sensory information as a function of practice for the on-line control of actions, task-based differences have emerged between simple tasks (e.g., Proteau, Marteniuk, Girouard, & Dugas, 1987) and complex tasks (i.e., real-world, multi-limb actions with naturally available action effects and acquisition phases lasting many years; e.g., Robertson, Collins, Elliott, & Starkes, 1994). For simple tasks, when the sensory conditions are held constant during practice, the performance of more experienced participants is typically more affected by the removal of one source of sensory information (typically vision) compared to the performance of novices (e.g., Proteau *et al.*, 1987). For complex tasks, the more experienced performers are less affected by removal of one source of sensory information in comparison to novices (e.g., Robertson *et al.*, 1994). It has been suggested that experts are able to maintain performance by switching control strategies to use alternative sources of sensory information (e.g., proprioception) to carry out the task (Williams, Weigelt, Harris, & Scott, 2002).

In many sport tasks the distal action effects are realistic consequences of the action, such as the trajectory of a ball, puck, javelin or discus. In these tasks the response effect also has an additional error alerting function to play (i.e., was the desired flight trajectory achieved). To date, there has been little examination of the importance of distal action-effect information pertaining to the trajectory of an object, such as a ball or discus, which is inherent in many popular sports (cf., Hodges, Hayes, Eaves, Horn, & Williams, 2005). If action-effect information is an important part of the action representation for skilled performers then we would expect that anticipation of the ball trajectory would be the optimal planning strategy for expert performers.

Focusing the attention of performers onto information external to their body induces an external focus of attention. Wulf and colleagues (e.g., Wulf, Höß, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Wulf & Weigelt, 1997; Wulf & Prinz, 2001) have shown that instructions or feedback which direct a performers' attention to the external-effects of the action on the environment are more effective for learning than instructions which direct their attention to the movement themselves (i.e., internal-focus). There is evidence that a focus on an external-effect (such as the ball leaving the racket in tennis) rather than a general external cue (such as the ball approaching the racket) is more beneficial for skill acquisition (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). Also, that a distal, external cue is better than a proximal, external cue for balance-related tasks (McNevin, Shea, & Wulf, 2003). However, Wulf *et al.* (2000) showed that learners benefited more from a focus on the club in golf than a focus on the trajectory of the ball. Whether this result is limited to situations where an implement, rather than the foot or hand, is required to exert force awaits testing.

These attentional effects have been suggested to be consistent irrespective of the skill level of the performer. For example, Wulf, McConnel, Gärtner, and Schwarz (2002) observed that volleyball serves were more accurate across skill levels under external- compared to internal-focus conditions. However, other researchers (e.g., Beilock & Carr, 2001; Beilock, Wieringa, & Carr 2002; Beilock, Carr, McMahon, & Starkes, 2002, Ford, Hodges, & Williams, 2005; Gray, 2004; Perkins-Ceccato, Passmore, & Lee, 2003) have observed skill-dependent attention effects. Manipulations to attention during skill execution in tasks such as soccer dribbling, golf putting, and baseball batting have generally shown that body-centred instructions interfere with performance at high levels of skill only. Novice performers are either not affected (e.g., Beilock *et al.*, 2002) or show detrimental effects when asked to focus on a feature external to the skill (e.g., Perkins-Ceccato *et al.*, 2003). Manipulations to the attentional focus of performers during skill execution have also been shown to impact on the movement kinematics. Movements have been shown to become more constrained and rigid when performers attend to their actual body movements (e.g. McNevin, Shea, & Wulf, 2003). Wulf, McNevin, and Shea (2001) forwarded the *constrained action hypothesis* to explain this phenomenon. This hypothesis predicts that performers who focus attention on their body movements actively intervene in the control of those movements, causing a reduction in the body's active degrees of freedom. This is typically evidenced in higher correlations across pairs of joints, such that joints are controlled as units (e.g., the lower leg rather than independent joints).

The following two experiments were designed to address the nature of the cognitive representations used to initiate and perform complex actions as a function of skill. Participants were required to kick a ball to clear a height barrier and land on one of two (near or far) targets under conditions designed to manipulate the planning process. Participants were instructed to plan their movements before the action either in terms of the anticipated trajectory of the ball, or in terms of the anticipated body actions. If actions are planned by anticipation of their distal effects, then planning actions in terms of the ball trajectory should lead to more accurate performance than a body-focused strategy. Since expert soccer players have amassed large amounts of practice it is assumed that they will have become highly proficient at planning actions by anticipation of their effects. For these performers, planning the actions in terms of the desired movements should be detrimental for performance in comparison to planning in terms of ball trajectory. In terms of movement kinematics, we would expect to see more constrained movements (i.e., higher correlations between pairs of joints), as indexed through increased couplings across joint pairs, under body- compared to ball-planning conditions (Wulf *et al.*, 2001).

Experiment 1

In Experiment 1, we attempt to manipulate the planning process through instructions that emphasise the planning of the upcoming action either in terms of body movements or in terms of ball flight. To do this, skilled and novice soccer players were instructed to demonstrate immediately before action execution the anticipated ball trajectory following ball contact or the anticipated movement form of the soccer kick. They were then instructed to 'keep that image in their mind' before and during the action. Participants demonstrated the anticipated ball trajectory through gesturing with their arm and hand. Distal action effects also enable the performer to detect errors in their performance that can then be used to correct the action and any subsequent attempts (Schmidt & Lee, 2005). Since distal action effects also serve this feedback purpose, as well as their suggestive role in action planning, in the present experiments we examined performance in the presence and absence of visual feedback of the ball trajectory. Feedback has been shown to be one of the primary variables affecting performance (see Hodges & Franks, 2004; Wulf & Shea, 2004). Therefore, changes in accuracy from trial to trial in this experiment might be more a function of visual feedback and KR (i.e., knowledge of results) concerning where the ball landed rather than the planning strategy and attentional focus. Participants will be required to kick a ball to different targets in a random order to encourage the need to evoke a new action plan across trials (see Lee & Magill, 1985).

Methods

Participants

Twenty undergraduate students (16 men, 4 women) aged 21.0 years (*range* = 18-31 yr) participated and provided informed consent. All procedures were conducted according to the ethical guidelines of Liverpool John Moores University. The first group comprised 10 male, skilled soccer players aged 21.4 years (*range* = 19-31 yr) with an average of 15.3 years (*range* = 9-27 yr) competitive experience. They were currently playing at Varsity level or above and had all played at a professional club's Youth Academy or in semi-professional leagues. The second group comprised 10 novice, recreational soccer players (6 men, 4 women) aged 20.6 years (*range* = 18-25 yr). Only four of the novice participants had played on recreational soccer teams at school level (i.e., before age 16 yr), whereas the rest had only played non-organised play soccer. Overall this group averaged 7.6 years (range 0-15 yr) playing experience.

Task and Apparatus

The experimental set-up is shown in Figure 2.1. Participants were required to kick a soccer ball from its starting position on a floor switch over a height barrier to either a near or far target. This task was chosen as a representative measure of skill in soccer due to the degree of control required (i.e., to kick, lift and place it accurately on a target). This skill is typically 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. It represents specialised skills of players beyond merely a beginner level. The experiment was conducted indoors, on a carpeted surface. The target measurement grid was a 400 cm x 600 cm rectangle divided equally into a grid with squares 50 cm x 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, F.I.F.A. regulation ball was positioned on this switch and visual occlusion spectacles (Translucent Technologies, Toronto, Canada, Model PLATO P-1) 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 (i.e., 'far target'). A height barrier was constructed using two 1 m long poles, each attached to a chair placed either side of the target grid. There was a 1 m gap between the ends of the poles directly in front of the participants' starting position, which prevented the ball striking the barrier. The poles were horizontally aligned with the ground at a distance of 70 cm from the ground, and were parallel to, and 100 cm away from the participant. A ruler was used for recording error in the ball's landing position compared to the centre of the target. In addition, a VHS Video Camera (Panasonic UK Ltd., Bracknell, United Kingdom, Model MS5 S-VHS) was used to aid in recording outcome attainment.

Three infrared cameras (Qualisys, Gothenburg, Sweden, Model MCU1000) 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.

Procedure

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 the ball from its starting position on the visual occlusion switch over a height barrier to the near or far target as specified by the experimenter. They completed ten familiarisation trials (five to each target). During these trials, participants wore transparent laboratory spectacles. Following these trials, participants completed 32 experimental trials under conditions where the planning process (and hence attentional focus) was manipulated via instructions, in the presence or absence of visual feedback (of both ball flight and outcome attainment).

Under ball-focused conditions (i.e., Ball), before each trial, participants were instructed to think about the expected ball trajectory for the upcoming target condition. They were also instructed to demonstrate the anticipated ball trajectory by standing still and gesturing with their right hand and arm. Participants were instructed to keep this image in mind as they were planning and executing the kick. Under body-focused conditions (i.e., Body), before each trial, participants were instructed to think about the expected body actions for the upcoming target condition. Participants were also instructed to demonstrate the anticipated movement form and to keep this image in mind as they were planning and executing the kick. In the full vision conditions (FV) participants wore transparent laboratory spectacles. In the no vision (NV) conditions, participants wore the visual occlusion spectacles. When the ball was on the switch the spectacles were transparent. Upon the ball being kicked from the visual occlusion switch the spectacles became opaque, occluding vision of the ball flight and landing position. The spectacles remained opaque while the experimenter measured the ball's landing position relative to the target. No verbal outcome feedback was provided under these conditions.

The order of conditions was counterbalanced across participants within a group, but was the same across groups. Both planning conditions (Body, Ball) were administered in a block of 16 consecutive trials, either as the first half or second half of the 32 experimental trials. Within each attention condition block, both vision conditions (FV, NV) were administered in a block of 8 consecutive trials, either as the first half or second half of the 16 attention condition trials. This was done under the proviso that two blocks of the same vision condition could not follow one another. Within each vision condition block, participants completed four trials to the near target and four to the far target. The target condition order was quasi-randomised within each vision condition. This was done under the proviso that no more than two trials to a single target could follow one another. Target condition order was the same for each participant.

Data analysis

Outcome error.

Height success data were collected, corresponding to the percentage success rate in clearing the height barrier across trial blocks. Since the percentage data were based on frequencies and was not normally distributed, as determined by a Kolmogorov-Smirnov test, the data were transformed using Bartlett's modified arcsine transformation (Bartlett, 1937, in Zar, 1996). The resultant data had an underlying distribution that was nearly normal. The primary measure of performance accuracy was radial error (in cm). Radial error (RE) 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 participant under each Planning x Vision x Target condition were calculated. All of the experimental trials were used except for trials in which participants failed to clear the barrier. Trials in which participants failed to clear the barrier were not included in the calculation of radial error. When data from a maximum of two cells for a single participant was missing an estimated value was substituted. This value was based on the individual participant's overall mean error and the mean of participants in that individual's group for the respective Planning x Vision x Target condition. If means corresponding to more than three cells were missing the participant was not included in the analysis. This proviso resulted in an analysis of n = 7 for the novice group and n = 9 for the skilled group.

To explore the effects of experimental conditions on RE and height success, a four-way factorial ANOVA was used to examine the effects of skill (skilled, novice), attention (ball, body) vision (FV, NV) and target (near, far), with repeated measures on the last three factors. Partial eta squared (μ_p^2) values are reported as a measure of effect size. Skill and interaction effects were followed up with Tukey HSD post hoc procedures. The alpha required for significance was set at $p < .05$.

Movement Kinematics.

Figure 2.2 shows an example of the type of kick required to achieve the task goal. The action was predominantly confined to the sagital plane, thus, effectively, the chip was established through the action of the hip, knee, and ankle joints in the kicking leg in this plane. The placement of the reflective makers on major joints of the body provided three-dimensional, Cartesian co-ordinates in the x-, y- and z-dimension, that is the sagital, transverse and coronal planes, respectively. Three trials for each Target x Planning x Vision condition were analysed. For each selected trial, the start point of the movement was defined as the beginning of knee flexion in the sagital plane immediately before ball contact. The end point of the movement was defined as the maximal displacement of the toe in the sagital plane.

To examine if pairs of joints are moved dependently, normalized cross-correlations with zero time lags were calculated using the co-ordinate data between two (i.e., x and y) of the three dimensions for co-ordination between the hip-knee, knee-ankle, and ankle-toe joint angles. The z dimension was excluded from this analysis as movement occurred predominantly in the x and y dimension. The cross-correlation values were transformed to Fisher z-scores for analysis and similar procedures were adopted as detailed for outcome measures. Data from one participant in each group could not be analysed due to corruption of data files. This resulted in an analysis of n = 9 for each of the two skill groups.

Results

Outcome error

Height success.

The proportion of trials in which the height barrier was successfully cleared to both targets within each condition is presented in Table 4.1. The skilled participants (M = 83.13 %, SD = 24.27 %) were significantly more successful than the less-skilled participants (M = 47.19 %, SD = 32.34 %), $F(1, 16) = 10.39$, $p < .05$, $\mu_p^2 = 0.37$. The ability to clear the height barrier was not affected by the planning or vision condition, F's < 1. There was a significant target effect, $F(1, 16) = 5.70$, $p < .05$, $\mu_p^2 = 0.23$. There was also a significant Target x Group interaction, $F(1, 16) = 10.07$, $p < .05$, $\mu_p^2 = 0.36$. Post-hoc analysis showed that the novice group was less successful clearing the barrier at the near target, but that the skilled group was unaffected by the target conditions.

Table 4.1: Experiment 1 mean (and between-subject SD) percentage (%) of successful height barrier clearances as a function of group, target and condition

Target	Near				Far			
Condition	Ball		Body		Ball		Body	
Group	Full vision	No vision	Full vision	No vision	Full vision	No vision	Full vision	No vision
Skilled	82.50 (31.29)	72.50 (34.26)	87.50 (21.25)	80.00 (30.73)	87.50 (31.73)	80.00 (30.73)	90.00 (17.48)	85.00 (31.62)
Unskilled	40.00 (33.75)	35.00 (39.44)	30.00 (30.73)	30.00 (34.96)	60.00 (35.75)	60.00 (35.75)	57.50 (42.57)	65.00 (33.75)

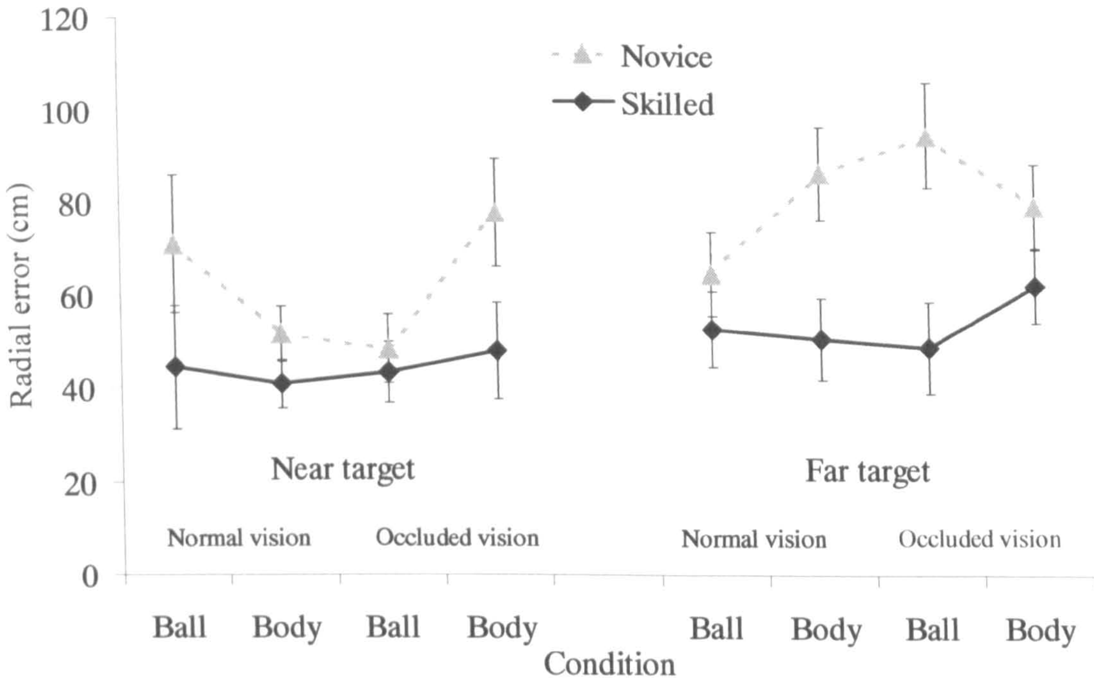

Figure 4.3. Experiment 1 mean radial error (cm) and between participant SD bars across the two vision conditions (FV = full vision; NV = No vision) and two attention conditions (Body, Ball) as a function of group.

Accuracy scores

The radial error scores for each condition are shown in Figure 4.3. There was a significant difference between groups, F (1, 16) = 16.94, p <.01, μ_p^2 = 0.55. Skilled participants were significantly more accurate compared to novice participants. There were no main effects for planning or vision conditions, F's < 1. There was a significant target effect, F (1, 16) = 6.87, p <.05, μ_p^2 = 0.33. Radial error was lower at the near compared to the far target. There was a significant four-way interaction comparing across Group and Planning condition as a function of Vision and Target, F (1, 16) = 13.32, p <.01, μ_p^2 = 0.49. Post hoc tests on this four-way interaction revealed that the skilled participants were not affected by the planning, vision, or target conditions. In comparison, novice participants were less accurate at the far target when planning the action in terms of the ball trajectory under occluded vision conditions. At the near target they were less accurate when planning the action in terms of ball trajectory under occluded vision conditions and planning in terms of body movements under normal vision conditions.

Movement kinematics

The *z*-transformed cross-correlations are presented in Table 4.2. There was a significant difference between groups for cross-correlation's in the x-dimension (but not the y-dimension) for the couplings between the hip-knee, F (1, 16) = 14.12, p <.01, μ_p^2 = 0.49, knee-ankle, F (1, 16) = 10.09, p <.01, μ_p^2 = 0.39, and ankle-toe, F (1, 16) = 14.46, p <.01, μ_p^2 = 0.48. Figure 4.4 shows that the correlation values were generally higher for skilled participants compared to novice participants. There were no significant effects involving the planning conditions. For vision, although there was no main effect, there was a Vision x Group interaction for the correlation of knee and ankle in the y-dimension, F (1, 16) = 14.46, p <.01, μ_p^2 = 0.48. Post hoc tests showed that skilled participants were not affected by the vision condition, whereas the novice participants showed a tighter, between joint coupling when vision was removed. There was a significant target effect for cross-correlations between the couplings of ankle-toe in the x-dimension, F (1, 16) = 6.86, p <.05, μ_p^2 = 0.30, as well as in the y-dimension for hip-knee, F (1, 16) = 11.17, p <.01, μ_p^2 = 0.43, knee-ankle, F (1, 16) = 4.78, p <.05, μ_p^2 = 0.23, and ankle-toe, F (1, 16) = 31.48, p <.01, μ_p^2 = 0.66. The cross-correlations for movement kinematics were higher, that is the couplings between joints were more constrained, at the near compared to the far target.

Table 4.2: Experiment 1 mean (and between-subject SD) movement kinematics cross-correlations expressed as z scores as a function of group, target, attention and vision condition.

Target	Near				Far			
Condition	Ball		Body		Ball		Body	
Group	Full vision	No vision	Full vision	No vision	Full vision	No vision	Full vision	No vision
x-dimension								
Skilled								
Hip-knee	2.26 (0.29)	2.29 (0.31)	2.29 (0.31)	2.31 (0.26)	2.19 (0.29)	2.31 (0.30)	2.31 (0.24)	2.33 (0.30)
Knee-ankle	1.93 (0.21)	1.90 (0.15)	1.94 (0.23)	1.93 (0.24)	1.89 (0.19)	1.85 (0.19)	1.90 (0.22)	1.90 (0.17)

Ankle-toe	3.20 (0.57)	3.17 (0.50)	3.13 (0.53)	3.15 (0.52)	3.20 (0.48)	3.18 (0.54)	3.25 (0.42)	3.24 (0.41)
Novice								
Hip-knee	0.22 (1.49)	0.25 (1.47)	0.44 (1.42)	0.37 (1.53)	0.33 (1.40)	0.25 (1.45)	0.33 (1.56)	0.22 (1.57)
Knee-ankle	1.05 (0.75)	1.17 (0.71)	1.24 (0.71)	1.19 (0.74)	1.29 (0.61)	1.24 (0.60)	1.25 (0.50)	1.32 (0.55)
Ankle-toe	1.89 (0.93)	1.94 (0.92)	1.98 (0.85)	2.01 (0.92)	2.03 (0.77)	2.00 (0.66)	2.18 (0.71)	2.22 (0.77)
y-dimension								
Skilled								
Hip-knee	2.66 (0.43)	2.63 (0.34)	2.59 (0.24)	2.48 (0.28)	2.38 (0.19)	2.45 (0.29)	2.41 (0.16)	2.32 (0.19)
Knee-ankle	1.71 (0.22)	1.70 (0.21)	1.66 (0.19)	1.67 (0.22)	1.55 (0.20)	1.59 (0.21)	1.62 (0.18)	1.58 (0.16)
Ankle-toe	1.58 (0.25)	1.65 (0.22)	1.61 (0.18)	1.72 (0.14)	1.87 (0.21)	1.78 (0.18)	1.80 (0.14)	1.93 (0.11)
Novice								
Hip-knee	2.32 (0.80)	2.35 (0.82)	2.27 (0.82)	2.36 (0.89)	2.21 (0.77)	2.19 (0.73)	2.17 (0.79)	2.15 (0.77)
Knee-ankle	1.70 (0.27)	1.76 (0.44)	1.69 (0.39)	1.85 (0.39)	1.62 (0.49)	1.71 (0.47)	1.63 (0.35)	1.69 (0.28)
Ankle-toe	1.60 (0.45)	1.50 (0.47)	1.59 (0.34)	1.54 (0.40)	1.77 (0.41)	1.63 (0.43)	1.77 (0.31)	1.77 (0.45)

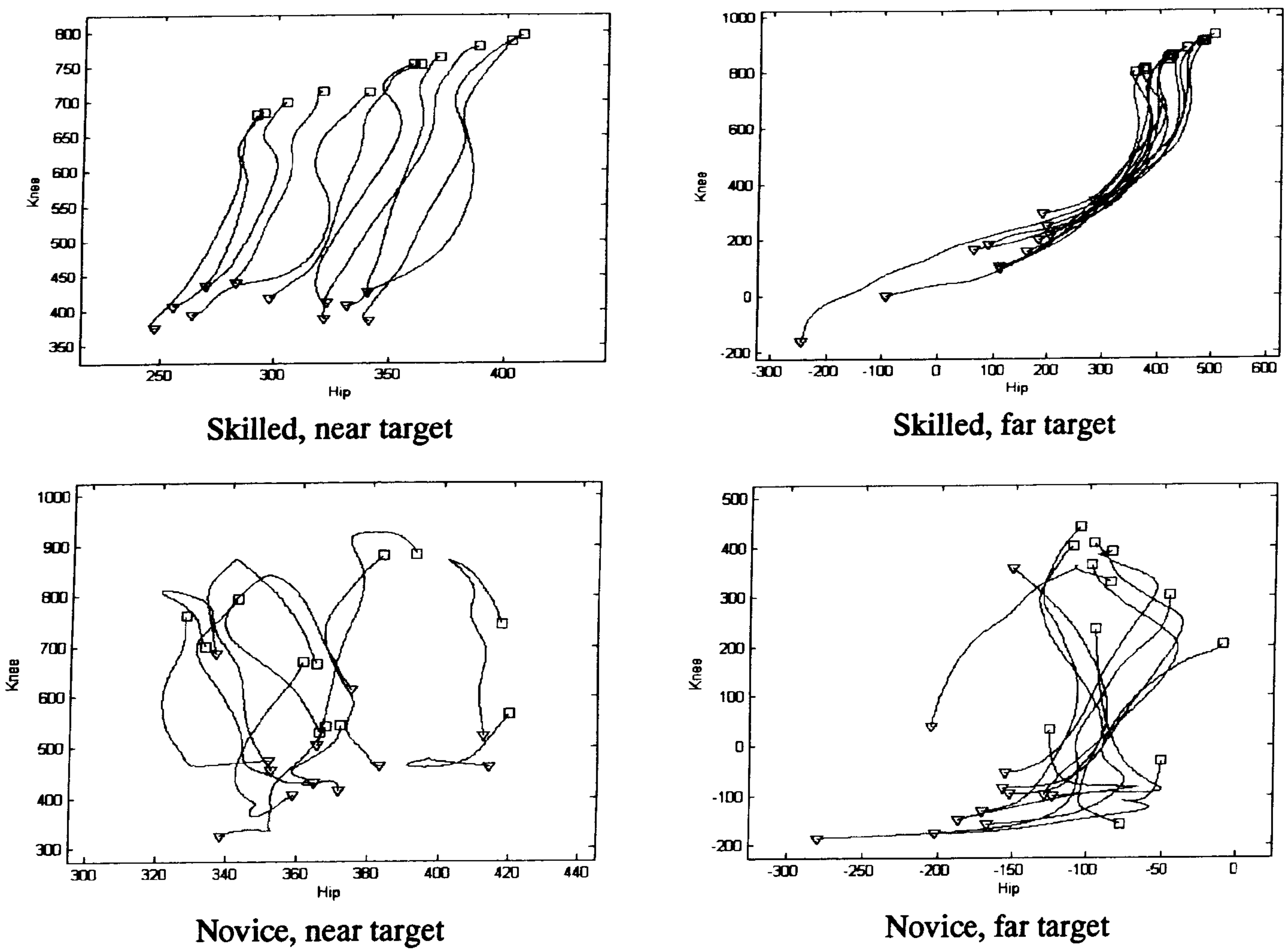

Figure 4.4. Experiment 1 hip-knee coordination in the x-dimension for each trial for Skilled Participant No. 9 and Novice Participant No. 1.

▲ = start of movement; □ = end of movement.

Discussion

In this experiment, the planning process was manipulated through instructions that emphasised planning of the upcoming action either in terms of ball flight or in terms of body movements. If actions are planned by anticipation of their distal effects, then planning the action in terms of ball trajectory was predicted to lead to more accurate performance. Skill-based differences were expected to exist in the strength of the association between an action and its effects. Expert performers were predicted to be more proficient at planning actions by anticipation of their distal effects than novices. These predictions would also be supported by research examining skill-based differences in attentional focus, whereby extended practice is expected to lead to a control focus away from the body in comparison to early in learning (e.g., Beilock *et al.*, 2002).

Despite these predictions there was no evidence to support the proposal that actions are planned by anticipation of their distal effects irrespective of the skill level of the performer. There may be methodological reasons for the lack of significant findings. First, since trials in which the participants failed to clear the height barrier were removed from the analysis, the actual number of trials used for the analysis was very low. Second, distal action effects also enable the performer to detect errors in their performance, which can then be used to correct the action and any subsequent attempts (Schmidt & Lee, 2005). The availability of visual feedback (on at least half of the trials) may have played a strong role in determining changes in performance from trial to trial making it difficult to see how action planning was related to accuracy. Third, since there was no control condition in this experiment it is difficult to assess whether the planning manipulations had a positive or detrimental effect on performance. Finally, it may be that participants did not adhere to the instructions to plan their action in terms of the body movements or in terms of the ball trajectory. Therefore, it is necessary to assess adherence in a post-test questionnaire. All of these factors were incorporated into the design of Experiment 2.

Experiment 2

In the following experiment, a further attempt was made to manipulate the planning process via instructions that emphasised the planning of the upcoming action either in terms of distal action effects (i.e. ball trajectory) or body movements. Skilled and novice participants were newly recruited and, to remove the effect of visual feedback, all trials were performed under no vision conditions. To enable the examination of any positive or negative effects of the planning conditions, a no planning control condition was included in the experimental trials. To determine if and how well participants were able to adhere to the instruction manipulations a post-experiment questionnaire was used to examine behaviours. Finally, in view of the difficulties in comparing error scores for trials that did and did not successfully clear the height barrier, pre-test criterion trials were included to encourage height success. The predictions were the same as for Experiment 1.

Methods

Participants

Twenty-four undergraduate students (12 men, 12 women) aged 20.1 years (*range* = 18-31 yr) volunteered and gave informed consent. All procedures were conducted according to the ethical guidelines of Liverpool John Moores University. The first group comprised 12 male skilled soccer players aged 20.5 years (*range* = 18-24 yr). They had 13.5 years (*range* = 8-17 yr) competitive experience. They were currently playing at Varsity level or above and had all played at a professional club's Youth

Academy or in semi-professional leagues. The second group comprised 12 female novice soccer players aged 19.7 years (*range* = 18-31 yr). They had 1.2 years (*range* = 0-9 yr) playing experience. None of the participants had participated in Experiment 1.

Task and Apparatus

The task and apparatus were the same as in Experiment 1.

Procedure

The procedure was generally the same as in Experiment 1. However, there were differences in the amount of warm-up trials, the inclusion of a control condition and the order the conditions were administered. Participants were required to complete a set of full vision criterion warm-up trials in which they had to clear the height barrier on twelve consecutive trials before moving on to the next phase of the experiment. When participants were unable to clear the barrier on a trial, the consecutive count of twelve trials began again, although only a maximum of 24 trials could be administered (in blocks of four trials to the near target, four to the far, four to the near etc.). Only one out of ten novice participants (*range* = 15-24 trials) managed to clear the barrier on twelve consecutive trials. The others reached the maximum amount of trials without achieving this criterion. All of the skilled participants cleared the barrier on twelve consecutive trials (*range* = 12-24 trials, *median* = 12 trials). Only one skilled participant required all 24 trials. Once participants had met this criterion, they completed six familiarisation trials (a block of three trials to the near target, three to the far) wearing the visual occlusion spectacles. No outcome feedback was provided. Participants then completed 36 experimental trials under three conditions where action planning was manipulated via instructions.

The attention conditions were the same as in Experiment 1, apart from the additional control condition in which the participants were instructed to perform the kick. The twelve trials for each condition were separated into two blocks of six trials. The order of conditions was random with the constraints that one block from each condition was allocated to the first half of the experiment and that the last condition in the first half of trials could not be the same as the first condition in the second half of the trials. Within each planning condition block, participants completed three trials to the near target and three to the far. The target order was randomised within each condition. The overall target order remained the same for each participant. During the experimental trials, participants wore earplugs and the visual occlusion spectacles, to remove visual and auditory performance feedback. No outcome feedback was provided. Participants were instructed before the experiment that summary feedback would be provided at the end of the experiment. Following the experimental trials, and before feedback had been given, participants were asked a series of questions related to the planning conditions (see Table 4.5).

Data analysis

Outcome error.

Procedures for calculating error scores and height success were the same as for Experiment 1. To explore the effects of experimental conditions on RE and height success a three-way factorial ANOVA was used to examine the effects of skill (skilled, novice), planning (ball, body, control) and target (near, far), with repeated measures on the last two factors. Based on predicted differences, comparisons involving the three planning conditions were examined using pre-planned contrasts. The contrast compared first the control condition to the experimental conditions and second the ball condition to the body condition. Partial eta squared (μ_p^2) values are reported as a measure of effect size. 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.

Calculation of movement kinematics was the same as in Experiment 1. As a result of occluded or missing markers, three participants in the skilled group and one participant in the novice group were excluded from the analysis. Four trials per Target x Planning condition were analysed. As in Experiment 1, correlations were transformed to Fisher *z*-scores for analysis.

Results

Outcome error

Height success.

There was a significant difference between groups, F (1, 22) = 14.52, p <.01, μ_p^2 = 0.40. The skilled participants (M = 91.90 %, SD = 14.92 %) were significantly more successful at clearing the height barrier compared to the novice participants (M = 70.60 %, SD = 24.15 %). The ability to clear the target height barrier was not affected by the planning condition, F < 1. There was a significant target effect, F (1, 22) = 5.70, p <.05, μ_p^2 = 0.21. There was also a significant Target x Group interaction, F (1, 22) = 6.28, p <.05, μ_p^2 = 0.22. Post-hoc testing showed that the novice were less successful at clearing the barrier at the near compared to the far target, whereas the skilled group were unaffected by the target conditions.

Accuracy scores.

The radial error scores for each condition are shown in Table 4.3. There was a significant difference between groups, F (1, 22) = 13.10, p <.01, μ_p^2 = 0.37. Skilled participants were significantly more accurate compared to novice participants. There was no significant main effect comparing across the control condition and the experimental conditions, F < 1. There was no significant difference between the two experimental planning conditions, F (1, 22) = 1.17, p >.05, μ_p^2 = 0.05. There was no significant target effect, F (1, 22) = 2.37, p = .14, μ_p^2 = 0.10. No interactions were significant.

Movement kinematics

The cross-correlations for movement kinematics are presented in Table 4.4. There was no significant difference between groups for cross-correlation's in the x- or y-dimension. The cross-correlation indexing the degree of coupling between the hip and knee in the x-dimension was significant, F (1, 17) = 6.46, p <.05, μ_p^2 = 0.28. This was also the case for knee-ankle cross-correlation in the y-dimension, which approached significance, F (1, 17) = 4.17, p = .05, μ_p^2 = 0.20. As predicted, planning the action in terms of the body movements resulted in more constrained movements in comparison to planning the action in terms of ball trajectory. For knee-ankle cross correlations in the y-dimension, movements in the control condition were significantly more constrained compared to the ball planning condition, F (1, 17) = 5.27, p < .05, μ_p^2 = 0.24. However, a significant interaction between Group and Planning for knee-ankle cross-correlation in the y-dimension demonstrated that it was the movements of skilled participants that were less constrained under ball planning conditions, whereas the novices were unaffected by the planning conditions, F (2, 34) = 3.77, p <.05, μ_p^2 = 0.18 (see Figures 4.5 and 4.6). These results lend some support to the constrained-action hypothesis of Wulf and colleagues (e.g., McNevin *et al.*, 2003), whereby instructions to plan the action in terms of body movements (and therefore adopt an internal focus of attention) resulted in increased coupling between the joints in comparison to a focus onto the ball (and hence an external, effects-based attentional focus).

Table 4.3: Experiment 2 mean (and between-subject SD) accuracy expressed as radial error (mm) as a function of group, target and condition.

Target	Near			Far		
Condition	Control	Ball	Body	Control	Ball	Body
Skilled	64.13 (24.02)	62.57 (27.28)	65.49 (23.85)	66.54 (19.69)	73.79 (36.24)	78.95 (33.52)
Novice	82.68 (35.44)	89.53 (23.68)	88.01 (33.07)	100.82 (33.18)	96.16 (33.77)	107.08 (34.45)

Table 4.4: Experiment 2 mean (and between-subject SD) movement kinematics cross-correlations expressed as z scores as a function of group, target and condition.

Target	Near			Far		
Condition	Control	Ball	Body	Control	Ball	Body
x-dimension						
Skilled						
Hip-knee	0.89 (1.33)	0.87 (1.28)	1.12 (1.15)	0.94 (1.50)	0.90 (1.43)	1.12 (1.28)
Knee-ankle	1.40 (0.17)	1.42 (0.14)	1.45 (0.15)	1.48 (0.11)	1.52 (0.15)	1.51 (0.16)
Ankle-toe	2.10 (0.29)	2.12 (0.29)	2.18 (0.26)	2.29 (0.26)	2.34 (0.28)	2.34 (0.31)
Novice						
Hip-knee	1.67 (0.94)	1.45 (0.67)	1.55 (0.54)	1.60 (0.60)	1.76 (0.56)	1.76 (0.51)

Knee-ankle	1.58 (0.40)	1.26 (0.41)	1.42 (0.19)	1.50 (0.17)	1.44 (0.24)	1.55 (0.17)
Ankle-toe	2.72 (0.56)	1.89 (0.98)	2.54 (0.45)	2.62 (0.44)	2.46 (0.72)	2.77 (0.32)
y-dimension						
Skilled						
Hip-knee	2.48 (0.36)	2.35 (0.21)	2.41 (0.31)	2.35 (0.28)	2.30 (0.19)	2.34 (0.20)
Knee-ankle	2.63 (0.27)	2.65 (0.27)	2.60 (0.32)	2.45 (0.24)	2.49 (0.26)	2.38 (0.24)
Ankle-toe	1.60 (0.17)	1.51 (0.09)	1.63 (0.20)	1.57 (0.11)	1.54 (0.11)	1.56 (0.10)
Novice						
Hip-knee	1.73 (0.26)	1.66 (0.16)	1.64 (0.15)	1.60 (0.15)	1.63 (0.21)	1.63 (0.15)
Knee-ankle	1.77 (0.47)	1.91 (0.33)	1.84 (0.48)	1.97 (0.36)	2.11 (0.35)	2.01 (0.38)
Ankle-toe	1.87 (0.56)	1.75 (0.23)	1.75 (0.28)	1.89 (0.29)	1.90 (0.39)	2.12 (0.25)

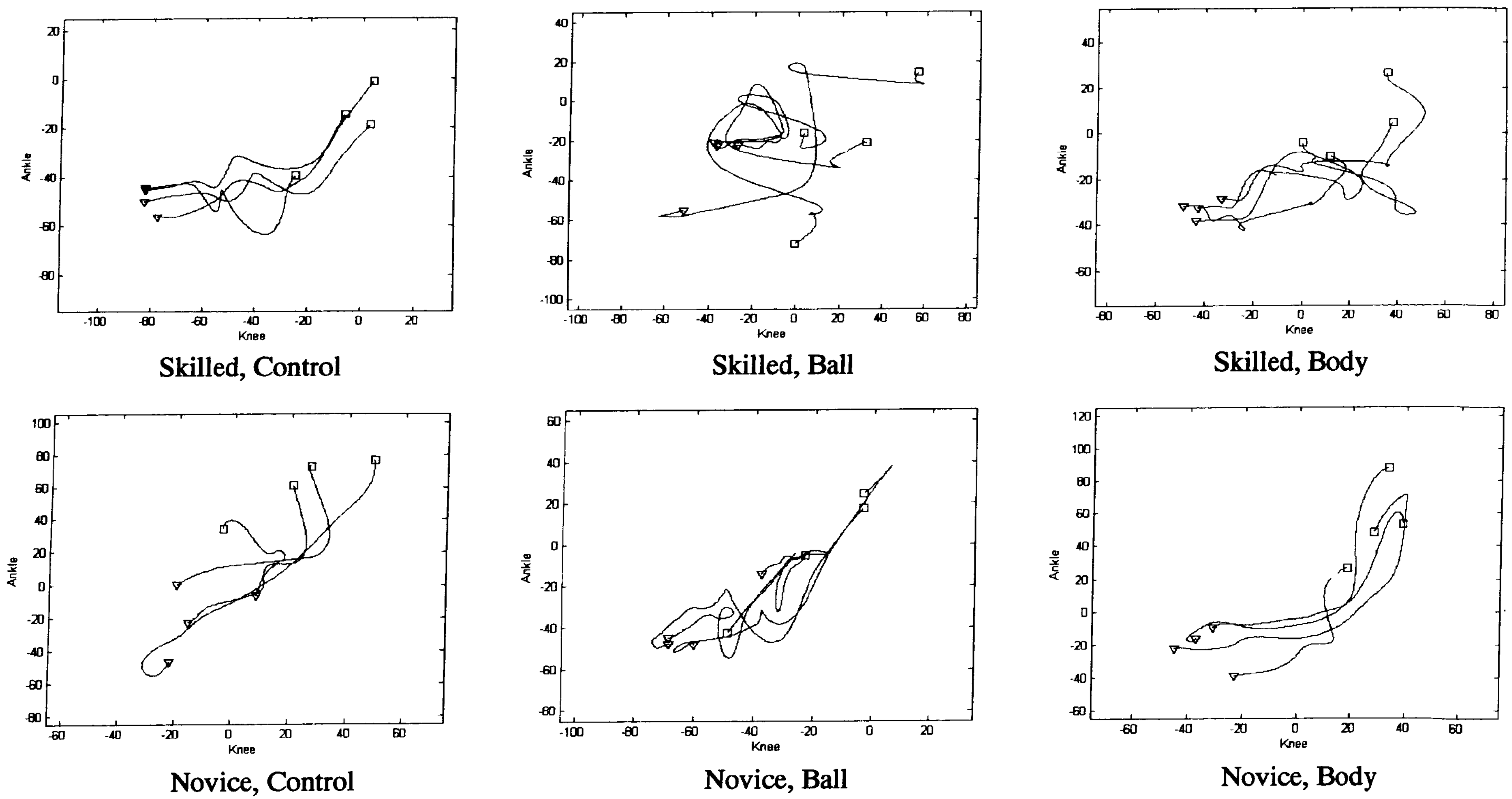

Figure 4.5. Experiment 2 knee-ankle coordination in the y-dimension for each trial at the near target for Skilled Participant No. 3 and Novice Participant No. 1. ▲ = start of movement; □ = end of movement.

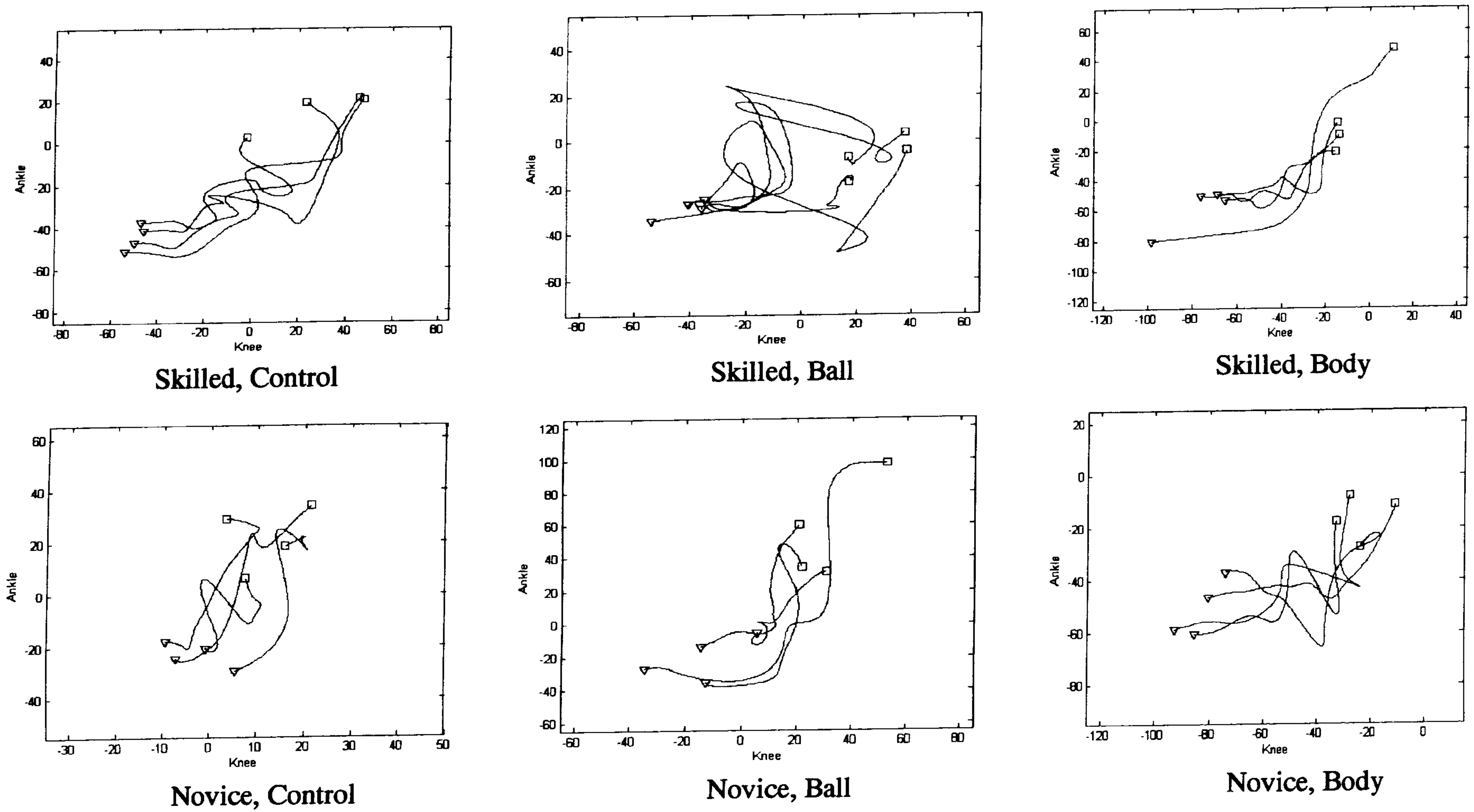

Figure 4.6. Experiment 2 knee-ankle coordination in the y-dimension for each trial at the far target for Skilled Participant No. 3 and Novice Participant No. 1. ▲= start of movement; □ = end of movement.

There was a significant target effect for ankle-toe cross-correlations, x-dimension = $F(1, 17) = 20.94$, $p <.01$, $\mu_p^2 = 0.55$; y-dimension, $F(1, 17) = 8.54$, $p <.05$, $\mu_p^2 = 0.33$; and hip-knee cross-correlations, y-dimension = $F(1, 17) = 19.75$, $p <.01$, $\mu_p^2 = 0.54$. Participants were using different movement solutions at the near compared to the far target. In general, at the near target, participants held their hip and knee relatively rigid and the movement occurred with flexion of the ankle joint. In comparison, at the far target the ankle joint was held relatively rigid, and the movement occurred with flexion of the hip joint.

Post experiment questionnaire data

Table 4.5 shows the post-experiment questionnaire data. Skilled participants reported that they were always able to focus on and keep in their mind the image of the ball trajectory or the movement form. In contrast, a quarter of novice participants were unable to focus on and keep in their mind the image of the ball trajectory. In general, participants felt that a planning the actions in terms of ball trajectory (59 %) and movement form (54 %) facilitated performance relative to the control condition. In keeping with predictions, the majority of the skilled participants perceived that planning the actions in terms of ball trajectory (67 %) felt closer to how they would normally plan the action when performing a soccer-kick, compared to movement form (33 %). The answers of the novice participants, however, were more mixed. Fifty-eight percent perceived that planning the action in terms of ball trajectory felt like how they would normally plan the action when performing a soccer-kick, whereas 42% reported that planning the action in terms of body movements was more normal.

Table 4.5: Experiment 2 post-experiment questionnaire data

	Skilled			Novice		
Question:	*Very able*	*Mostly able*	*Not at all*	*Very able*	*Mostly able*	*Not at all*
1. How well were you able to focus on and keep the image of the ball trajectory in your mind?	41.67%	58.33%	0.00%	16.67%	58.33%	25.00%
2. How well were you able to focus on and keep the image of the movement form in your mind?	58.33%	41.67%	0.00%	33.33%	66.67%	0.00%
	Better	*Worse*	*No change*	*Better*	*Worse*	*No change*
3. How did the ball trajectory condition affect performance relative to the control condition?	66.67%	25.00%	8.33%	50.00%	33.33%	16.67%
4. How did the movement form condition affect performance relative to the control condition?	58.33%	8.33%	33.33%	50.00%	41.67%	8.33%

		Ball trajectory	Movement form	Ball trajectory	Movement form
5.	Which of the two planning focus conditions felt most 'natural' (i.e. how you would normally do it)?	67.00%	33.00%	58.00%	42.00%
6.	During the control condition trials, where was your attention focused just prior to executing the kick?	50.00%	50.00%	58.00%	42.00%

Discussion

In this experiment the prediction that actions are planned by anticipation of their distal effects and that differences in this ability occur as a function of skill was examined. Skilled and novice participants were required to kick a soccer ball over a height barrier to either a near or far target under conditions where the planning process was manipulated using instructions that emphasised the planning of the action either in terms of body movements or in terms of a distal action effect (i.e. ball trajectory). If actions are planned by anticipation of their distal effects, then planning actions in terms of ball trajectory was predicted to lead to more accurate performance and a greater ability to clear the height barrier. Experts were predicted to have become highly proficient at planning actions in this way, such that planning the action in terms of ball trajectory was expected to lead to more accurate performance and a greater ability to clear the height barrier compared to planning in terms of body actions. Novice performers were not expected to have developed strong associations between actions and their distal effects. Consequently, planning the action in terms of the ball trajectory was expected to lead to a decrease in accuracy compared to planning in terms of the body movements and control conditions.

In this experiment there was no evidence to support the predictions that actions are planned, or more effectively planned, in terms of their distal action-effects (i.e., ball flight). There was also no evidence that skill-based differences exist in the strength of the association between an action and its effects. Radial error and clearing the height barrier were not dependent on whether participants planned the action in terms of body actions or in terms of ball trajectory. Self-report data from the post-experiment questionnaire administered at the end of Experiment 2 lent some support to the idea that skill-based differences exist in the strength of the association between an action and its effects. The novice participants found it difficult to image the desired ball trajectory, which might have diluted the effects of these manipulations. In contrast, the majority of the skilled participants had no difficulty imaging the ball trajectory or the movements. Also, when planning the action under regular, control conditions skilled participants reported that they imaged the ball, rather than movements. However, at least in terms of measures of outcome examined here, the type of planning focus does not appear to significantly affect performance accuracy. In previous experiments designed to examine whether participants plan their actions in terms of action-effects, reaction time (RT) has been the primary measure of performance. When participants are asked to plan in terms of the distal effects of their action, they display initiation time advantages after extended practice (e.g., Kunde *et al.*, 2002). It might be the case that accuracy is not a sensitive enough measure for examining these processes.

It was predicted that planning the actions in terms of body movements would lead to more rigid movements, where the joints of the body are highly coupled (i.e., *constrained action hypothesis*, Wulf, McNevin & Shea, 2003) compared to planning the action in terms of ball trajectory. In Experiment 2 this was the case for the cross-correlation indexing an increased degree of coupling between the hip and knee in the x-dimension, as well as for the skilled participants between the knee and ankle in the y-dimension. These results lend some support to the constrained-action hypothesis of Wulf and colleagues (e.g., McNevin *et al.*, 2003). Instructions to plan the action in terms of body movements (and therefore adopt an internal focus of attention) led to increased coupling between the joints in comparison to a focus onto the ball (and hence an external, effects-based attentional focus). This constrained-action hypothesis predicts that performers who focus their attention on their body movements actively intervene in the control of those movements, causing a reduction in the body's active degrees of freedom.

General Discussion

The aim of these experiments was to investigate the prediction that actions are planned by anticipation of their distal effects (e.g., Kunde, 2001) using a complex task rather than the typically examined simple tasks. The ability to plan actions by anticipation of their effects requires the prior acquisition of action-effect associations, the strength of which is dependent on the amount of practice. Expert performers were therefore expected to plan actions by anticipation of their effects, rather than plan the movement in terms of body actions. Therefore, they were predicted to be more accurate under ball-planning in comparison to body-planning conditions. Novice performers were not expected to have developed strong associations between the action and its effects. They were expected to plan their actions in terms of movements of the body, rather than the ball-trajectory. They were predicted to be more accurate under body-planning in comparison to ball-planning conditions.

There was little evidence in these experiments to support the proposal that participants plan their movements in terms of their end-effects (i.e., ball trajectory), nor that a body-related strategy is detrimental to performance. The only evidence in support of these predictions was provided in Experiment 2, in which movement kinematics were affected by the planning manipulations. When participants planned the action in terms of body actions compared to ball-trajectory tighter couplings were observed between the joints. These results lend some support to the constrained-action hypothesis of Wulf and colleagues (e.g., McNevin *et al.*, 2003). This hypothesis holds that instructions to plan the action in terms of body movements actively intervene in the control of those movements, causing a reduction in the body's active degrees of freedom, which is evidenced by increased coupling between the joints. There was also little evidence supporting the prediction that skill-based differences exist in the strength of this association between an action and its effects. The only evidence in support of this prediction was provided in Experiment 2, in which self-report data from the post-experiment questionnaire showed that novice participants found it difficult to image the desired ball trajectory, whereas the majority of the skilled participants had no difficulty imaging the movements or the ball trajectory. Skilled participants also imaged the ball, rather than movements, when planning the action under regular, control conditions. However, at least in terms of measures of outcome examined here, these preferences were not reflected in differential performance as a function of planning condition.

The accuracy measure used in these experiments might not have been sensitive enough to reveal any effects. Outcome accuracy has previously been successfully used as a measure of attentional focus effects in golf putting (Beilock *et al.*, 2002) and golf-chipping (Perkins-Ceccato *et al.*, 2003). Since anticipatory cognitive representations cannot be directly observed, providing evidence for them is not an easy task (Kunde *et al.*, 2004). In experiments to date where the action-effects hypothesis has been examined, speed (i.e., RT) rather than accuracy of the movements has been the primary measure of performance. The examination of this hypothesis has been restricted to relatively simple movements typically involving only a key-press response (see Kunde *et al.*, 2004). Although reaction time has long been used as a measure of the cognitive processes that occur before action (Schmidt & Lee, 2005), increases in movement complexity have been shown to increase reaction times (Henry & Rogers, 1960). This problem may limit the use of this measure for complex tasks such as soccer kicking. The complexity of the movement pattern for soccer kicking can vary across individuals. Performers may solve this complex motor problem in different ways and there are structural characteristics of the body (e.g., somatotype) that are variable across individuals (i.e., organismic constraints, Newell, 1986).

In summary, across two experiments there was very little evidence in terms of measures of accuracy to support the prediction that actions are planned by anticipation of their effects. There was also very little evidence to support the prediction that skill-based differences exist in the strength of this association between an action and its effects. Whether these results are reflective of methodological problems or of the processes reflected in real life waits further testing. If the associations between an action and its effect become bidirectional as suggested by Kunde and colleagues (e.g., Kunde *et al.*, 2004), then it might be the case that the skilled performers are able to plan their actions easily in terms of either the ball or the body. Lack of differences for the novice participants might just be a reflection of the variability inherent in performing this relatively difficult task for this group of individuals.

Chapter 5

Epilogue

There is evidence (e.g., Kunde, Hoffman, & Zellmann, 2002) that practice leads to stronger associations between an action and its ensuing effects. These effects are then thought to play an important role in action initiation and execution. This research has been predominately limited to simple laboratory-based tasks involving uni-limb actions and acquisition phases of hundreds of practice trials. Task-based differences in the relative importance of various sources of sensory information have occurred in other experiments investigating the *online* control of motor skills (i.e., how actions are controlled and executed in real time). For example in more simple tasks that are acquired during relatively short acquisition phases with consistent sensory conditions, vision becomes the primary source of sensory information that is most suited to ensure optimal performance (e.g., Proteau Marteniuk, Girouard, & Dugas, 1987). For more complex, real-world skills that are acquired across many years of practice, vision is required for purposes other than monitoring limb movement and an increasing dependency on vision for action is not normally observed (e.g., Robertson Collins, Elliott, & Starkes, 1994).

Similar task-dependent conclusions to these have been drawn by researchers investigating the importance of *offline* feedback (i.e., sensory information about how the movement was performed and the outcome of the movement on the environment). For example, dependencies on feedback have been observed in simple key press tasks (what has been termed the guidance effect, see Winstein & Schmidt, 1990), but not in more complex tasks, such as whole-body movements on a ski-simulator (e.g., Wulf, Shea, & Matschiner, 1998). Despite the considerable interest in how the various sources of sensory information change in their importance as a function of practice there has been little examination of sensory information pertaining to distal or remote action effects, such as the trajectory of a ball in kicking and throwing. There is growing evidence (e.g., Kunde Koch, & Hoffmann, 2004) that this action-effect information forms an important part of the representation during action selection, initiation, and execution, even though it is distally removed from the movements themselves.

In this thesis five experiments are presented that were intended to examine the relative contribution of ball trajectory information for the successful planning and execution of a complex, real-world task as a function of skill. Since the associations between actions and their effects are thought to take time and practice to develop (e.g., Keller & Koch, in press), skilled performers were predicted to have formed strong associations between actions and effects. Therefore, only these performers were expected to be negatively affected by visual occlusion or perturbation of ball trajectory information, and not affected when required to plan their actions in terms of this information (i.e., ball flight). In contrast, novice performers, who have not amassed many hours of practice, would be expected to have weak associations between actions and their effects. If this were so, then removal of action effect information would not be predicted to affect their performance, especially if outcome information (i.e., KR) is unaltered. For these performers, instructions to plan their actions in terms of the anticipated ball flight would be expected to negatively impact on performance. Perkins-Ceccato, Passmore, and Lee (2003) have also shown that novice performers are more consistent under conditions that encourage attention to the movements rather than the external effects of the action, which is opposite to expert performers.

Summary of key findings

In Chapter 2 (Experiment 1 and 2), the contribution of ball trajectory information to the successful performance of a soccer chip was examined. Skilled soccer players (Experiment 1) and novice, intermediate, and skilled soccer players

(Experiment 2) performed a soccer kicking task with the intention of getting the ball over a height barrier to a near or far ground level target. They performed under three conditions: full vision, occluded vision following ball contact with and without knowledge of results (KR). In Chapter 2 (Experiment 1 and 2), skilled participants performed as accurately when visual information of the ball's trajectory was withheld compared to when it was available. Novice participants relied upon ball trajectory information at the near target, but KR at the far. Intermediate performers were affected by the removal of ball trajectory across both target conditions, whereas skilled participants were not affected by visual occlusion. Across skill groups, when vision of the ball trajectory was removed, variability in knee-ankle coordination significantly decreased. Although this finding was taken as evidence that action effects information is used to execute the action when it is available regardless of skill level, 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 ball trajectory information increases.

In Chapter 2 (Experiment 1 and 2), the ability of the skilled group to perform as accurately under occluded compared to normal vision conditions might reflect flexibility in their behaviour, rather than demonstrating that a certain information source is typically used when it is available. Although it was shown that skilled performers were not dependent on visual information of the ball trajectory to accurately perform the action, this does not imply that ball trajectory information was not important or is not typically used to aid execution when it was available. In Chapter 3 (Experiment 3), to determine whether this information is used when it is still available, ball trajectory information was perturbed. Skilled players were required to kick a ball over a height barrier to a ground-level target area. Ball trajectory and landing position information were occluded after ball contact. One group received erroneous ball trajectory feedback via video, which showed a ball trajectory apex approximately 75 cm lower than their actual kick but with a landing position that was unaltered. The second group received correct feedback of both ball trajectory and landing position via video. The erroneous feedback group showed a significant bias toward higher ball trajectories than the correct feedback group. These differences were observed in the presence and absence of erroneous feedback. It was concluded that the visual consequences of the action in terms of ball trajectory are used to plan and execute an action at high levels of skill.

In Chapter 3 (Experiment 3), when erroneous ball flight feedback was provided, participants adapted their movements on the basis of this erroneous information. Since target and height barrier success were achieved in the majority of the instances when erroneous ball flight information was provided, this demonstrates that ball trajectory information played more than an error-detecting role (as in previous KR studies). It is suggested that the skilled performers had an expectation of what the ball flight should look like (i.e., an internally driven anticipation of the sensory consequences) and that when this did not match their expectations, the action was modified on subsequent attempts. Researchers have shown that the role of these representations of action-effects is not only to evaluate and correct an action (cf. Adams, 1971), but also to select and initiate an action (Koch, Keller, & Prinz, 2004; Kunde, 2001). Koch *et al.* (2004) have argued that at higher levels of skill actions are planned by anticipation of their end-effects. A more direct manipulation of the planning process was therefore needed to determine whether there is evidence to support this claim.

In the previous chapters, ball trajectory information had been shown to be important for skill execution, especially at lower levels of skill. The next step was to show that this effect information was being used in the planning of the action (e.g., Kunde, 2001) and whether or not this ability was skill dependent. In Chapter 4 (Experiment 4 and 5), there was little evidence to support the prediction that actions are planned by anticipation of their effects or that the ability to do so is skill-dependent. In Experiment 4 (Chapter 4), skilled and novice participants performed the same task as in Chapter 2 (Experiment 1 and 2). They were instructed to plan their actions in terms of the anticipated ball flight or in terms of the anticipated body movements for the upcoming trial. Radial error and movement kinematics for both skill groups showed little evidence that these planning conditions were altering the action. Researchers (e.g., Koch *et al.*, 2004) believe that action-effect associations are bi-directional, such that anticipation of an effect can initiate the action associated with that effect. Since these associations are bi-directional, it may be that actions can be planned in terms of their movements just as effectively as by their external effects. Alternatively, methodological reasons (e.g., the availability of visual feedback) may have led to the lack of significant findings.

A second experiment (Experiment 5) was conducted in which a further attempt was made to manipulate the planning process via instructions that emphasised the planning of the upcoming action either in terms of anticipated distal action effects (i.e. ball trajectory) or anticipated body movements. This experiment differed from the previous one in that visual feedback was occluded on all experimental trials (so no feedback was provided that could lead to changes in performance across trials independent of the planning conditions), a baseline control condition was added, and to determine if and how well participants were able to adhere to the instruction manipulations a post-experiment questionnaire was used. Despite these various changes, in this final experiment the planning manipulations did not affect outcome attainment. In terms of movement kinematics, correlations across body joints were generally higher for body rather than ball planning, suggesting that this focus acted to produce more constrained movements for both the novice and skilled participants.

Implications for theory

Since the associations between actions and their effects are thought to take time and practice to develop (e.g., Proteau *et al.*, 1987), skilled performers were predicted to have formed strong associations between their actions and effects. Therefore, only these performers were expected to be reliant on this information, such that occlusion or perturbation of ball trajectory information would be predicted to negatively affect their performance. In comparison, novice performers, who have not amassed many hours of practice, would be expected to have weak associations between actions and their effects. For these performers, removal of this information is not expected to be harmful for performance as long as outcome information about the accuracy of the skill is still presented. During these early stages of acquisition for a specific action, novice performers begin to acquire associations between an action and its consequences (Elsner & Hommel, 2001). Therefore, skilled performers were expected to be more dependent on ball trajectory information for successful performance compared to novices.

However, in Chapter 2 (Experiment 1 and 2) rather than being characterized by an increased dependence on ball trajectory information, skilled performers were able to adapt to changes in their sensory environment. Although a change in movement kinematics following occlusion of ball flight was taken as evidence that the experts used ball trajectory information to prepare and execute movements, their accuracy of responding was not affected by the removal of this information. Since there were no negative consequences associated with removal of ball trajectory information for the experts in comparison to the intermediately and low skill participants, it was proposed that visual information (both ball flight information and KR) had become less important for the offline control of actions (c.f., Schmidt & McCabe, 1976).

Also in contrast to the predictions, the accuracy of the novice performers decreased when visual information pertaining to the ball trajectory was removed, although their performance depended on the current task constraints. Only when the constraints on ball flight were particularly challenging (i.e., for the near target) were novice participants affected by removal of ball flight information. When the constraints on accuracy were challenging (i.e., for the far target) they were affected by removal of KR. These findings were taken as evidence that the novice performers were in the process of acquiring associations between the action and its visual consequences (e.g., Elsner & Hommel, 2001). Further evidence for this claim was provided in the data for intermediate participants in Chapter 2 (Exp. 2). As predicted, the accuracy of the intermediate participants decreased when ball trajectory information was removed at both targets, supporting 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 (e.g., Proteau *et al.*, 1987). For the highly skilled performers this dependency was not observed. Skilled performers may have been generally more accurate than the intermediate participants (and as such less dependent on feedback), or perhaps they were able to vividly image the anticipated consequences without being dependent on actual feedback. These issues are discussed in more detail below.

When information is removed or occluded it has been suggested that this might change the way the task or skill is normally performed (see Khan, Elliott, Coull, Chua, & Lyons, 2002). Some evidence for this proposition was provided in Chapter 2 (Experiment 2). When ball trajectory information was occluded there was a change in the movement kinematics (specifically a decrease in the variability of knee-ankle coordination) across skill groups. This finding suggests that performers in all groups were attempting to use ball trajectory information to plan and perform subsequent actions. Similar results and conclusions were presented by Robertson and associates (1994) who observed that expert gymnasts took more steps to cross a beam under occluded compared to control conditions, although movement times remained constant. They also observed that novice gymnasts took more steps to cross a beam, committed more form errors, and increased movement time under occluded compared to control conditions. Presumably these less skilled participants were using the visual consequences of the action to cross the beam when they were available, perhaps making online corrections to the movement based on this information. When vision was removed the novice participants had to rely on a less reliable source of information (i.e., proprioception) to perform the task. In the case of soccer kicking, the removal of visual information pertaining to the ball trajectory might have served to change the way the movement was planned and executed, again potentially causing the novices to pay more attention to how the movement felt (i.e., proprioception) and relying on KR to make adaptations on subsequent attempts.

The findings in Chapter 2 (Experiment 1 and 2) could be taken to suggest that as skill is acquired the importance of visual information has decreased (e.g., Schmidt, 1975). However, although it was shown that skilled performers were not dependent on visual information of the ball trajectory to accurately perform the action when it was occluded, this does not imply that ball trajectory information was not important or is typically used to aid execution when it was available (Robertson & Elliott, 1996). The findings in Chapter 2 (Experiment 1 and 2) might also reflect flexibility in skilled behaviour in that they can switch to use alternative sources of sensory information when vision is unavailable (e.g., Robertson *et al.*, 1994; Robertson & Elliott, 1996). In

Chapter 3 (Experiment 3) these predictions were examined in an experiment where ball trajectory information was available but perturbed through the provision of erroneous feedback (i.e., a ball trajectory apex 75 cm lower than achieved with an unaltered landing position). Participants in the erroneous feedback group were not made aware during the experiment that the feedback they were receiving was perturbed. Under these perturbed vision conditions there was no reason for participants to switch control strategies. Erroneous visual feedback (i.e., a ball trajectory lower than that achieved) caused a significant bias toward higher ball trajectories and a tendency to overshoot the target area as opposed to that observed for a correct feedback group. These findings suggest that when it is available ball trajectory information is used to evaluate and plan actions and hence is an important part of the representation guiding actions at higher levels of skill. In this respect, information about the ball's trajectory provided feedback (in this case erroneously) about the action that enabled the participants to detect "errors" in performance (which altered the action-effect representation, although only temporarily when vision was unavailable) (Swinnen, 1996). This discrepancy between the participant's desired/expected ball flight and that achieved led them to change their action on subsequent attempts (even at the expense of ball landing position accuracy), even though they still landed on the target area and cleared the height barrier.

Robertson and Elliott (1996) have also presented evidence that both novice and expert gymnasts crossed the beam slower and with a high number of attempts to obtain success under perturbed visual conditions compared to normal vision control conditions. Although expert performance would be expected to be less disrupted by this perturbation if vision had become less important, these findings were taken as evidence that when vision is available both expert and novice performers use it. The studies of Robertson and colleagues (e.g., Robertson *et al.*, 1994; Robertson & Elliott, 1996; see also Williams & Weigelt, 2002) also support the prediction that when vision is unavailable experts are able to make use of alternative feedback sources for the online control of actions. When taken together, the findings presented in Chapters 2 (Experiment 1 and 2) and 3 (Experiment 3) suggest that expert performance is characterized by this ability to be flexible and adaptable to different sources of sensory information. These finding contradict the theories presented by other researchers who have observed that practice leads to one source of sensory information becoming more (Proteau *et al.*, 1987) or less (Schmidt, 1975) important for performance, or that practice leads to a switch occurring from the importance of one sensory source to another (e.g., Adams, 1971). Task-based differences between studies may have led to these contradictory findings and different conclusions.

In Chapter 2 (Experiment 1 and 2) there were two possible reasons that experts were able to maintain high performance in the absence of ball trajectory information. First, they may have been able to vividly image the expected end-effect to help guide their movements, whereas less-skilled performers were not able to image the optimal ball trajectory as effectively (Koch *et al.*, 2004). Self-report data from the post-experiment questionnaire administered at the end of Experiment 5 (Chapter 4) lent some support to this idea. This showed that skilled performers were better able to image both the desired ball trajectory and body movements compared to novices. Second, during the early part of the movement when the foot was in contact with the ball, proprioceptive information might have been sufficient to enable effective control. The experts might have then planned their movements in such a way that sensory consequences associated with how the movement felt (rather than what the ball flight looked like) were upgraded in importance (see Bennett & Davids, 1995 who also demonstrated this flexibility in sensory processing and control depending of the task conditions).

The anticipated action-effects hypothesis

Researchers (e.g., Elsner & Hommel, 2001; Kunde, 2001) have recently presented evidence that during practice associations are acquired between an action and its effects, and that once acquired an action can be intentionally selected and initiated by anticipation of its effects. This idea can be traced back to the earlier writings of James (1860) and others, who asserted that action effects not only inform the performer about the consequences of their action, but they are also anticipated so as to initiate the action itself. This became known as the ideo-motor approach. In the twentieth century the role of action effects in the planning of actions was largely forgotten (Hommel, 1998). During this period two major theories of motor learning emerged that emphasised the informational role of action effects, but did not acknowledge their role in action planning.

First, in the closed-loop approach proposed by Adams (1971) learners were thought to acquire two different traces: a perceptual trace and a memory trace. The perceptual trace was a representation of the sensory consequences that was used as a reference against which subsequent attempts were compared. The motor trace was a motor control structure (or program) that was thought to initiate the movement. Second, in the programming approach forwarded by Schmidt (1975) action-effects were thought to be temporarily stored following an action in a recognition memory responsible for movement evaluation. Movement selection and initiation were then controlled by the recall memory that was involved with selecting the appropriate "motor program" for action in addition to setting the parameters for this program to produce the desired movement. Both of these approaches are characterized by the proposal that the action-effects are evaluated in response to the desired action consequences, but neither proposes that the action-effects lead to and control the response (i.e., the processes responsible for movement initiation and response evaluation are explicitly separated). Two separate memory structures must be learnt independently (albeit concurrently), one for motor commands and the other for evaluation of sensory consequences.

In contrast to these views, proponents of the ideo-motor approach believe that actions are inevitably planned by anticipation of their effects (e.g., Kunde *et al.*, 2002), and that actions and representations of their effects become integrated so that they share, or operate on, a common representational domain (e.g., Hommel, Musseler, Aschersleben, & Prinz, 2001). This has been forwarded as a simple and economic way for the motor system to constrain its many degrees of freedom (i.e., independent dimensions of the body that are free to vary, such as joints, muscles) (Bernstein, 1967). Although these ideas have been around for the past century, it is only recently that techniques have been adopted to show the commonality of these processes and the importance of sensory consequences for action initiation and selection. Despite these differences, the three approaches share the belief that cognitive representations mediate action execution. The existence of these representations has typically been inferred in studies where reaction time between a signal and the beginning of the response is taken to indicate the time taken for mental processes to occur (Schmidt & Lee, 2005). Schack and colleagues (e.g., Schack & Mechsner, 2006) have used sorting tasks to show that the representations underpinning complex athletic skills become more refined and functionally structured as a function of expertise. However, there are researchers who believe that learning is a process of progressively attuning to the many relevant sources of perceptual information for the task, without reference to intervening representations (e.g., Newell, 1986; Gibson, 1988; Kelso, 1995). Although researchers debate the mechanisms underlying sensory dependence, most agree that this attuning to the various relevant sources of sensory information for the action is a necessary process during the earlier stages of practice (e.g., Elsner & Hommel, 2001; Beek, Jacobs, Daffertshofer, & Huys, 2003; Schack, 2004).

Researchers investigating the anticipated action effects hypothesis suggest that skill level will mediate the ability to plan actions by anticipation of their effects (for a review, see Koch *et al.*, 2004). Expert performers in motor skills have amassed large amounts of practice at specific motor skills (e.g., Helsen, Hodges, & Starkes, 1998). Therefore, it is assumed that they will have attuned themselves to the relevant perceptual information for the task and will have built up strong associations between their actions and effects, such that anticipation of these effects is the defining or preferred way of planning actions (see Koch *et al.*, 2004). Novice performers are not expected to have developed strong links between actions and their effects, and consequently the planning of actions at low levels of skill is expected to be different. Perkins-Ceccato *et al.* (2003) have shown that novice performers are more consistent under conditions that encourage attention to the movements rather than the effects of the action, which is opposite to expert performers. Therefore, there is reason to suspect that at this beginner level, actions are more effectively planned by anticipation of the desired movements rather than response effects (e.g., Schmidt, 1976).

In Chapter 4 (Experiments 4 and 5) there was little evidence to support the prediction that actions are planned by anticipation of their effects or that the ability to do so is skill-dependent. Skilled and novice soccer players performed the kicking task under conditions in which they were required to plan the action in terms of ball trajectory (i.e., a distal action effect) or in terms of body movements. Although there were significant group effects in both experiments, accuracy was not significantly affected by the planning focus. In Experiment 5 (Chapter 4), correlations across body joints were generally higher for body rather than ball planning, suggesting that this focus acted to produce more constrained movements, although this was observed across skill groups. This result lends some support to the constrained-action hypothesis of Wulf and associates (e.g., McNevin, Shea, & Wulf, 2003), whereby instructions to plan the action in terms of body movements (and therefore adopt an internal focus of attention) are proposed to result in an increased coupling between the joints in comparison to a focus onto the ball (and hence an external, effects-based attentional focus). It has been proposed that action-effect associations are bi-directional, such that anticipation of an effect can initiate the action associated with that effect, so it may be that actions can be planned in terms of their movements just as effectively as by their external effects (see Koch *et al.*, 2004).

Considerations for future research

The findings within this thesis regarding the relative importance of ball trajectory information as a function of skill may be specific to the task used. Although they are likely to transfer to other open actions in team sports (e.g., basketball throw), they may not transfer to certain other tasks, especially those of a closed nature (e.g., archery). The role of vision may be different in these types of tasks in which higher levels of accuracy are required compared to the task used in this thesis. Further research is required to examine the role of action-effect representations in these other types of tasks. Also, in the work of Kunde and colleagues (e.g., Kunde, 2001) the action effect that performers anticipate in the key press task (i.e., an effect tone) is a form of KR, and it does not contain any extra information, such as ball trajectory. In Chapter 4, anticipating ball trajectory information did not affect the accuracy of skill and novice performers. Future research is required to examine whether anticipation of KR, in tasks such as soccer kicking, leads to improved accuracy and whether this ability is skill dependent.

Some researchers (e.g., Koch *et al.*, 2004) believe that the anticipation of action effects that guide action selection and initiation is an implicit and automatic process in which conscious awareness plays no role. Support from this idea can be found in theories of skill acquisition (e.g., Anderson, 1982) in which extended practice is thought to lead to 'proceduralisation' of a skill. This proceduralisation means that the skill can be executed rather automatically without the need for constant control by working memory. In Chapter 4 (Experiments 4 and 5), when participants were instructed to plan the action in terms of the anticipated ball trajectory or in terms of the anticipated body movements this made them explicitly aware of the process. It has been proposed that consciously attending to the step-by-step control of a well-learned skill may disrupt its execution (e.g., Beilock, Carr, MacMahon, & Starkes, 2002). If the planning instructions in Chapter 4 (Experiments 4 and 5) had caused participants to pay attention to otherwise automatic processes then it would be expected that accuracy in the two planning conditions would be impaired in comparison to the control condition. However, in Experiment 5 (Chapter 4) there was no difference in accuracy across the experimental and control conditions. Further research is required to determine whether effect anticipation is a consciously-driven process.

Another reason why a focus on ball trajectory information in this task may have failed to facilitate performance is because it occurs at a relatively large distance from the performer, and hence it might be hard for them to relate this effect to their movements. Evidence has been presented by Wulf, McNevin, Fuchs, Ritter, and Toole (2000) showing that learners benefited more from a focus on the club in golf than a focus on the trajectory of the ball (i.e., a more distal effect). There may be an optimal distance for external effects to be a useful focus of attention. In Chapter 3, participants were shown to use the apex of the ball trajectory to adjust actions. Further research is required to examine which portion of ball flight information (i.e., early, middle, late) is more beneficial for movement control (see Wulf & Prinz, 2001).

In Chapter 4 (Experiments 4 and 5), methodological (e.g., the availability of visual feedback) or measurement reasons may have led to the lack of significant findings. First, the task itself may have been too difficult for novice performers, who demonstrated high variation in their accuracy scores, which makes it difficult to draw conclusions about the effectiveness of the planning conditions. This is compounded by the fact that novice performers had a large percentage of trials removed from the analysis because of height barrier clearance failures. In future research a combined measure that takes into account accuracy and height barrier clearance success may be more appropriate, although it is difficult to know how to weight these two aspects of performance. It might be that a different task with only one measure of outcome to determine (such as in batting or throwing) would be needed to assess these action-effect ideas.

Although outcome accuracy has previously been successfully used as a measure of attentional focus effects in golf putting (e.g., Perkins-Ceccato *et al.*, 2003), it may not have been a sensitive enough measure to reveal changes in the planning focus of the performers in these two experiments. Increased accuracy in this task might not be a function of an increased ability to plan actions by anticipation of their anticipated effects or anticipated movements. In experiments to date where the action-effects hypothesis has been examined, facilitation in the response has been indexed by measures of RT rather than response accuracy. The response has typically been a simple key-press response, which has relatively low accuracy demands. Although reaction time has long been used as a measure of the cognitive processes that occur before action (Schmidt & Lee, 2005), increases in movement complexity have been shown to increase reaction times (Henry & Rogers, 1960), which may limit the use of this measure for complex tasks such as soccer kicking. For example, the complexity of the movement pattern for soccer kicking will vary as a function of target distance and even within individuals there has been shown to be considerable variability across trials (see Hodges, Hayes, Horn, & Williams, 2005). However, the complexity of the movement should not deter researchers in the future from employing speed (i.e., RT) as the primary measure of performance in studies investigating the anticipated action effects hypothesis. Further experiments are necessary to determine whether response time is facilitated or inhibited as a function of an action-effects control focus in these more complex tasks.

The use of imagery may be a means to test the hypothesis that actions are planned by an anticipatory representation of their intended effects. For example, the basketball free throw shooting performance of children with limited prior experience of the task was enhanced using imagery in which the performer imaged the throw from their own visual perspective, which means they were visualising the moving limbs and ball trajectory (Wrisberg & Anshel, 1989). This finding supports the action-effects hypothesis, and also models that propose commensurate representational codes for action, perception, and intention (e.g., Hommel *et al.*, 2001). For novice performers especially, imagery may provide a means of forming representations between the action and its effects, although confirmation of this requires further research. Researchers have suggested supplementing this early learning stage with action templates that serve to provide a 'reference of correctness' role so that the learner has an appreciation of the desired sensory consequences before these are actually achieved (Swinnen, 1996). Other researchers have suggested that this reference of correctness should contain information about the goal of the task, which for soccer kicking would be the ball's trajectory and outcome (Hodges & Franks, 2004; see also Newell, Carlton, & Antoniou, 1990). Imagery, verbal instructions and demonstrations, which are directed towards external goals, may also be suitable for this purpose, yet there was no evidence in support of this proposal in Chapter 4 (Experiment 4 and 5) (cf., Wulf & Prinz, 2001; Hodges & Franks, 2004; Koch *et al.*, 2004). Further research is required to determine the effectiveness of these strategies in forming action templates during the early learning stages.

In Chapter 2 (Experiment 1 and 2) skilled performers were able to compensate for the occlusion of visual information, perhaps by vividly imagining the effect (Koch *et al.*, 2004) or by switching to alternative sources of sensory information, such as proprioception. It is assumed that this ability has been developed during the many hours of practice that the experts had amassed. Learning studies in which complex skills are practiced under controlled conditions are required in order to understand the processes that lead to the development of this ability. Some researchers (e.g., Soucy & Proteau (2001; Bennett, Button, Kingsbury, & Davids, 1999; Bennett, Davids, & Woodcock, 1999) have presented evidence showing that acquiring a task during practice conditions in which different sensory constraints are manipulated (i.e., occluded vision, normal vision) in a controlled manner leads to performers developing the ability to plan and control their actions on the basis of the most efficient source of available sensory information. Other researchers have forwarded several ways to manipulate the informational constraints associated with the task. For example, one way to remove vision of the limbs or the ball is to require sports performers to wear glasses that have a small protruding surface under each eye (Williams *et al.*, 1999). Further research is required to examine if manipulating the sensory informational constraints in a controlled manner during the acquisition of complex tasks leads to the ability to be flexible and adaptable to different sources of sensory information or to a dependence on one important source of information.

Conclusion

In conclusion, the results of the 5 experiments in this thesis have provided information about the role of ball trajectory in the successful execution of a kicking action. Although ball trajectory information does not seem to be critical for task success, there was evidence that it is used to plan and perform actions across skill levels. Skilled performers were shown to use this information to execute actions when it was available, but when it was not available they were shown to be able to maintain performance by switching to different sources of sensory information. Less-skilled performers were generally more affected by the removal of visual information pertaining to the ball trajectory than the skilled performers, although there was evidence that their performance was dependent on the difficulty of the task and the importance of ball flight for achieving the task goals. Further research is required to determine fully if complex actions are planned by anticipation of their effects and whether skill level mediates this process. However, the data presented in this thesis provide an important first step in elucidating on the role of this information for successful actions.

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