MOTOR SIMULATION IN ACTION PREDICTION: SPORT-SPECIFIC CONSIDERATIONS

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Introduction

In sports settings, athletes must be able to accurately predict the actions and moves of opponents and teammates. The more precisely a performer can predict the outcome of observed actions, the better they will be at responding to that action. A primary question of interest concerns how this ability to predict future actions comes about? A common view is that after years of viewing a broad array of action sequences and patterns the visual system becomes better at extracting important kinematic information through improved visual search strategies and cue use (e.g., Abernethy, Zawi, & Jackson, 2008; Williams & Davids, 1998; Williams & Ward, 2007). In this view, the visual and motor systems are considered mostly as distinct. More recently, a nuanced view has unfolded, which suggests that motor experience, and particularly the motor system, plays a significant role in perceptual processing, and in action prediction. In this sense, an observer's motor abilities (such as their ability to kick or throw accurately) exert a direct effect on perceptual understanding of these actions in others. It is thought that the brain uses motor representations, based on past experiences, to internally simulate the actions observed in others to aid in anticipation of action consequences (e.g., Blakemore & Decety, 2001; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003).

In this chapter, we explore the contribution of the human motor system to action prediction in sports. We describe the neural and representational underpinnings driving motor simulation and review research which helps us understand the role of action experiences in predicting action outcomes. We first present behavioural and neurophysiological evidence which suggests the existence of a common representational domain for perception and action and a corresponding mechanism that allows for covert simulation in order to recognise or make predictions. In a second section, we present converging evidence from several lines of research supporting the idea of motor simulation in action prediction, particularly as it relates to sport. In a final section we consider practical implications and suggest avenues for future research.

Theoretical framework for motor simulation in action prediction

A common medium for action and perception

The idea of a common representational framework for encoding the goals and actions of others is not new. James (1890, in his ideomotor theory) suggested that, imagining one's own action could induce the execution of the same action. In the theory of 'common coding', a common representational domain for action and perception is proposed, such that observing someone performing an action and performing the action oneself, activates the same internal motor program (Prinz, 1997). In this way, action execution (doing) creates a common representation between the motor program that generates the movement and the sensory effects (perceiving) that are produced by that movement. This process can also proceed in the opposite direction. Perceiving an action can induce a similar or complementary action in the observer and arguably assist in movement prediction (Hommel, Muesseler, Aschersleben, & Prinz, 2001).

If such a common "code" exists between actions and their sensory effects, observed and executed actions should exert reciprocal effects on each other, especially in situations of tight temporal coupling. Behavioural studies have yielded support for this idea. When an observed action matches the action to be produced (e.g., watching a karate kick, as such a kick is being prepared by the observer), a facilitating or priming effect on action occurs, such that the prepared action is initiated faster. Similarly, when a seen and to-be-produced movement do not match, performance is degraded (i.e., initiation is slowed; for reviews see Blakemore & Frith, 2005; Schutz-Bosbach & Prinz, 2007; Thomaschke, Hopkins, & Miall, 2012; Vogt & Thomaschke, 2007).

Motor simulation as a mechanism for action prediction

Related to the common coding approach is the idea of a mechanism that uses the observer's own motor system to simulate the actions of others (Blakemore & Decety, 2001; Wilson & Knoblich, 2005). Action-simulation can perhaps most simply be thought of as the covert or internal re-enactment of an action, without (necessarily) an overt behavioural response (e.g., Witt & Proffitt, 2008). In this way, the motor commands that could produce the observed action are activated to some degree, enabling a prediction of the sensory consequences of that action. This process can facilitate, in real-time, an understanding of action goals (Rizzolatti & Craighero, 2004; Springer et al., 2013a, 2013b), as well as the prediction of future actions and their consequences (e.g., Aglioti, Cesari, Romani & Urgesi, 2008; Urgesi, Savonitto, Fabbro & Aglioti, 2012). This is of course important for sports involving partners, opponents, or teams, when accurate predictions and timely responses are critical for success.

Neural correlates of action simulation

Over the past several decades, evidence of a neural analogue to the common-coding/simulation framework for action understanding has been accumulating. A class of neurons was first identified in a monkey's premotor cortex, which fired when the animal both performed and observed a goal-directed actions. A similar system has since been identified in humans (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Grezes & Decety, 2001; Iacoboni et al., 2005; Rizzolatti et al., 2001; Rizzolatti & Craighero, 2004). There is considerable evidence showing that action observation involves a type of motor simulation in the observer, primarily based on activation of parietal, frontal and temporal regions of the brain, which activate during both action execution and action observation. This so termed "Mirror Neuron System" (MNS; Rizzolatti & Craighero, 2004), part of a broader "Action Observation Network" (AON; Cross, Hamilton, & Grafton, 2006), is thought to provide the appropriate anatomical substrates to support the common links between perception and action, and the simulation mechanisms described above (for sport related reviews see Karlinksy, Zentgraf & Hodges, 2017; Zentgraf, Munzert, Bischoof, Newman-Norlund, 2011).

Neuro-computational implementation of action simulation

It has been suggested that when we learn, an internal representation or model of the action being performed is generated (Miall, 2003). When we view someone else's action, we are able to activate this model (or models) in order to predict outcomes of others' actions. At an implicit, computational level, physical practice affords the acquisition of forward models which allow prediction of the sensory consequences of actions, based on the corresponding motor commands associated with the action. When we send a motor command, an efference copy of this motor command is fed into a forward predictor, allowing us to predict what the action we've initiated should feel and look like. If there is a discrepancy the model will be updated (Miall, 2003; Miall & Wolpert, 1995). It is possible that these forward models are activated when we watch others, such that predicted sensory (visual and proprioceptive) consequences are still generated. Of course, the program that is planned and potentially initiated is either later inhibited and/or not of the same 'detail' or 'quality' as during action execution and, as such, is not produced (see also Maslovat, Chua & Hodges, 2013).

Evidence for motor simulation during action prediction

Self-other recognition

When you watch yourself perform, there will be a close match between the internal representations of the action and the perceptual input, in line with common coding notions. In several studies, researchers have shown that people are better able to recognize and/or predict the consequences of their own actions, compared to those of others (e.g., Knoblich & Flach, 2001; Knoblich & Prinz, 2001). For example, they were better able to predict the landing position of a dart thrown previously by themselves, rather than others, just by viewing body kinematics (i.e., no dart flight was shown; Knoblich & Flach, 2001). Similar evidence was shown for the prediction of ball flight direction in table tennis (Bischoff et al., 2012). Physically trained performers were better able to predict the trajectory of their own strokes than those of others, even though none of the ball flight was shown, and the athletes were shown only as moving points of light. In terms of the implications of this research, the suggestion is that when using videos to train athletes to improve in their predictive capabilities, maximum gains would be observed if the athlete practised with videos of themselves acting, or people that were made to look like themselves. The better the match between the motor skills of the observer and the actor, the better the simulation and ultimately prediction accuracy.

How the eyes alert to action prediction and motor simulation

Another line of evidence in support of simulation-based prediction based on the acquisition of motor representations comes from research examining the proactive nature of the human oculomotor system. In a reaching and grasping task, observers and actors of the same task showed similar patterns of visual search, with both groups showing predictive saccades onto a subsequent object to be grasped (Flanagan & Johansson, 2003). Evidence that these saccades were related to action simulation came from a study showing that such saccades were no longer predictive if the observer had their arms restrained when watching (Ambrosini, Sinigaglia & Constantini, 2012). We return to this idea that action simulation requires the effector involved in the action to be available or “unoccupied” in discussion of some of our own research below. There are of course questions concerning the type and degree of experience required for such predictive saccades to be shown, as well as the types of actions that interfere with or potentially facilitate predictions. This latter question is pertinent with respect to movement of the eyes as well as accuracy on the task. For example, are such predictive saccades only noted when an observer has had previous physical experience with the observed action, rather than purely observational experience? Although in sports-related tasks, visual search has been measured to determine key events for anticipation, to date, researchers have not studied how these saacades might change based on the movement context in which they are performed (e.g., when fatigued or performing an action somewhat incongruent to the one being watched).

Long-term visual and motor experience effects in action prediction

A long-standing view concerning expert perception is that after years of visual exposure, experts develop long-term memory structures made up of familiar visual patterns, chunks or templates that become quickly accessible during action perception (Ericsson & Kintsch, 1995; Gobet & Jackson, 2002; Hodges, Starkes, & MacMahon, 2006). The visual system becomes more efficient at extracting early kinematics of body motion or patterns of game-play and matches these cues to the appropriate memory structure in a kind of visual-recognition process (for sport related evidence see Abernethy et al., 2008; Abernethy, Farrow, Gorman & Mann, 2012; Williams & Davids, 1998; Williams & Ward, 2007). In early work in this area, static (photos or player position diagrams) or dynamic (video) action sequences were briefly shown and either recall or recognition was subsequently tested (see Karlinsky, Lohse & Hodges, 2016). These actions typically showed either game-representative plays (structured) or random positions of players (unstructured). Sport experts, as compared to less elite athletes, fans, or athletes from different sports, were generally more accurate at recalling or recognising information portrayed in the "structured" displays. This expert memory for previously seen "patterns" was thought to underlie the ability of the athletes to make fast and accurate decisions, whereby the recognised action was associated with the appropriate decision (i.e., “if see this…, then do this…”, e.g., Allard & Starkes, 1991).

Researchers have distinguished between two types of sport-related decision scenarios which likely have different impacts on the reliance of visual memory and how decisions are made. The first represents the reading of global patterns of play and positions in game-like situations, so termed “far” events. This might be deciding whether a player with the ball should pass left or run/dribble in rugby or field hockey. The second refers to one-on-one situations where the opponent is determining how to act primarily based on an opponent’s body cues, when the player is relatively “near” to the opponent. This might be stopping a shot as a goalkeeper in soccer or hockey, or reacting to a serve (see Roca, Ford, McRobert & Williams, 2013). It is this second “near” situation, where action-simulation researchers have focused their attention.

A popular method for assessing the predictive, decision making abilities of athletes has been the temporal occlusion paradigm (for a review, see Abernethy et al., 2012). Accordingly, athletes view the early part of an action sequence, up to a point of occlusion, and then they indicate how the action would end. Based on this method, evidence has accumulated in sports tasks supporting the idea that the perception of early kinematic cues in an unfolding action leads to the activation of action representations/motor programs in elite performers (e.g., Aglioti et al., 2008; Mulligan, Lohse & Hodges, 2016a, b; Tomeo, Cesari, Aglioti & Urgesi, 2012).

Expert basketball players, expert coaches, sports writers and novices were asked to predict the success of free throw shots which were presented using a temporal occlusion paradigm (Aglioti et al., 2008). These groups were chosen based on their relative motor versus visual experiences with basketball. The expert players were most accurate in their decisions and based on differences at early occluded clips, it was concluded that the shooter's kinematics were driving the accuracy of their decisions. This expert-novice advantage is not new, and has been shown in many sports including predicting shot direction in tennis (e.g., Balser et al., 2014; Williams, Ward, Knowles & Smeeton, 2002; Farrow, Abernethy & Jackson, 2005); determining location of a kicked ball in a penalty situation in field hockey (Williams, Ward & Chapman, 2003) and soccer (e.g., Savelsbergh, Williams, van der Kamp & Ward, 2002)), as well as in handball (e.g., Loffing & Hagemann, 2014), volleyball (e.g., Urgesi et al, 2012; Exp 1), cricket (e.g., Weissensteiner, Abernethy, Farrow & Müller, 2008) and badminton (e.g., Abernethy et al., 2008). What was new about the study by Aglioti and colleagues was that in the second part of the study they showed effector-specific MEPs (Motor Evoked Potentials as determined by electromyography) from the muscles involved in shooting the ball. This evidence of motor activity when watching, although shown by both the skilled watchers and athletes, was most pronounced in the experts when watching a shot which subsequently missed. The authors argued that these anticipatory predictions were realized through activation of the observer's motor system (i.e., action simulation). However, because the muscle activation was seen in both the watchers and athletes and because it was not closely tied to accuracy of the decisions, it remains unclear whether the motor system played a causal role in predicting action outcomes for both groups, or was mostly a consequence of observing.

Motor system activation was also noted in a study of action prediction in basketball, based on measurement of cortical activation inside an fMRI scanner (Abreu et al., 2012; see also Balser et al., 2014; Wright & Jackson, 2007; Wright, Bishop, Jackson & Abernethy, 2010). In studies of deceptive actions in soccer penalty/goalkeeper situations, evidence has been presented showing that soccer players potentially simulate what they are seeing, even when this may be to their disadvantage (Tomeo et al., 2012). Based on videos edited to show ball trajectories incongruent to body kinematics, skilled kickers, as compared to skilled goalkeepers and novices, were more likely to be “fooled” by the body positions of the kicker. This finding supports the idea that, for the kickers, the predictions concerning direction were based on body position and less so on ball flight. The authors also measured MEPs from the lower leg muscles during observation of these videos. There was some evidence that, for the kickers, MEP activation correlated with the degree the watchers were fooled by the actions of the players. Similar, though more direct, evidence for the role of the cortical motor system in prediction accuracy was subsequently shown by Makris and Urgesi (2014) with these same stimuli. rTMS (repetitive Transcranial Magnetic Stimulation) applied to the dorsal premotor cortex (dPMC), which effectively prevents this area from activating properly, significantly affected the predictive decision accuracy of the kickers and goalkeepers (i.e., those with physical motor experiences).

Short-term visual and motor experience effects in action prediction

While an increasing amount of work is being done to quantify the motor and visual contributions to prediction expertise in sports, up until now, such studies have tended to compare the visual prediction performance of motor-visual experts (i.e., basketball players) to visual experts (i.e., coaches), and/or novices. As such, it is possible that in each of these groups the participants may have had at least some expertise in both modalities (motor, visual), making it unlikely that purely motor or visual effects could be fully isolated. Further, it is unclear from existing research if the motor system activation that is exhibited during action prediction contributes causally to prediction accuracy, or is simply a consequence of action observation.

Researchers have shown that short-term motor practice and visual practice result in similar increases in perceptual prediction accuracy, albeit seemingly via different mechanisms

(Springer et al., 2013a,b; Urgesi et al., 2012). However, in these studies, the authors did not demonstrate that these motor or visual representations were activated *during* prediction, and as such were causally responsible for predictive performance. For example, following manipulation of practice experiences of a volleyball float serve in children, physical practice facilitated predictive judgements about accuracy, particularly when actions were viewed from behind the server (1st person; Urgesi et al., 2012). This was in comparison to two further groups that either watched videos of serves or defensive plays not involving serves. Group differences were most notable for judgements based on videos showing only body actions. Although observers of serves improved in their anticipatory judgments, this was mostly when ball flight videos were viewed. Because the physical practice group had both motor and visual training group, it is unclear whether the ability to pick up body kinematics was strictly a function of 'motor' learning, or an interactive effect of 'visual-motor' learning. No evidence of direct motor system involvement (simulation) was presented in this study.

We have conducted a series of studies in this area based on a methodological framework targeting key criteria required to accurately measure the differential contributions of motor- and visual-based neural processes in action prediction (Mulligan & Hodges, 2014; Mulligan, Lohse & Hodges, 2016a,b; Mulligan & Hodges, in preparation). First, in order to draw conclusions about the separate contributions of visual and motor processes to action prediction, it is important to be able to quantify the acquired levels of visual and motor experience. Second, the methods (or data) should provide evidence that visual and/or motor processes are activated *during* prediction; either through manipulation or measurement. Third, a demonstrated relationship should be evidenced between the activation of these visual or motor representations and action prediction accuracy, in order to enable causal statements. Fourth, comparisons should be made within the same individual in order to best understand the ways in which contextual factors affect how and when motor- and visual-based predictive mechanisms are deployed, and how these processes interact with each other. Using these criteria as a guide, we present below a series of experiments, designed to help further our understanding of motor and visual influences on action prediction. These studies have been summarized in Table 1.

***No-vision "motor" training and action prediction*:** In a first experiment, we compared anticipatory predictions about the final position of a dart thrown at a dartboard, before and following either physical practice (visual-motor training), physical practice without vision (i.e., motor-only training; vision was occluded, but feedback was provided about the landing position of the dart), observational practice (visual-only training) or no training (control; Mulligan & Hodges, 2014). Using the temporal occlusion method, we compared the various training groups' predictions before and after practice. Both groups that received physical practice (with and without vision), improved at the prediction task in comparison to no-practice and observation-only groups, and improvements were seen in the early frames before dart release. These results confirmed the suggestion that motor experience is important for predictive accuracy, and at least for a task based on passive observation, visual experience was not. However, without direct manipulation or measurement of the motor system during action prediction, we were unable to determine whether such anticipatory prediction advantages were guided by online, motor simulation processes.

Motoric secondary task probes: To test if and how the motor system is implicated in anticipation, we have used a secondary motor task to selectively interfere with motor components of the action during prediction. The advantage of such a technique is that it is possible to determine direct costs in accuracy in an economical manner, in order to assess motor system involvement in the decision process. Similar motor interference paradigms have been used in studies probing motor-system influences on stimulus detection (e.g., Paulus. Lindemann & Bekkering, 2009; Witt & Proffitt, 2008). In these studies, it has generally been shown that performing a secondary motor task (e.g., ball squeezing) while viewing a stimulus, results in the modulation of perceptual estimations concerning the stimulus.

A dart-prediction task was again our primary task, where no physical (reactive) response was required in the observer, just a judgement as to where the dart would land. To first test the effectiveness of this secondary task paradigm, experienced and non-experienced dart players engaged in two different types of motor secondary tasks during action prediction, which were either congruent to the observed action (action mimicking) or incongruent to the action (pushing against a force gauge; Mulligan et al., 2016a, see Figure 1). The latter task was designed to prevent or at least interfere with the participants' ability to simulate the observed action, as the effector involved in the action would be tasked with pushing.

In support of the action-specific simulation account, only skilled darts' players were susceptible to motor interference from a simple, right arm push task. There was a significant reduction in accuracy predicting the dart's landing position, such that accuracy was similar to a novice level only in this condition. This was seen when they watched videos of themselves throwing and videos of another person. The mimicry condition showed no interference (or benefits). It appears that motor experience plays a direct role in modulating the prediction of action outcomes, through mechanisms that work (potentially in real time) to covertly simulate the observed action, aiding in prediction of sensory consequences.

In the future it will be important to validate these data using relatively more complex actions, but there are of course difficulties in isolating effector-specific roles. For example, a tennis serve involves movement of the whole body and there is evidence that predictive decisions are based on various features of the action as it unfolds, such as the hips and shoulders first, then arm and racket position (e.g., Ward, Williams & Bennett, 2002). However, it may be possible to use this secondary task methodology to test how predictive decisions are made when occlusion points are tied to key information sources (such as the hip area ~240-180 ms before ball-racket contact).

In sports that require a response to anticipatory decisions, we are less certain if and how the motor system is activated. This is especially true when this response could be opposite to the seen action, such as blocking a shot in soccer or volleyball. There is evidence that similar simulation mechanisms are at play in these opposition type actions (e.g., Makris & Urgesi, 2014; Tomeo et al., 2012; yet see Urgesi et al., 2012). It is difficult to know whether activation of the motor system involves effectors involved in the observed action, or those from the response. It has also been suggested that both visual- and motor-based processes are relied on by experienced performers when anticipating the outcomes of observed actions (Tomeo et al. 2012; Urgesi et al. 2012; see also Bach & Schenke, 2017; Springer, Brandstadter, et al., 2013). We explored the suggestion that multiple processes may be at play during action prediction in the studies detailed below.

Separately acquired visual and action experiences**:** Evidence supporting the idea that action prediction involves at least two different processes was shown in a study comparing the ability of experienced soccer goalkeepers and kickers to determine the trajectory of edited penalty kicks (Tomeo et al., 2012; see also Makris & Urgesi, 2014). In these videos, the ball trajectory was not always congruent to the body kinematics. The goalkeepers' visual expertise with the penalty kicks, from a third-person (mirrored) perspective, arguably allowed them to inhibit simulation mechanisms based on body movements and switch to using visual representations. Because the kickers had not acquired separate visual representations, they were unable to inhibit motor simulation, resulting in more prediction errors.

In two recent experiments we have tested how purely-visual or visual-motor experiences affect engagement in action simulation during prediction, through manipulations to both the type of prior experience (visual/motor) and the types of secondary tasks performed during prediction (Mulligan et al., 2016b; Mulligan & Hodges, in prep). The key questions we asked were: under what conditions is the motor system activated when (accurately) predicting action outcomes and how specific is this activation to the observed effector? Effector-specific interference (e.g., right arm only) during prediction, as a function of manipulated motor experience throwing darts (i.e., throwing with the right arm), would provide strong evidence that motor simulative processes are directly implicated in the predictive decision processes of physically trained individuals.

As illustrated in Table 1, in Study 3 we physically trained one group of participants to improve in their spatial accuracy at throwing darts (motor-visual training; see Mulligan et al., 2016b). Another group received only perceptual training, where they practised associating static action pictures of occluded dart throws with their outcomes. Prediction accuracy was tested before and after training. During some of these prediction tasks, participants additionally performed a secondary motor task of pushing against a force gauge with either their throwing or non-throwing arm. A third, no-practice control group was compared.

Both training groups significantly improved in prediction accuracy and in comparison to the control group. Only the physically trained (motor) group was significantly affected by the right-arm push task in the prediction post-test, as illustrated in Figure 2 (for all occlusion points). This group showed a decrease of 21% in overall accuracy, compared to the control, no secondary task condition. No decrement in prediction accuracy was shown when performing the same push-task with their left arm (less than 1%). The perceptually-trained group showed no significant decrease in prediction accuracy with either effector, when compared to the control condition (~3%). Because of the effector specific nature of these effects, the interference appears to be a somatotopic simulation-type process that prevents the motor system from activating in an action-congruent manner, interfering with outcome prediction (for evidence of this effector-based mapping during observation, see Lorey et al., 2014). As illustrated in Figure 3, the degree of interference experienced by participants in this experiment, for the right-push task only, was correlated with their improvement in accuracy on the motor post-test (i.e., bivariate variable error at hitting the three targets).

The fact that the perceptually-trained group showed a similar improvement in outcome prediction, but no interference from the secondary motor tasks, provides evidence that accurate predictions can still be reached through mechanisms outside of motor simulation. This is likely a more “cognitive” mechanism that works through a visual-matching process. Much like differences seen between fans and players in sport-expertise studies, the perceptually-trained group had acquired knowledge from watching which allowed them to make quite accurate predictions about outcomes, independent of the motor system and motor experiences. There was no evidence that the physically trained group developed separate, purely visual representations, enabling them to switch to a visual matching strategy to avoid the interference effects of the motor secondary task. By contrast, in the Tomeo et al. (2012) study, the goalkeepers had extensive, purely visual experience anticipating, from the same perspective that the stimuli were presented. Based on these differences, we hypothesized that, within the same individual, visual experiences would need to be acquired independently from motor experience for this flexibility in prediction processes to be evidenced. We have tested this idea in a fourth, as yet unpublished study (Mulligan & Hodges, in preparation) where we provided separate visual and motor training episodes to determine whether participants could effectively switch between prediction-strategies.

The group that had physical practice on day 1 improved prediction accuracy, except when performing the secondary task with the right (throwing) arm (replicating past results). After a second day of perceptual practice, prediction accuracy was maintained, but now there was no right-arm interference. The other group, which had perceptual practice on day 1, showed a similar improvement in prediction accuracy, with no decrement under secondary task conditions. After physical practice on day 2, accuracy was maintained, but there were still no decrements associated with the secondary, right-arm push task despite motor practice. These data suggest that motor simulation is not automatic and that separately-acquired motor and visual representations allow flexibility in adopting predictive strategies most robust to external task demands. Although these were short-term training studies conducted with novices, the idea that separate training episodes might work to an athlete's benefit when the motor system is taxed has appeal. However, it is important to be cautious in assuming that training the perceptual system will positively transfer to situations where a physical action response is required. We know that visual-only practice conditions do not always engage the motor system (e.g., Ong & Hodges, 2010; Ong, Larssen, & Hodges, 2012). The time course of these processes might also be different, such that under time-constrained conditions (as is typical in sports), more implicit, motor-based, predictive processes dominate, but when more time allows, perceptually-driven processes might take over.

Implications for training and research

Research showing that physical practice fosters simulative processes, which allow athletes to better perceive actions and predict action outcomes in others, has helped to expand our understanding of the processes involved in action prediction. We know that motor-based simulation processes can aid perceptual decisions, but we also know from research using deceptive actions and motor interference paradigms, that there may be negative consequences associated with simulation, and by extension, physical practice experiences. Performers may suffer when the outcome of their simulated, predictive (forward) model, is incongruent with the observed action. This might be due to the concurrent enactment of actions different to that observed, responding to deceptive actions or fakes where body movements may not accurately relate to outcomes, or responding to differently skilled individuals. For example, an expert athlete engaging in prediction when watching a novice might erroneously anticipate outcomes based on their own abilities rather than the person they are watching or responding to (see Ikegami & Ganesh, 2014). If performers have separately acquired visual-only experiences, through observational or perceptual practice, they may be able to inhibit or bypass motor-driven simulative processes and switch to a more strategic, visual-based predictive mechanism. As yet, it is unclear if observational/perceptual learning, which promotes this switching capability, requires an active response to the observed action (as would be the case with a goalkeeper responding to ball placement), or simply a predictive judgement, followed by feedback (as was the case with the learners in our dart-throwing studies). Moreover, the time course of these processes as a function of the mode of experience has not been investigated. It may be that more perceptually-driven cognitive processes can only be used when “sufficient” time is available to respond and under time-constrained conditions, simulative mechanisms always dominate.

Though there is reason to think that scheduling separate sessions of perceptual-only training experiences into practice would be useful, there might also be potential costs. If an athlete learns and practises primarily through watching, because this type of training does not appear to activate motor-based representations (at least not well), then we might not expect transfer from the visual-training environment back to the game. In many situations in sport, fast anticipatory decisions are required, which are likely to be based on action-simulation. Although we have evidence that, for novices who have undergone short-term physical or visual practice, visually-based knowledge (representations) appears to dominate prediction processes (at least when time allows), it is unclear whether this would be true for experts who have thousands of hours of physical practice. Beyond the suggestive research of Tomeo and colleagues (2012) with skilled goalkeepers, this skill-based effect has not been tested.

As discussed earlier, it is unclear as to whether such simulation type processes are involved in action decisions about events which unfold on a larger scale, such as anticipating how a player with a puck or ball will act as they approach the goal (i.e., shoot, dribble or pass?). Although this may too, at some level, be based on anticipation of a player's action (i.e., simulating the actions of the player with the ball), there is an additional component of game reading required which underpins judgements about the accuracy (effectiveness) of a decision.

More empirical research needs to be directed towards actions that require a complementary, yet opposite response. This might be responding to a partner in dancing or figure skating or diving to save a kicked penalty shot with the hands. Although there is some evidence that simulation-type processes are involved when the partner or athlete responds in opposition, research is needed where there is control of motor or visual experiences, or where interference tasks are used which target the main effector of the actor (e.g., foot for a kicker) versus that of the responder (i.e., hand for a goalkeeper).

There is evidence that simulation-type mechanisms are best engaged from a first-person (same direction, often slightly behind), rather than third-person perspective (facing as though mirroring). Urgesi and colleagues in volleyball (2012) showed evidence that after physical practice, prediction accuracy was enhanced when watching actions from behind, but not facing. In some of our recent work, we have been studying whether simulation type processes are still engaged in decision making when people practice throwing with their dominant hand, but make predictive decisions based on videos which has been flipped to make it appear like someone throwing with their opposite hand (see Table 1, Study 5). We have preliminary evidence showing that predictive accuracy only improves for videos that appear to be of the same hand as physically practiced (for abstract see Mulligan, Chan, Kuehne & Hodges, 2017). It therefore appears that there are quite sensitive perspective/contextual effects which dictate how predictive decisions will be made, and further testing is needed in order to better inform best practice for coaching anticipatory skills.

In summary, we have reviewed theoretical frameworks that help explain how predictive anticipatory decisions are made during situations that are common in sport, involving an actor and respondent/opponent. Under these conditions, it is assumed that the respondent or active observer of these actions engages their motor system in order to predict the outcomes of their opponent or potentially another team-mate. Empirical research has been presented in support of this view, based on: 1) measurement of neurophysiological processes in the brain (e.g., Wright & Jackson, 2007); 2) increased activation of muscles involved in the action when selectively primed through TMS procedures (e.g., Aglioti et al., 2008; Tomeo et al., 2012); 3) impaired performance following rTMS applied to the dorsal premotor cortex in experts (Makris & Urgesi, 2014) and through 4) impaired performance when experienced performers were required to perform a secondary motor task which disrupted their ability to activate their motor system in an action congruent manner (e.g., Mulligan et al., 2016a,b). Although the conditions which appear to regulate motor simulation are still being explored, the suggestions for coaching are that separately acquired visual experiences, through perceptual-video based training of decisions, might have both benefits and potential costs which need to be weighed. These decisions could be dependent on the sport (and time demands), the athlete’s skill and experience and the types of tasks that the athletes are primarily expected to undertake when making anticipatory action decisions. This is an exciting line of inquiry which will hopefully offer new insights into best methods (and conditions) for training perceptual skills relevant to sports.

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Table 1: General design table for the dart prediction studies

	DAY 1: Pre tests			**Practice**	**DAY 2: Practice**	**Post-tests**		
	Motor-test	Prediction-tests		Practice	Practice	Prediction-tests		Motor-test
	Aiming condition	Model (thrower)	Dual-tasks	Condition	Condition	Model	Secondary	Aiming condition
Study 1 *Mulligan & Hodges (2014)*	bulls-eye	RH	NO	1=PP, 2 = PP, no vision 3 =OBS, 4= CTL	same as Day 1	RH	NO	bulls-eye
Study 2 *Mulligan et al (2016a)*	bulls-eye	RH	RH, Mimic, Tone	none (expert-novice)	none	RH Self*	RH, Mimic, Tone	bulls-eye
Study 3 *Mulligan et al (2016b)*	Top, mid, bottom	RH	RH, LH, Tone	1 = PP, 2 = PER, 3 = CTL	same as Day 1	RH	RH, LH, Tone	Top, mid, bottom
Study 4 *Mulligan & Hodges (in prep)*	Top, mid, bottom	RH	RH, LH, Tone	1 = PP 2 = PER	PER (switched) PP (switched)	RH	RH, LH, Tone	Top, mid, bottom
Study 5 *Mulligan et al (2017 & in prep)*	Top, mid, bottom	RH LH	RH, LH, Tone	1 = PP,LH,L-Handed 2 = PP,LH, L-Handed	same as Day 1	RH LH	RH, LH, Tone	Top, mid, bottom

NOTE: Self= self-model (made self-predictions under same conditions). RH = right-hand, LH = Left-hand, R-Handed = Right handed person, L-Handed = Left-handed person. PP = physical practice, OBS = observational practice, CTL = no practice control, PER = perceptual training with feedback

Figure 1: Photo depicting a participant in the right-hand push, secondary task condition during prediction testing. As they are watching the video and making a decision about where the dart is expected to land they simultaneously push lightly (15% of max force) against a force gauge.

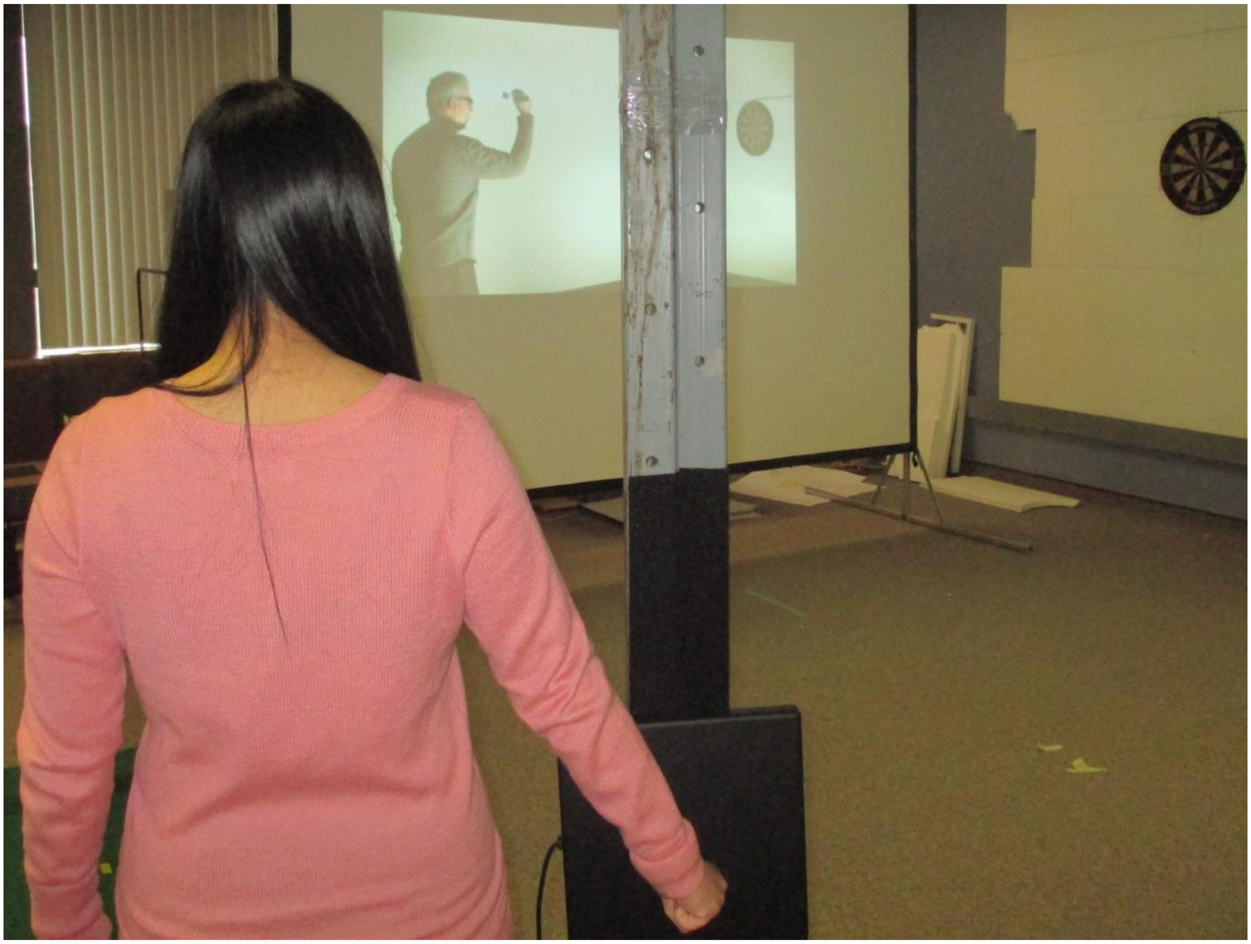


Figure 2: Percent accuracy in the post-practice prediction task as a function of group (Perceptual, Motor or No-practice), secondary task condition (None, Right-hand push/force task or Left-hand push/force task) and Occlusion frame (1 - 3). Note 33% = chance. For details of study see Mulligan et al (2016b).

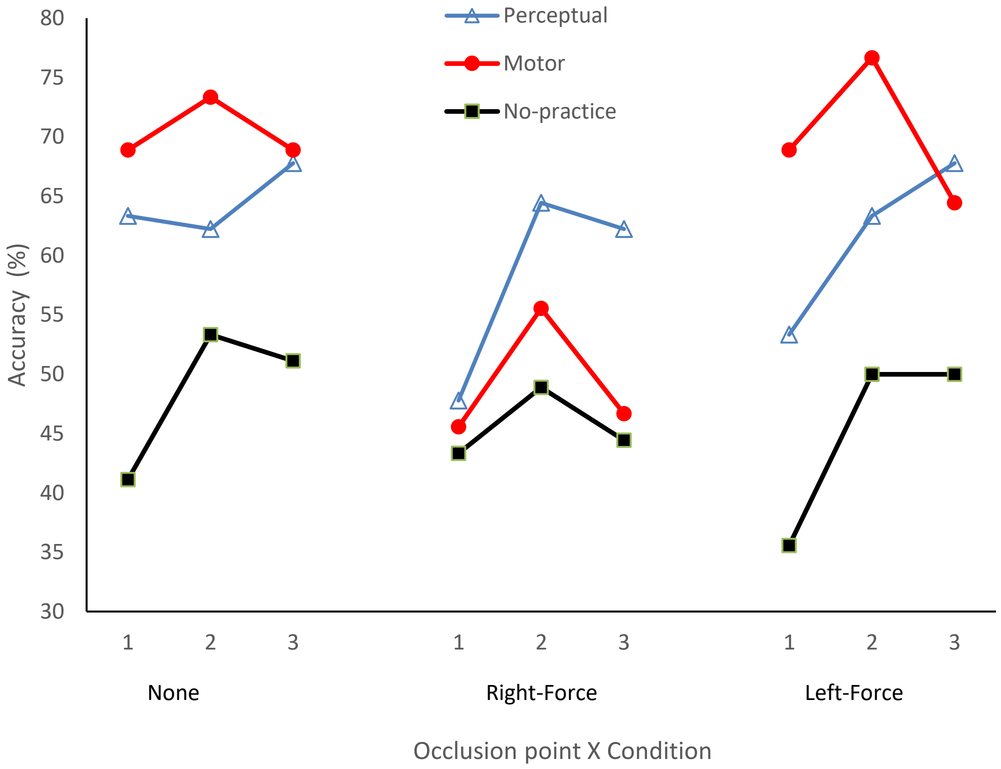
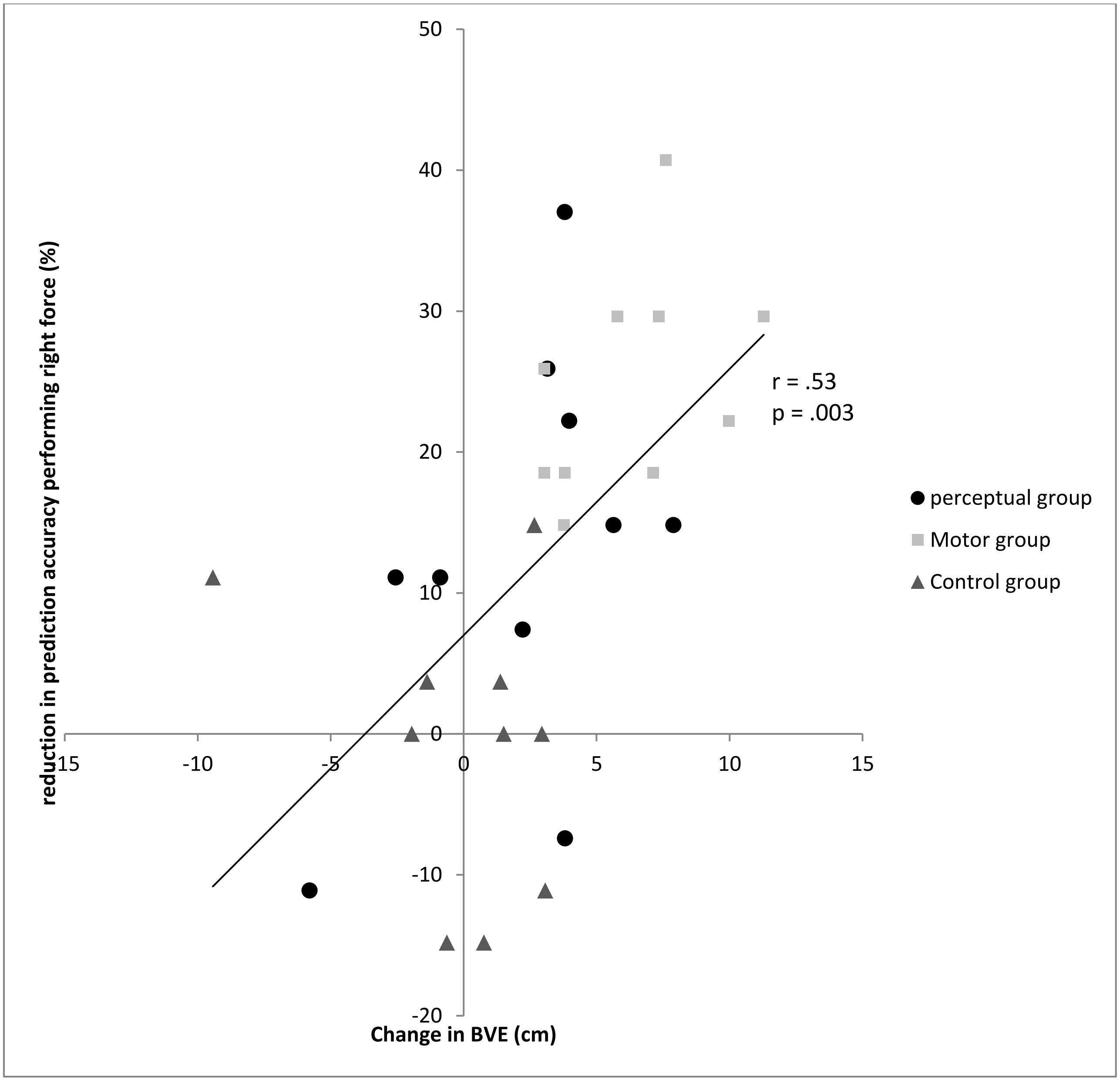


Figure 3: Scatter plot showing the relation between improvement on the motor task (i.e., throwing to the three targets) as indexed by differences in bivariate radial error (BVE) before and after practice and how much participants were affected by the right-push task when watching videos and making predictions (i.e., difference from control). For details about the study see Mulligan et al. (2016b).


50
40
30
20
10
0
-10
-20
-15
-10
-5
0
5
10
15
reduction in prediction accuracy performing right force (%)
Change in BVE (cm)
r = .53
p = .003
● perceptual group
■ Motor group
▲ Control group