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What is modelled during observational learning?

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Abstract

In this article, we examine the question of what information is processed during observational learning by evaluating a variety of methods, theories, and empirical data. Initially, we review work involving neuroimaging techniques and infant imitation. We then evaluate data from behavioural experiments involving adults, wherein a variety of attempts have been made to isolate the critical or minimal information constraining the acquisition of coordination. This body of research has included comparisons between video and point-light displays, manipulations to the amount and type of information presented in the display, the collection of point-of-gaze data, and manipulations to the task context in terms of outcome goals. We conclude that observational learning is governed by specific features of the model's action (i.e. motions of the end effector) and the task (i.e. outcome constraints) and, in contrast with traditional theoretical modelling, more global aspects of a model (i.e. the relative motions within and between joints) do not appear to be the primary method for constraining action execution.

Keywords: *Imitation, point-light displays, skill acquisition, point-of-gaze*

Introduction

It appears that people learn from watching others. Much of early development has been attributed to the processes of imitation (Meltzoff & Moore, 1977, 1983; Piaget, 1962) and social learning (Bandura, 1986). In adulthood, motor skill learning is most commonly observed in the context of sport, where demonstrations are the most frequent method of conveying information to learners (Williams & Hodges, 2005). The main questions that have underpinned recent observational learning research in the sport and exercise sciences are: "What information is perceived and used for movement reproduction?" and "How do different task constraints drive the type of information used for observational learning?" In this article, we review attempts to answer these questions with particular reference to recent data collected in our laboratories.

Several different concepts and terms have been used to describe the observational learning process. Typically, imitation is inferred when individuals copy an action – that is, "when actors match their own movements to those of others" (Wohlschläger, Gattis, & Bekkering, 2003, p. 1). This process has also been referred to as modelling and observational learning. It is assumed that the action performed by an observer is a direct result of the observation process and is believed to be due to the perception and use of action-related features picked up from viewing the model. In observational learning research, considerable emphasis has been placed on the quality of action-reproduction in a retention phase (typically performed at a later time in the absence of a demonstration) and the cognitive processes that underlie the learning process, such as attention and memory (e.g. Carroll & Bandura, 1982, 1985, 1990; McCullagh & Weiss, 2001).

There is also evidence that observational learning is not a result of viewing the model's action in isolation. It is argued that the observer perceives the intention of the actor such that the action reproduction process is goal or object driven, rather than action or means driven (see also Bekkering, Wohlschläger, & Gattis, 2000; Erlhagen, Mukovsky, & Bicho, 2006). This process has sometimes been referred to as "emulation" (Heyes, 2001; Tomasello, Kruger, & Ratner, 1993) or "program-level imitation" (see Byrne & Russon, 1998). It is very likely that emulation is influenced by the actions of the performer and that the information used for imitation will be dependent on the context, difficulty, and novelty of the task. An important task for researchers, therefore, is to determine *how* and *what* information

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is organized and prioritized during the learning process in view of these various constraints.

A variety of methods have been employed to help clarify what information guides reproduction and how this is influenced by various task constraints. The most common method has been to manipulate the presentation of information to the viewer through perturbation or occlusion techniques. During this process the type and, often incidentally, the amount of information provided within a demonstration is controlled. These techniques are usually followed by measurements that quantify action reproduction (and outcome success). Visual gaze tracking has also been used as a method for exploring what information is picked up or attended to during the observational learning process. Perceptual recognition and discrimination tests can also help researchers understand what information is remembered or attended during observation for later reproduction, in isolation from an individual's ability to reproduce the movement. The latest techniques for exploring the observation process have involved neuroimaging, including functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans. These latter methods have been helpful in identifying the brain locations involved in observation, motor execution, and imitation. They have resulted in proposals that action-observation activates similar areas of the brain to that involved in the execution of the action and associated ideas of "mirror neurons" as a potential neurophysiological mechanism for motor simulation during observation (di Pelligrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti, Fadiga, Fogassi, & Gallese, 1996; Rizzolatti, Fogassi, & Gallese, 2001).

In this article, we examine how these various methods have recently been used to aid understanding of the observational learning process and detail the main conclusions that have resulted from this body of work. We present research from our laboratories involving behavioural manipulations and detailed comparisons between the kinematics of the model and those of the learner. In the final section of the article, we consider the implications of this body of work for future research and applied practice. We begin by briefly reviewing some of the neurophysiological and developmental literature that pertains to the question of what information is used to guide observational learning. In particular, we examine evidence supporting either a direct-matching or an indirect, goal-directed view of action reproduction. As stated, and given that this review paper is not explicitly related to the neurophysiological mechanisms underpinning imitation, we will only touch on some of the neurophysiological work in an attempt to offer an idea of the underpinning mechanisms operating during the observational learning process (for a more detailed review of the literature, see Rizzolatti & Craighero, 2004 and Vogt & Thomaschke, this issue).

Neurophysiological research methods and infant development

In recent years, developments in brain imaging technology have allowed researchers to identify locations of the brain involved in imitation. It has been proposed that observation of an action evokes activity in areas of the brain associated with execution of the action, what has been referred to as a "mirror–neuron system" in the human brain (e.g. Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Grèzes & Decety, 2001; Iacobonni *et al.*, 1999; Rizzolatti *et al.*, 2001). The proposal is that when we observe we are actually involved in a degree of simulation, perhaps activating a motor program for action (e.g. Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Jeannerod, 1994). This mirror-neuron system activates a very complex network in the human brain that is formed by the occipital, temporal, and parietal visual areas and two cortical regions fundamentally associated with motor activity (located in the rostal part of the inferior parietal lobule, lower part of the gyrus, and the posterior part of the inferior frontal gyrus; for more details, see Rizzolatti & Craighero, 2004). This mechanism would perhaps support proposals that individuals are "hard-wired" for imitation. In support of this latter suggestion, it has been shown that infants aged 14 months imitate the details or means of an action by, for example, choosing to turn on a light with their head one week after watching a model perform this same action (e.g. Meltzoff, 1998).

As a result of this research and other work, Meltzoff and colleagues (e.g. Meltzoff & Moore, 1977, 1983, 1989, 2002; Meltzoff, 1993) have proposed a direct-mapping view of imitation. They suggest that the perception of a stimulus activates the perceptual response. Moreover, this activation can be cross-modal, as evidenced by the finding that an infant does not need to see their limbs to know they are replicating the action. For example, a newborn can copy the tongue protrusions of adults, even when these are relatively unusual movements (e.g. turning the tongue). Although Meltzoff and colleagues have provided substantial evidence to support a theory of matching, they acknowledge (e.g. Meltzoff, 2002) that as children grow older this mapping process is less direct and instead is based on understanding of the model's intentions.

In a replication of Meltzoff's (1998) study with one minor modification, Gergely, Bekkering, and Király (2002) showed that infants do not imitate without some *a priori* rationalization as to the reasons for the action. In the modified experiment, when the infants saw the model turn the light switch on with her head while her hands were occupied, only 21% of the infants replicated this action. The authors argued that the infants inferred that this unusual and perhaps inefficient method was being used because of additional constraints (the hands were occupied), which they themselves did not face when asked to turn on the light. According to these authors, action-reproduction is primarily driven by emulatory processes, resulting in the achievement of an outcome by the most direct means. Infants are capable of evaluating the constraints of the situation to determine whether the means are an important part of the observation for action process (see also Meltzoff, 1995). This cognitive-mediated explanation for imitation is based on the idea that infants and adults are goal-oriented and organize their perceptual scene based on a hierarchy of goals. Bekkering *et al.* (2000) have also shown that young children prefer to imitate the action goal (e.g. reaching to touch the correct ear) rather than the means used to achieve that goal (e.g. using the contralateral limb to achieve the goal instead of the correct ipsilateral movement; see also Wohlschläger *et al.*, 2003). As highlighted by Gergely and colleagues (2002), the imitated action is governed by task and individual constraints, whereby the main goals of the task or the perceived intentions of the model form the executed movement pattern.

Neurophysiological data consistent with the above intentional or goal-directed hypothesis have been presented (Chaminade, Meltzoff, & Decety, 2002). Similar cortical areas were activated during observation of both the means (i.e. grasping and moving only) and goals (i.e. placing) of the action in an object manipulation task. Although activated in both conditions, the dorsolateral prefrontal cortex showed increased activation when only the means were shown, even though this area has been suggested to be involved in representations of the action goal (Pochon *et al.*, 2001; see also Koski *et al.*, 2002). This led Chaminade *et al.* (2002) to conclude that imitation is a "creative reconstruction" (p. 327), based on an implied goal-state that does not need to be present during observation.

Finally, researchers have demonstrated an increased cortical sensitivity to human versus non-human actions, such as grasping with a hand versus a tool or robotic arm (e.g. Perani *et al.*, 2001; Stevens, Fonlupt, Shiffrar, & Decety, 2000; Tai, Scherer, Brooks, Sawamoto, & Castiello, 2004) and to actions that are biomechanically plausible (Shiffrar & Freyd, 1990, 1993). As we discuss below, recognition of biological motion, as assessed through point-light displays (see Figure 1), sometimes activates similar areas of the brain (e.g. middle temporal gyrus and superior temporal sulcus) to those observed with the processing of normal video displays (e.g. Beauchamp, Lee, Haxby, & Martin, 2003). This finding suggests that humans are able to fill in missing details of an action in these impoverished displays. There is also cortical evidence that the mirror-neuron system is sensitive to the similarity or correspondence between observation and motor capability (or expertise/experience), implying some degree of sensitivity to the behavioural limits of the performer. For example, Calvo-Merino *et al.* (2005) have shown that practice in specific domains of dance produce differential patterns of activation during observation that involves motor areas only when the actions are a part of the observer's movement repertoire.

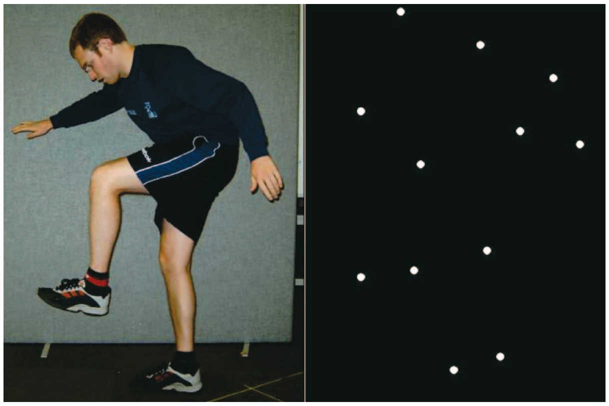


Figure 1. An individual performing a specialized soccer kicking action in film and point-light format.

In summary, there is evidence that during observation for later imitation, similar areas of the brain are activated to those involved in actual movement execution (e.g. Rizzolatti *et al.*, 1996). Moreover, activation of these areas appears to be goal-directed rather than a result of a direct mapping between what is seen and what is subsequently re-enacted. In attempting to provide an answer to our primary question of "what is modelled during observational learning?", the developmental literature and neurophysiological evidence would point to an important role for task context and familiarity. In the remainder of this article, we examine how this question has been approached in behavioural experiments that were designed to examine adult observational learning using point-light displays, visual occlusion techniques, and measures of visual point-of-gaze.

Point-light displays

Since the work of Johansson (1973, 1975), there has been considerable evidence to support the claim that people are attuned to invariant features of biological motion (for reviews, see Blakemore & Decety, 2001; Bruce, Green, & Georgeson, 1996). People are able to discriminate actions based on limited information pertaining to the invariant relationships across and within joints. For example, people can determine whether individuals are running or walking and even their gender when the action is displayed as a series of small light sources (called a point-light display) against a black or dark background (as illustrated in Figure 1). These point-light displays can be constructed by attaching reflective markers or light-emitting diodes to the major joint centres of the body, recording the body in motion, then displaying these against a dark background (see Johansson, 1971; Marey, 1972). In the resulting point-light displays, all structural and contextual information sources are removed in an attempt to isolate critical features of motion perception. Comparisons with unedited displays and manipulations to these displays through the removal of certain features of a movement have provided insights into the question of what is modelled during observational learning. We first review evidence from the perception literature where point-light displays have been used to help understand the critical features underlying accurate movement perception.

Assessing the perception of biological motion

The ability to determine actions from point-light displays has been observed early in development (Bertenthal, Proffitt, & Cutting, 1984; Booth, Pinto, & Bertenthal, 2002; Fox & McDaniel, 1982; Pavlova, Krageloh-Mann, Sokolov, & Birbaumer, 2001). However, it has been shown that this ability is facilitated by perceptual training and mediated by skill level (Ward, Williams, & Bennett, 2002; see also Hayes *et al.*, this issue). The critical information underlying biological motion perception is believed to be both the common motion across elements of the action, such as the limbs (i.e. directional information), and the relative motion across these elements (i.e. how the different limbs move in relation to one another). There has been some debate in the adult perception literature as to what information is most important for perceptual discrimination of biological movement and whether there are particular features that are more informative than others.

One proposal is that distal information (i.e. movement at the extremities) is critical for discriminating motion perception, as opposed to more proximal features, because the extremities of a movement exhibit the most complex trajectory and typically move through greater ranges of motion (see Mather, Radford, & West, 1992). However, it is the relative positions of the distal musculature that are important for discriminating across whole-body actions. This proposal is supported by research by Mataric and Pomplun (1992), who showed that during observation of a whole-arm movement for later reproduction, successful performers fixated on the fingers and the distal musculature rather than motions of the whole arm and features more proximal to the body. In contrast, Pinto and Shiffrar (1999) found that an observer's sensitivity to perception of human form from dynamic models decreases more prominently when mid-limb elements of a display are occluded (such as the elbows and knees), rather than the extremities, although in their study participants were only required to judge whether the movement was human or not. Giese and Poggio (2003) also showed that although the elbows were important for recognition of motion, the feet were critical for more accurate discrimination across actions, in particular the opponent motion of these effectors. There appears to be substantial evidence that relatively small or local spatial areas across the human body are important for the detection of human form (see Bertenthal & Pinto, 1994; Pinto & Shiffrar, 1999). For example, it has been shown that masking the motions of a human point-light walker with noisy markers representing a whole limb rather than the same number of individual, randomly placed markers, was most disruptive for action recognition (Bertenthal & Pinto, 1994).

Although this literature provides some signposts as to where to look for critical motion information that informs action execution, there are some potential limitations in extrapolating from perception to action imitation. There is both behavioural and neuroscience evidence to suggest that perception for action might be governed by different processes than perception for recognition. Milner and Goodale (1995) have differentiated between the roles of the dorsal and ventral streams in the brain during visual-perception tasks involving discrimination judgements as opposed to movements. In most observational learning contexts, the observer is required to replicate a movement in the absence of a model and, consequently, it is likely that there are more similarities in the processes involved in the detection of motion and its execution. However, as we discuss later, the specific information guiding these two processes could be quite different.

These ideas concerning the perception of biological motion, specifically research with point-light displays (e.g. Johansson, 1973, 1975), led Scully and Newell (1985) and Newell (1985) to propose the visual-perception perspective to observational learning. In this approach, the assumption is that learners pick up the relative motion between key anatomical areas, with this information constraining practice and subsequent reproduction of the skill. The acquisition of coordination (i.e. the constraining of individual joints to move together in a coordinated and effective fashion) is seen as a fundamental problem for movement control (see Bernstein, 1967; Kugler, Kelso, & Turvey, 1980, 1982). Scully and Newell (1985) argued that the relative motion information present within a demonstration acts to constrain the to-be-learnt coordination pattern early in learning, and that with physical practice the pattern of coordination is effectively scaled to skilfully meet the demands of the task. They further proposed that demonstrations are most effective early in practice, aiding the acquisition of coordination through the perception and use of relative motion information, both in action, when simultaneously watching and performing, and out of action, when watching with the goal of later imitation (Newell, 1991). In this way, relative motion information is seen as the primary constraint on action interacting with other task, individual, and environmental constraints to bring about movement (Newell, 1985, 1986).

In the ensuing sections, we evaluate the claim that relative motion is the critical source of information that is imitated during observational learning. In contrast to perceptual discrimination, observational learning typically requires the learner to observe a relatively novel or unusual action and then reproduce that action under various task constraints. The process of observational learning is likely to be more complex than perceptual discrimination because it requires a greater understanding of the perceptual scene, how it relates to the observer, and decisions as to the critical information that needs to be attended to for imitation and task outcome attainment (if required).

Highlighting relative motion information

Where individuals are required to learn novel actions, such as is typically the case with sports skills, it is assumed that considerable attention is paid to the means of achieving that action. Therefore, the main question becomes one of determining what information is prioritized and used in this process. One of the proposals to emerge from the visual perception perspective proposed by Scully and Newell (1985) is that relative motion information is critical for observational learning. Consequently, if this information is made salient (i.e. all non-essential information is removed) through the use of point-light models, skill acquisition will be facilitated, in comparison to non-edited film displays (e.g. Runeson, 1984). This proposal has only gained attention within the last 7–8 years perhaps as a result of access to motion analysis systems that enable point-light displays to be constructed with relative ease and that allow for an objective look at the approximation of coordination (see Horn & Williams, 2004).

This hypothesis was first examined by Scully and Carnegie (1998). In a series of experiments, individuals who practised a ballet sequence following the presentation of a point-light model showed better replication of the model's actions than groups who only saw a video display (whether at regular speed or in slow motion). Although certain features of the model's movement were edited from the display (either hip, ankle or toe), participants who viewed a point-light displays performed better than those who viewed filmed images. It should be noted, however, that the removal of the distal effectors (i.e. ankles and toes) disrupted both coordination and force reproduction, implying that perhaps end-point features of the display are more critical than other kinematic sources in guiding movement recognition and reproduction (see also Cavanagh, Labianca, & Thornton, 2001; Giese & Poggio, 2003).

No researchers have subsequently shown that this method of isolating relative motion information in a demonstration is more beneficial than providing an unedited film display. In fact, there has been evidence to the contrary showing that point-light displays are impoverished and fail to convey the action as well as film (e.g. Romack, 1995; see also Hayes *et al.*, this issue). These discrepancies have been discussed in terms of the different task constraints that might impact upon the information that is attended. For example, when there is a lack of an explicit outcome goal, as in learning a ballet sequence, the task is less constrained and action-observation is elevated in importance. Despite this possibility, subsequent manipulations to both the availability of feedback (Horn, Williams, Scott, & Hodges, 2005) and task goals (see Hayes *et al.*, this issue) have failed to show any advantages of point-light displays over normal video. In general, however, both video and point-light display demonstrations are more effective for the acquisition of coordination, although not necessarily attainment of movement outcome, than control conditions where no demonstrations are provided or only verbal instructions are given.

Several authors have concluded that it is the relative motion information contained within these demonstrations that provide the advantage in replication of movement form, despite the fact that relative motion information has not been directly manipulated. Al-Abood, Davids, and Bennett (2001) examined the acquisition of an underarm dart throw under point-light display, film, and no-demonstration (control) conditions and found that only the demonstration groups adopted the correct movement form (i.e. intra-limb coordination of an underarm throwing action). Although members of the no-demonstration group adopted different actions to the group who viewed a demonstration (e.g. executing a standard overarm dart-throwing action), there was no difference in outcome performance between the two groups. It appears that when the motor task can be solved in many different ways, there is no outcome performance advantage in adopting the technique demonstrated by the model (see also Horn, Williams, & Scott, 2002). As noted earlier (see Gergely, Bekkering, & Király, 2001), unless there is sufficient motivation to change the means to achieving a task goal, a change in the learner's movement form is unlikely, regardless of whether or not a model is presented.

Comparisons of a point-light display and video model by Horn *et al.* (2002) also failed to yield differences in terms of movement form or outcome attainment when modelling a soccer kicking action. Moreover, presenting a demonstration did not convey any additional benefits compared with a no-demonstration, physical practice only group. The authors proposed that in this task demonstrations, and arguably relative motion information, were not the primary constraints on movement acquisition and performance. The requirement to lift the ball in the air and land it on a target, in addition to receiving feedback as to how well this was achieved, was proposed to be the major constraint and the model's criterion movement pattern was viewed as less important. The only differences between the demonstration and control groups were in terms of more strategic parameters. The demonstration groups copied the approach to the ball (i.e. the number of steps), suggesting that demonstrations help to convey general, strategy-related features of the movement, rather than as initially proposed, higher-level perceptual features such as within- or between-limb coordination (see also Brooks, Hilperath, Brooks, Ross, & Freund, 1995; Hodges & Franks, 2004; Kohl & Shea, 1992; Martens, Burwitz, & Zuckerman, 1976). However, caution is required in assuming that replication is necessarily indicative of perception. Individuals may be attuned to relative motion information when watching a demonstration and in attempting to recognize an action (Johansson, 1973, 1975), but they may use more general features when replicating the action.

In a follow-up experiment, Horn *et al.* (2005) prevented access to knowledge of results in an attempt to downplay outcome attainment and feedback-based changes in movement form. Participants in the demonstration groups did show better approximation of the model's lower-body coordination pattern than no-demonstration, control participants, although again no differences were seen in outcome attainment. Participants in the video, rather than the point-light display group, also acquired the movement pattern at a faster rate. In accordance with the original arguments proposed by Newell (1985), when replication is the only goal, the model's coordination pattern is the optimal (or only) solution to the coordination problem. However, more typically, a demonstration is only one of a number of possible task constraints which influence movement reproduction. Although these type of manipulations (e.g. point-light display vs. film) allow researchers to draw conclusions as to the importance of demonstrations and to infer what information guides acquisition based on changes in movement kinematics, they do not allow for an evaluation of the specific features of the model's action that are used to guide reproduction.

Manipulation of relative motion information

It is not possible to conclude how important relative motion is for observational learning without some form of direct manipulation of this information. In a recent series of experiments conducted in our laboratories, point-light models were edited in an attempt to remove relative motion information; both the motions of joints within the same limb (i.e. intra-limb) and between different limbs (i.e. inter-limb). The removal of this information provides a strong test of the importance of relative motion information in observational learning and the relative importance of these two sources in constraining action.

In one experiment, individuals watched a full body-size demonstration and executed a whole-body action that they believed was associated with the observed demonstration (Hodges, Hayes, Breslin, & Williams, 2005). In the first part of the experiment, the observed demonstration did not contain any contextual cues that might have provided the participants with augmented information about the nature of the to-be-imitated action. Three groups of participants were compared who received various amounts of information concerning a left-footed, specialized soccer kick, shown as an edited point-light display (see Figure 1 for a static illustration of the movement end-point). One group viewed the left toe marker from the start until the end of the kick (i.e. no relative motion information). A second group observed two points of light pertaining to the foot (toe and ankle) and a third group viewed the lower leg as three points of light pertaining to the toe, ankle, and knee. The hip – knee relative motion plots for the LEG (top panels) and TOE (bottom panels) groups are illustrated in Figure 2. The group viewing the toe marker approximated the model's coordination profile as well as, and in some instances better than (i.e. hip – knee coordination), the foot or leg groups (see left panels, a and c, where the first and last trials are compared with the model) and did not show a significant change in coordination following the introduction of a full-body model in a second

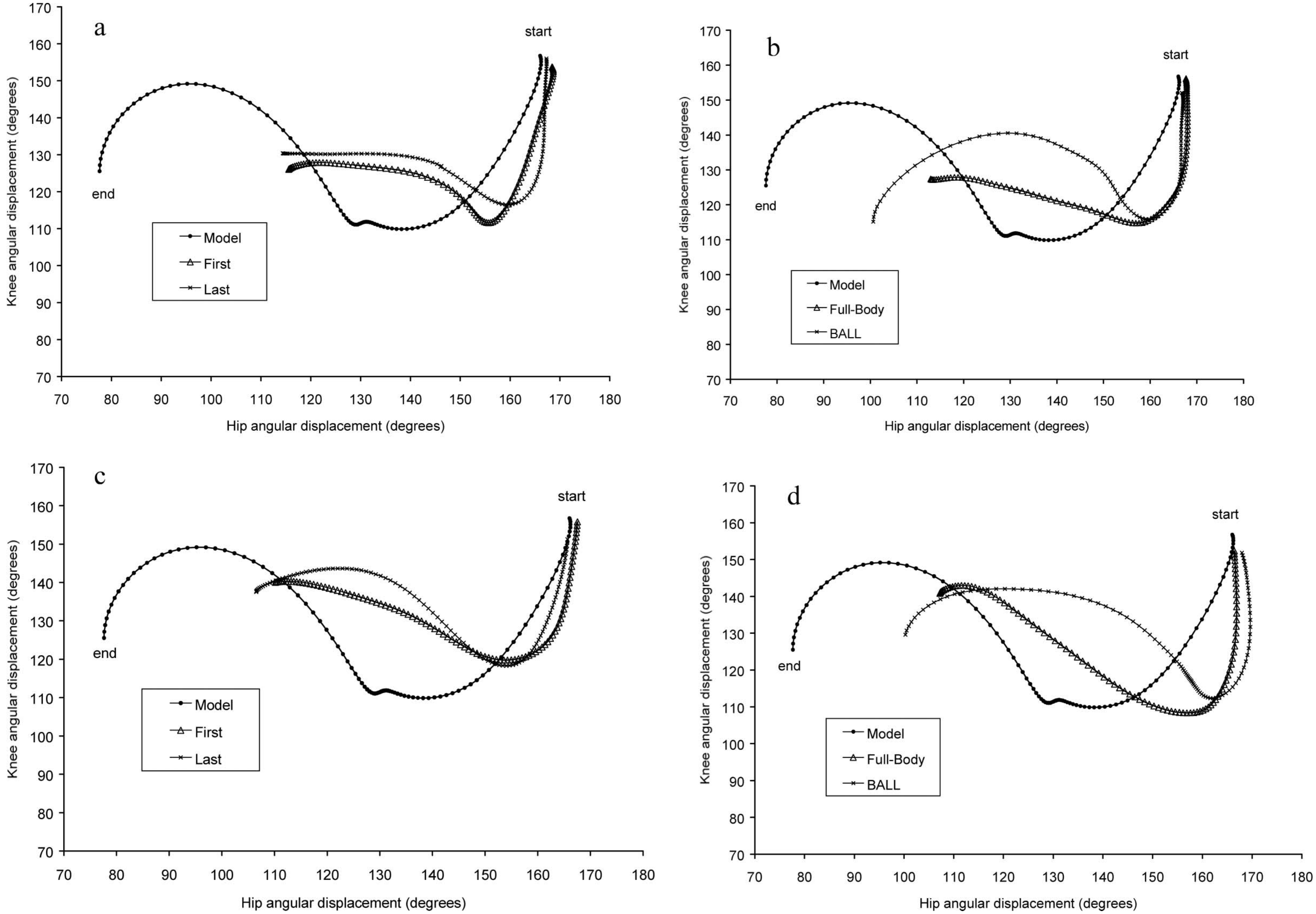


Figure 2. Mean hip–knee angle–angle (degrees) plots for the LEG (a and b) and TOE (c and d) groups. In all plots the model's trace is illustrated (circles). The left-hand panels shows hip–knee coordination from early to late in practice (Phase I); the right-hand panels correspond to hip–knee coordination for the full-body transfer (Phase II) condition and after introduction of the task constraints (i.e. Phase III, BALL). These data are reproduced from Hodges *et al.* (2005).

phase of testing (see right panels, b and d). In a third phase, we introduced further task constraints such that participants were now required to kick a ball over a height barrier to land on a target, while adopting the movement pattern conveyed by the model. This condition resulted in the most significant change in intra-limb coordination and the closest approximation of the model's coordination pattern (denoted "BALL" in the right panels of Figure 2).

No evidence was presented to show that relative motion is an important constraint during observation for later reproduction. Individuals were able to extract information from limited action features (in this case, the end-point of the action) to reproduce the required movement. As reported earlier, individuals were able to "fill in the gaps" and infer the type of action from impoverished displays, suggesting that much of the observation process is based on inference, rather than direct-matching. Therefore, a change in the learner's movement form to more closely resemble that of the model should not necessarily be taken as evidence that individuals are being constrained by relative motion information from the display. The variable that brought about a pattern of coordination that was most like the model was the requirement to kick a ball in the final phase of the experiment, rather than merely imitating a full-body model. Although we do not rule out the suggestion that relative motion information is used by an observer to identify or recognize a specific class of action (see Cutting & Proffitt, 1982; Ferrari, 1996; Pinto & Shiffrar, 1999), following the identification or labelling of an action within a class of movements, information pertaining to the end-point of the action can be sufficient to guide reproduction.

To be able to generalize from this study (Hodges *et al.*, 2005), several possible limitations need to be addressed. The task itself primarily required lower-body coordination emphasizing within-limb rather than between-limb coordination. A full-body group was not included in the experimental design and reproduction accuracy was only examined over a limited number of trials, rather than across multiple practice trials and into retention, as is typical in observational learning research. Consequently, in a number of follow-up studies we manipulated access to relative motion information during observational learning of a crown-green bowling action and a cricket bowling action; these tasks involve varying degrees of complexity in the coordination within and between limbs.

In one study, both relative motion information and the task constraints were manipulated in a between-participants design requiring a whole-body, crown-green bowling action (Hayes, Hodges, Huys, & Williams, in press). Participants either copied the action or copied while additionally bowling a ball. In addition to determining any benefits in highlighting end-point features of a movement (in this case the motions of the wrist and toes), a retention test was included. We were interested in determining long-term learning effects and whether an impoverished, yet potentially informative display helps to decrease reliance on a demonstration when the action is assessed under no-model conditions. To further determine whether participants are able to use relative motion information to improve coordination and performance, a re-acquisition period was introduced during which all participants watched a full-body demonstration. Newell (1985) and Scully and Newell (1985) have argued that demonstrations are most useful early in practice to help constrain and acquire the desired pattern of coordination. According to these researchers, even if relative motion information is presented later in the learning process, participants in the end-point groups will be at a disadvantage relative to the early presentation full-body groups.

In terms of shoulder–elbow coordination (as quantified through NoRMS-D analysis; see Horn *et al.*, 2005), a full-body demonstration group did not show better approximation of upper-body coordination (either in acquisition or retention) than an end-point model group. These data are illustrated in Figure 3. There was a trend for participants in the end-point groups to show closer proximity to the model in terms of intra-limb coordination than the full-body groups. These results were observed irrespective of whether participants were asked to additionally bowl a ball. No further improvements in coordination were observed when the end-point groups saw a full-body model in the reacquisition period, as illustrated on the right side of Figure 3. Although the groups generally did not differ in terms of lower-body coordination (i.e. hip–knee), an interaction indicated that the full-body group approximated this aspect of coordination more closely than the end-point groups early in practice. In retention, the requirement to bowl a ball facilitated retention of the desired lower-body movement pattern. No further benefits in lower-limb coordination were observed following observation of a full-body model in the reacquisition period for the end-point groups.

In terms of outcome attainment, both the end-point and the full-body group performed to a similar level of outcome accuracy and consistency across the acquisition period. In retention, when the model was no longer available, the end-point group was more consistent than the full-body group. Moreover, after viewing an end-point model in the first acquistion phase, seeing a full-body model in reacquisition resulted in improved outcome accuracy compared

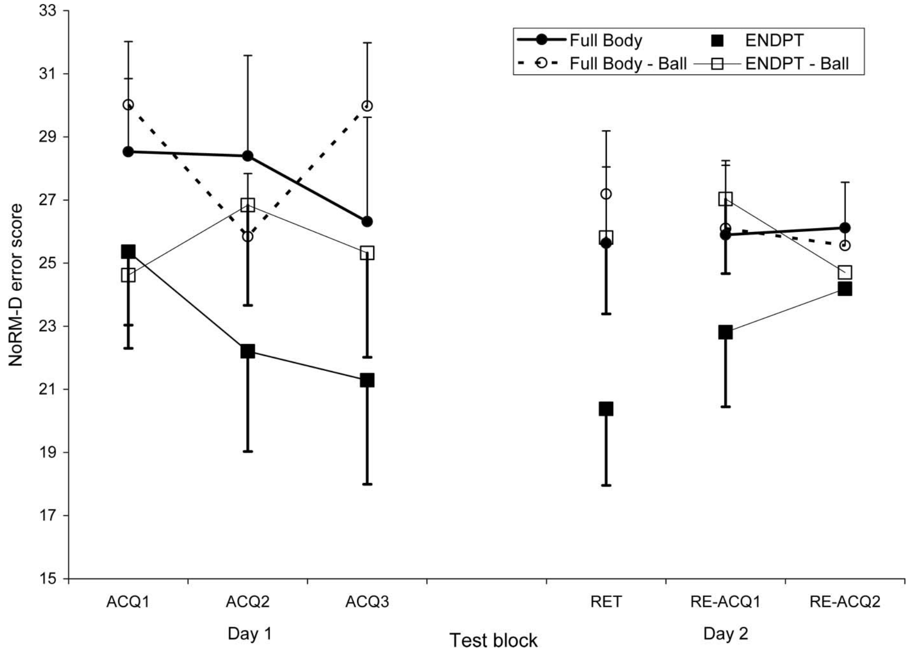


Figure 3. Mean shoulder–elbow NoRM-D error scores for participants in the four practice groups who either saw a full-body or end-point (END-PT) model during acquisition (ACQ) blocks 1–3. Two groups also bowled a ball (BALL) throughout testing. Performance was also assessed in retention (RET) tests on day 2 and in two blocks of re-acquisition trials (RE-ACQ) when all groups viewed the full-body model.

with the full-body group who observed the full-body model in both phases. It appears that encouragement to attend to end-point features of a movement (through removal of other information) is beneficial for outcome accuracy and consistency on goal-directed tasks. These findings are consistent with other motor learning experiments where reducing the amount of augmented information in practice encourages the learner to engage in key learning operations (cognitive processes) that facilitate the recall of movement information in a no-augmented information retention phase (e.g. Badets and Blandin, 2004, 2005; Hodges, Hayes, Eaves, Horn, & Williams, 2006; Salmoni, Schmidt, & Walter, 1984).

The results partially support those observed in our previous experiment (i.e. Hodges *et al.*, 2005) in that the full-body groups did not perform any better than the end-point groups, particularly with respect to upper-limb coordination. The additional constraint of bowling a ball did not adversely (cf. Horn *et al.*, 2002) affect the pattern of coordination in terms of similarity to the model. In line with findings of Hodges *et al.* (2005), there were some benefits of these additional task constraints (i.e. bowling) in terms of approximating and retaining the desired coordination pattern, especially for lower-body coordination.

Based on these two experiments, where relative motion was removed and only end-point models were provided, we hypothesized that individuals adopt a "local" processing strategy (see Mather *et al.*, 1992), focusing on the motions of distal features of the end effector. However, this ability to replicate actions based only on the end-point of the primary effector (i.e. the bowling arm in the present experiment and the foot in the kicking action study) could be somewhat task or skill specific. It might be the case that as the complexity and novelty of the movement increases, a more sophisticated processing system operates that perhaps is more reliant on intra-limb and inter-limb relative motion information as suggested by Pinto and Shiffrar (1999). In subsequent experiments, these manipulations were repeated and design parameters extended to allow further evaluation of the type of information used during observational learning. The acquisition of coordination in a whole-body cricket bowling action was examined. A cricket bowling action is a relatively novel and complex movement requiring an almost windmill-like pattern of between-arm coordination as well as a relatively difficult intra-limb coordination pattern between the elbow and wrist of the bowling arm.

In the first cricket bowling experiment, the removal of relative motion information through a point-light demonstration of the action of the model's wrist had a negative effect on skill acquisition (both the rate of acquisition and retention; see Breslin, Hodges, Williams, Kremer, & Curran, 2005). This was determined through comparisons with full-body, video, and point-light display demonstration groups who showed a pattern of intra-limb coordination (i.e. elbow and wrist) more like the model than the end-point, wrist group. The demonstration groups did not differ however in terms of movement times compared with a no-demonstration control group that was slower than the model, and there were no group differences in outcome attainment or in the accuracy of replication of the non-bowling arm. The poorer performance of the no-relative motion, end-point group in this experiment is of course in contrast to our findings from the lower-limb kicking and underarm bowling actions (cf. Hayes *et al.*, submitted; Hodges *et al.*, 2005). It appears that for a more complex, whole-body movement skill, intra-limb relative motion information is needed and used to constrain action. The findings from the kicking and bowling actions could be reconciled if we considered the hypothesis that it is end-effector information that is prioritized during observation for later reproduction, particularly for goal-directed actions. According to this hypothesis, the motion of the whole arm, rather than just the end-point (in this case the wrist), is the information that is extracted from a display to facilitate the acquisition of coordination (see also Pinto & Shiffrar, 1999).

In a follow-up experiment (Breslin, Hodges, Williams, Kremer, & Curran, 2006), two further groups were examined, referred to as an intra-limb group, who viewed the motions of the whole bowling arm, and an inter-limb group, who observed only the motions of the left and right wrists. These groups were compared with no-relative motion (i.e. wrist only) and full-body point-light display groups from the first experiment. As expected, there was no difference between the intra-limb group and the full-body group in their accuracy of replication of either intra- or inter-limb coordination, suggesting that inter-limb coordination is not being picked up and/or used to facilitate skill acquisition.

Surprisingly, however, the inter-limb group was not significantly different to these groups in terms of both their within- and between-limb coordination. Since the inter-limb group outperformed the wrist-only group, it was speculated that the additional constraints on action (i.e. more information conveyed by the two opposing wrists) helped to bring about the desired intra-limb coordination pattern. However, in a third experiment using the same bowling action (Breslin, Hodges, Williams, Curran, & Kremer, submitted), no positive effects in terms of replication of movement form were observed in an inter-limb coordination group, in comparison with full-body and intra-limb groups. This inconsistency across experiments may be explained by differences in the amount of practice, in that in the latter experiment only half the amount of practice was provided before assessment.

Measurement of visual search and manipulations to the timing of relative motion presentation

In an effort to increase the saliency of between-limb coordination, Breslin *et al.* (submitted) manipulated the time when particular information sources were provided during the acquisition of a cricket bowling action. Participants either received a full-body demonstration across two days of practice or only on the second day. On the first day, the groups and conditions replicated Breslin *et al.* (in press), where as detailed above two partial information groups (intra- and inter-limb groups) were compared with a no-demonstration control group and a full-body point-light display group.

It was reasoned that the gradual introduction of information during the learning process would help make salient sources of information other than the main effector (i.e. inter-limb coordination). It was also predicted that later in practice the learners would be better able to use information in the display to help constrain their action. This hypothesis was based on the theory that early in learning observers use a local and specific search strategy (i.e. what is referred to as a "freezing" of perceptual degrees of freedom) that with practice becomes "released", such that more information is attended (see Savelsbergh & van der Kamp, 2000; Savelsbergh, van der Kamp, Oudejans, & Scott, 2004). A limitation to previous research is that perception has been inferred based on action. So far, no attempt has been made to examine where participants look and what they remember independent of their ability to reproduce an action. Therefore, in this experiment, the visual search behaviours of participants were recorded during the observation phases. Horn *et al.* (2002) adopted this method to help in delineating differences between observation of point-light displays and video images. Participants who viewed point-light displays showed what might be classed as a more selective visual search, involving less fixations of longer duration than participants who viewed film displays. Point light displays encourage a more focused and selective search, perhaps lending support to the idea that the early removal followed by gradual reintroduction of information would aid in the observational learning process.

A second reason for manipulating the timing of information presentation was to examine Newell's (1985) proposal that relative motion information and demonstrations are of most value early in skill acquisition to constrain coordination. It has been argued that later in practice demonstrations do not play a useful role in facilitating skill acquisition, as the learner can only learn to effectively scale the approximate pattern of coordination through practice (see also Scully & Newell, 1985; yet see Hayes *et al.*, 2006). According to this reasoning, no-demonstration and partial information groups will be disadvantaged by having relative motion information withheld early in practice.

The full-body and intra-limb groups (i.e. bowling arm only) showed a pattern of intra-limb coordination in the bowling arm that most closely approximated the model across the two days of practice. Although all groups viewed the full-body model on the second day, the full-body and intra-limb groups maintained their superiority in replication and there was no Group × Day interaction. All groups improved their bowling accuracy and inter-limb coordination to become more like the model across practice days, but there were no group differences.

During the second observation session, when all participants watched the full-body display, there were differences in visual search behaviour across the four groups (as indicated by Group × Day interactions). The intra-limb group fixated less on the bowling arm on the second day ($\sim$40% of the time) and also in comparison with the full-body throughout group ($\sim$60%; see Figure 4). This finding was primarily a result of increased fixations on the legs and on the non-bowling arm for the intra-limb group. There was also a general reduction in the length of fixations as a function of practice days for the two partial information groups, probably allowing for additional search of the display (and the model). On the second day, the no-demonstration group who had not seen a demonstration before showed a similar pattern of fixations as the full-body group on day 1, despite the additional day of practice for the former group. The data from this experiment lends support to Savelsbergh's view that after learners receive visual information, with practice their visual point of gaze becomes wider (a characteristic of releasing perceptual degrees of freedom). In the study of Breslin *et al.* (submitted), the visual gaze of participants took into view other information than just the end effector (i.e. bowling arm). Regardless, no support was available to link the visual gaze data and patterns of coordination performed by the same participants.

As a result of the lack of improvement in intra-limb coordination of the non-bowling arm and the lack of group differences in between-limb coordination, we hypothesized that physical practice and task constraints were likely to be the most important factors in bringing about this aspect of coordination rather than mere observation. There is substantial evidence to show that this aspect of coordination cannot be easily taught through observation unless the motions of the two limbs are displayed in a simplified manner such as a Lissajous figure, where the motions of the two limbs are graphically displayed as a single pattern (e.g. Hodges & Franks, 2000, 2001, 2002).

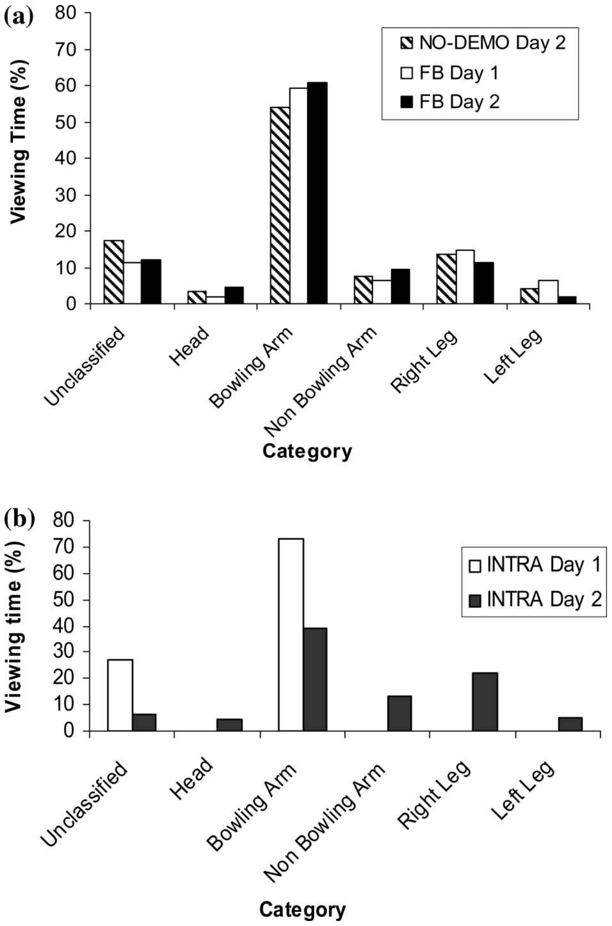
Discussion and conclusions

At least three general findings emerge from this body of work. First, when an observer executes a relative motion profile that is similar to a criterion model's movement pattern, this movement is not by default a result of accurately imitating the model's movement. For example, when the model's relative motion information is manipulated such that participants are only able to view the movement end-point (at least in the case of single-limb actions), or there are sufficient task constraints (such as the requirement to kick a ball over a target barrier), participants employ relative motion patterns that closely match that of the model. Therefore, the information used by learners acquiring complex action patterns seems to be underpinned by the nature of the task (single or multi-limb actions) and its surrounding constraints (i.e. goal-directed). Second, there are specific features of a model, in particular relative motion features, which are difficult to imitate from observation alone. The replication of between-limb coordination, at least for unusual actions, has not been accurate and only marginal improvements have been observed across practice. This is despite evidence that constraints on inter-limb coordination dominate the quality of intra-limb coordination (see Li, Levin, Forner-Cordero, & Swinnen, 2005). Moreover, these marginal improvements have occurred irrespective of the type and timing of relative motion information in the display. Third, observers appear to minimize their visual search and prioritize the replication of the primary distal effector, presumably because it is this point or limb that provides the most accurate information relating to goal attainment. As suggested by Mather *et al.* (1992), the distal effector or action end-point typically reflects the most complex trajectory during an action.

Practitioners are obviously interested in knowing what information should be provided or highlighted during observational learning in order to facilitate this process both in terms of efficiency (i.e. the rate of skill acquisition) and proficiency (i.e. the quality of the movement and outcome attainment in retention). Although we did not find benefits in movement behaviour (i.e. the quality of coordination) when visual information was gradually introduced into the learning process, we did see changes in visual search and outcome performance. In terms of goal attainment, outcome performance appears to be facilitated when learners are provided with end-point information early in practice (i.e. relative motion was removed) followed by full-body relative motion information later in practice. Therefore, the timing of relative motion provision seems to have benefits in skill acquistion and perhaps is a variable that could be manipulated by skill acquistion practitioners. Similarly, visual search behaviour also differed as a function of relative motion presentation. Although these changes in eye movements did not result in beneficial effects in outcome performance or co-ordination changes, it is likely that additional practice is required to impact upon performance.

Since there are some beneficial effects associated with end-point models compared with full-body models (at least for the single-limb actions), additional research is required to identify what is the end-point of an action and how this information acts to constrain action. Latash and Turvey (1996) suggested that during movement execution of everyday tasks, individuals attempt to control the movement end-point and it is the point about which they are most concerned (see also Hodges & Franks, 2002). However, it has been suggested that this point does not even need to be in direct contact with the body (such as the trajectory of the ball in throwing or kicking). This is a question that we are currently exploring, through comparisons of ball trajectory, end-effector, and full-body templates (e.g. Hodges *et al.*, in press). Moreover, it is worth noting that the development of digital, video-based editing and analysis systems (e.g. www.quintic.com; www.dartfish.com) provides practitioners with a viable method to manipulate access to relevant (perhaps end-point or ball trajectory) information in the field setting.

In the initial sections of this article, we reviewed imitation from developmental psychology and neuroscience to shed light on the brain processes involved in action-observation. There are possible avenues for future research in the field of observational learning where these techniques might be useful in helping us to understand how people learn novel and complex motor skills. For example, one of the questions of interest is how observation and what we might refer to as "understanding" change as a function of action-ability. While we may be able to perceive and discriminate actions at a relatively tertiary level before the action can be produced, it is likely that the processes involved in this observation, and hence its perception, changes as a function of practice. Accordingly, our ability to detect subtleties (or higher-level, organizational features) of movement to perhaps enhance performance, such as the pattern of between-limb coordination, might develop as a consequence of these action abilities. There is some evidence that action-observation and discrimination improve following practice (e.g. Hecht, Vogt, & Prinz, 2001; Hodges, Chua, & Franks, 2003), and perhaps more interestingly changes in the brain associated with action capabilities have recently been demonstrated by Calvo-Merino *et al.* (2005). These authors showed that perception of domain-specific dance moves activated areas of the brain associated with movement (i.e. motor areas) only in people specialized in that specific skill and domain.



Figures 4. Mean percentage of visual fixations on regions of the model's body as a function of practice day for the full-body (FB) and no-demonstration (NO-DEMO) groups (a) and the intra-limb (INTRA) relative motion group (b).

We have also shown that observational learning is dependent on the learner's goals and whether action-reproduction as well as outcome attainment is emphasized. Through systematic manipulations to various task constraints, such as the requirement to attain a target goal or kick or bowl a ball, the movement reproduction process is altered to either more favourably match the desired movement (e.g. Hodges *et al.*, 2005; see also Hayes *et al.*, this issue) or to deviate further from the model (e.g. Horn *et al.*, 2005). The latter case seems more likely when task attainment can be achieved in numerous ways and it is not readily apparent that one method or technique is better than another. Therefore, like Bekkering and colleagues (2000), we argue that the question of what information is used to facilitate observational learning needs to be considered in the context of the task or skill and the learner's intentions. Even when instructions emphasize achievement of movement form, this does not necessitate that action-related information from the model will be prioritized. Removal of additional task goals and feedback is perhaps an effective method for encouraging increased attention to the means of the action.

In view of the fact that so much of motor learning is directed through observation, especially during the acquisition of ontogenetic skills that characterize much of youth and adult learning in sports, it is surprising that we know so little about what information guides this process. It is hoped that a better understanding of this question will aid attempts at facilitating the learning process such that information can be beneficially structured to the task, the individual, and their stage of learning.

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