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Beyond the playing field: sport psychology meets embodied cognition

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In contrast to traditional views of the mind as an abstract information processor, recent theories of embodied cognition suggest that our representations of objects and events are grounded in action. In this review, I document recent behavioral and neuropsychological evidence in support of an embodied viewpoint, and I argue that sensorimotor experience plays a pivotal role in the embodied cognition framework. As such, not only can cognitive science and cognitive neuroscience inform sport psychology theory and research, but sport psychology (and motor skill expertise research in particular) is imperative for advancing theories of embodied cognition.

Keywords: embodied cognition; expertise; cognitive science

In recent years, cognitive scientists' conceptualization of the mind as an abstract information processor has been reworked to include connections to the body. Theories of *embodied cognition* suggest that our internal representations of objects and events are not solely grounded in amodal propositional code, but rather subserved by the sensorimotor systems that govern acting on these objects and in the events in question (Glenberg, 1997; Barsalou, 1999; Zwaan, 1999; Wilson, 2002; Garbarini & Adenzato, 2004). This embodied viewpoint has roots in ecological psychology's refutation of a distinction between perception and action (Gibson, 1979) and finds support across multiple levels of psychological inquiry.

In this article, I provide a brief review of recent cognitive science and neuroscience research that supports the embodied cognition viewpoint. I then ask how motor skill experience on the playing field or ice rink might impact our perception, understanding, and representation of action – even when there is no intention to act. In this way, I hope to illustrate how the science of sport (and particularly work on sport expertise and motor skill acquisition – e.g., see Beilock & Carr, 2001; Beilock *et al*., 2002; Beilock *et al*., 2004) can further our understanding of cognitive operations that, at first glance, appear to be unrelated to the motor skill domain. As research on sport expertise is highly relevant to the emergent cognitive science viewpoint of embodied cognition, I hope to make the case that not only should sport psychology look to cognitive and neuroscience disciplines to inform theory and research, but vice versa.

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The embodied viewpoint

Traditional views of cognition suggest that conscious experience gives rise to abstract codes that are arbitrarily related to the objects or concepts they represent (Kintsch, 1988; Pylyshyn, 1986; Newell & Simon, 1972). Broadly speaking, an individual's knowledge is conceptualized as a network of connected nodes or concepts in the form of amodal propositions (Collins & Quillian, 1969). However, recent embodied approaches propose that amodal propositions are not the only manner in which knowledge is represented. Theories of embodied cognition, such as *perceptual symbols systems* (PSS; Barsalou, 1999), suggest that our representations of objects and events are built on a system of activations much like amodal views of cognition. However, in contrast to amodal views, PSS purports that such activations are based on the brain states that were active during the actual perception and interaction with the objects and events one encounters. That is, our cognitive representations of a particular action, item, or event are subserved by perceptual symbols that are analogically related to the states that produced these experiences. Perceptual symbols are believed to be multimodal traces of neural activity that contain at least some of the affordances and motor information present during actual sensorimotor experience (Barsalou, 1999; for embodied cognition reviews, see Glenberg, 1997; Zwaan, 1999; Wilson, 2002; Garbarini & Adenzato, 2004; Niedenthal *et al*., 2005).

In attempt to capture how individuals understand and process information they encounter, PSS, and the embodied viewpoint more generally, has been used to predict behavior across a number of diverse domains ranging from language comprehension (Stanfield *et al*., 2001; Zwaan *et al*., 2002) to social interactions (for a review, see Niedenthal *et al*., 2005). For example, with respect to language comprehension, Zwaan and Taylor (2006) hypothesized that if reading about an action recruits the sensorimotor operations governing actual action production, then comprehending a motion-directed act one reads about (e.g. 'Eric turned down the volume') should be facilitated when individuals produce a congruent action (a counter-clockwise hand movement) in comparison to an incongruent one (a clockwise hand movement). This is exactly what was found. Despite research supporting the notion of cognition grounded in action however, there is little work examining how it arises. That is, what is necessary to form such representations? To the extent that our knowledge is underlain by neural operations that embody previous actions and experiences, then those with extensive motor skill experience in a particular domain should represent information in that domain quite differently than those without such experiences – even when there is no intention to act.

In this article, I review work demonstrating that variations in individuals' motor skill repertoires carry implications for (a) the ability to perceive and predict the actions of others; (b) the ability to comprehend action-related language; and (c) the judgments individuals make about objects and events in their environment. On the surface, cognitive operations ranging from language comprehension to making preference judgments about the objects one encounters may appear unrelated to the body and previous motor skill experience. Here, I present research demonstrating that this is not the case. As such, only by taking into account one's previous action experiences can we gain a full understanding of how individuals represent and comprehend information in their environment – whether they are on the playing field attempting to anticipate an opponent's move or in a classroom setting attempting to comprehend action-related language.

Motor skill expertise beyond the playing field

Action perception, understanding, and prediction

When we observe others performing actions, how do we come to form an understanding of their movements and their intended outcomes? This question is of obvious interest to the field of sport psychology – not only with respect to understanding how observing others impacts learning (for a review, see Vogt & Thomaschke, 2007), but also in terms of maximizing individuals' ability to predict the action outcomes of others so as they know how to act themselves. Recent work demonstrates that one means by which we understand the actions we encounter is by calling upon some of the same cognitive and neural operations that drive our own overt skill execution. However, such recruitment is largely dependent on one's experience performing the actions in question. Calvo-Merino *et al.* (2005) used functional magnetic resonance imaging (fMRI) to study brain activity patterns when individuals watched an action they were skilled in performing versus one they were not skilled in. Experts in classical ballet and Capoeira watched videos of ballet or Capoeira actions while their brains were being scanned. When the brain activity of individuals who were watching their own dance style was compared to activity when individuals were watching the other dance style (e.g. ballet dancers watching ballet versus ballet dancers watching Capoeira), greater activation was seen in a network of brain regions (e.g. bilateral activation in premotor cortex and intraparietal sulcus, right superior parietal lobe, and left posterior superior temporal sulcus) thought to support both the observation and production of action (Rizzolatti *et al.*, 2001).

A follow-up study suggests that it is the influence of motor experience on action observation, beyond visual experience, that drives such effects. Calvo-Merino *et al.* (2006) examined brain activation while male and female ballet dancers observed dancers performing moves specific to the observer's gender and moves specific to the opposite gender. Male and female ballet dancers train together and thus spend a significant amount of time watching each other's moves. Nonetheless, these dancers also perform several moves that are limited to their own gender. Calvo-Merino *et al.* found greater premotor, parietal, and cerebellar activity when dancers viewed moves from their own motor skill repertoire compared to moves performed by the opposite gender. These results suggest that action perception is subserved by the systems involved in action production and the more experience one has performing the actions they observe, the more so this holds.

Moreover, such motor experience-driven effects go beyond the mere observation of action (for a review, see Wilson & Knoblich, 2004). Recent work by Calise and Giese (2006) demonstrates that motor experience can actually have an impact on individuals' ability to make perceptual discriminations among different actions they observe. In their study, Calise and Giese trained individuals to perform an unusual gait pattern. Typical human gait patterns are characterized by a phase difference of approximately 180° between the two opposite arms and the two opposite legs. Calise and Giese trained participants to produce arm movements that matched a phase difference of 270° (rather than the typical 180°). Participants were trained blindfolded with only minimal verbal and haptic feedback from the experimenter. Both prior to and following training, participants performed a visual discrimination task in which they were presented with two point-light walkers. Participants had to determine whether the gait patterns of the point-light walkers were the same or different. In the display, one of the walkers' gait pattern always corresponded to phase differences of 180°, 225° or 270° (the phase difference participants were trained to perform). The other point-light walker was manipulated to have a phase difference either slightly lower or higher than one of these three prototypes.

Overall, individuals improved in their perceptual description performance as a function of non-visual motor training. However, such improvement was limited to the discrimination of point-light walkers from the 270° prototype participants had learned to perform. This result suggests a direct influence of learning motor sequences on visual recognition of such sequences – an influence that is independent of visual learning as individuals were blindfolded during motor skill acquisition. Further support for this conclusion comes from the fact that individual differences in the learning of the 270° phase pattern predicted visual discrimination performance after training. That is, the better participants learned to perform the 270° gait pattern, the better their perceptual discrimination performance after learning (but not before). (For confirmatory results, see also Hecht *et al.*, 2001.) Thus, experience performing motor skills not only carries implications for individuals' success in performing such actions, but sensorimotor skill experience affects the cognitive and neural substrates recruited during action observation which, in turn, carries implications for individuals' ability to discriminate between actions they observe.

If similar cognitive and neural operations are involved in the planning, execution, and perception of actions, then it follows that when people view their own actions, the same system that had once planned that action should also be involved in perceiving the action. As a result, predicting the outcomes of actions one has performed in the past should be easier than predicting the actions of another individual. This is because the same cognitive and neural operations are involved in predicting and performing in the former, but not in the latter case. Support for the above hypothesis has been found. Individuals make more accurate predictions about the landing locations of thrown darts when they view videotapes of themselves throwing the darts relative to viewing others throwing darts (Knoblich & Flach, 2001). Individuals can also predict more accurately about their own versus others' handwriting strokes. When asked to determine whether a stroke was produced alone or before another stroke, Knoblich *et al.* (2002) found that individuals' predictions were more accurate for handwriting strokes that they themselves had produced in the past. Similar effects obtain even when action perception is non-visual. Pianists are able to distinguish audiotapes of their own performances from other pianists' performances several months after playing the pieces in question – even when dynamic nuances (e.g. tempo, intensity) have been removed from the music (Repp & Knoblich, 2004). If individuals' sensorimotor systems are most strongly activated when perceiving their own actions in comparison to the actions of others, this is precisely what should occur.

Even in situations in which there is no intention to act, motor experience carries implications for the ability to predict and discriminate between observed actions and their outcomes. Thus, in order to develop an embodied account of how individuals understand and represent information they encounter, it is important to take into account the motor experiences of the perceivers themselves. Moreover, such expertise effects go beyond the perception and observation of movement – having an impact on the understanding of action-related language as well.

Language comprehension

Although traditional views of language comprehension suggest that our representations of objects and events we read about are limited to amodal or propositional code that is arbitrarily related to the concepts it represents (Pylyshyn, 1986), recent work suggests that language comprehension is interconnected with the sensorimotor experiences implied by the text one reads or the words one hears spoken. Support for this assertion comes from a number of different findings. For example, when individuals make sensibility judgments about sentences by pushing a button that is either close to or away from their bodies, the sentence's implied action direction interacts with the direction of the response (Glenberg & Kaschak, 2002). Reading the sentence 'Close the drawer' increases the time needed to respond with a movement directed toward the body (the opposite direction of the implied action) relative to a response involving movement directed away from the body (the same direction as the implied action). Similarly, sensibility judgments of sentences such as 'Can you squeeze a tomato?' are facilitated when participants are primed with an associated hand shape (a clenched hand) relative to an inconsistent hand shape (a pointed finger; Klatzky *et al.*, 1989). This interaction between the actions implied by language and motor behavior performed concurrently with comprehension has been taken to suggest that language comprehension is interconnected with the systems involved in the understanding and planning of actions (Barsalou, 1999; Glenberg & Kaschak, 2003).

Converging evidence from cognitive neuroscience supports this idea. For example, reading action words associated with the leg and arm (e.g. 'kick', 'pick') activates brain areas implicated in the movements of these body parts (Hauk *et al.*, 2004), and reading action-related sentences, such as 'I bit the apple' or 'I kick the ball' activates the same areas of premotor cortex as those activated during the actual movement of mouth and leg effectors, respectively (Tettamanti *et al.*, 2005). A recent study using transcranial magnetic stimulation (TMS) suggests that activation of the motor substrates governing the actions one reads about is actually an important component of comprehension, rather than a superficial by-product. Pulvermuller *et al.* (2005) found that when stimulation was applied to arm or leg cortical areas in the left hemisphere, lexical decisions to words denoting arm or leg actions were, respectively, facilitated. This finding suggests that these motor-related cortical areas play an important role in understanding linguistic descriptions of body-relevant actions.

To the extent that our comprehension of action-related language is grounded in sensorimotor systems, then those who have experience interacting with the objects and performing the actions they read about should represent linguistic information very differently than those who do not have such experiences. We have been exploring this issue by examining differences in how novice and expert athletes represent both everyday and sport-specific objects and actions they read about.

In a first experiment, Holt and Beilock (2006) requested ice-hockey experts and novices read sentences describing hockey and non-hockey situations. The non-hockey situations depicted everyday objects and individuals (e.g. 'The child saw the balloon in the air'). The hockey situations were hockey specific (e.g. 'The referee saw the hockey helmet on the bench'). A picture of a target object was presented after each sentence. Participants judged whether the target was mentioned in the preceding sentence as quickly as possible. The target either matched the action implied in the sentence (match) or did not (mismatch) (Figure 1). The correct response to all target items, whether matches or mismatches, was always 'yes'. Filler items that were not mentioned in the preceding sentence required a 'no' response and were used to equate the number of 'yes' and 'no' responses across the experiment. Although the

Non-hockey sentence — Picture

Scenario 1:

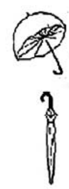
(A) The child saw the balloon in the air. (A)

(B) The child saw the balloon in the bag. (B)

Scenario 2:

(A) The woman put the umbrella in the air. (A)

(B) The woman put the umbrella in the closet. (B)



Hockey sentence — Picture

**Scenario 1:*

(A) The referee saw the hockey helmet on the player. (A)

(B) The referee saw the hockey helmet on the bench. (B)

***Scenario 2:*

(A) The fan saw the hockey net after the player slid into it. (A)

(B) The fan saw the hockey net after the puck slid into it. (B)

* Helmet has different configuration depending on whether or not it is on a player.

**Net is either knocked over or upright depending on who or what collides with it.

Figure 1. Examples of experimental stimuli. Picture A serves as a 'match' for Sentence A and a 'mismatch' for Sentence B. Picture B serves as a 'match' for Sentence B and a 'mismatch' for Sentence A. Reprinted from Holt and Beilock (2006).

correct response to all target items was always 'yes', the action orientation of some items (i.e. matches) corresponded more closely to the action implied in the sentence that preceded these items than the action orientation of other items (i.e. mismatches). Building on the initial logic and work of Zwaan *et al.* (see Stanfield & Zwaan, 2001; Zwaan *et al.*, 2002), we hypothesized that if individuals represent perceptual qualities and action possibilities of the information they comprehend linguistically, then responses should be facilitated for matches relative to mismatches.

We predicted that both novice and expert hockey players would show the match-mismatch effect (i.e. responding faster to items that matched the action implied in the preceding sentence versus items that did not) for *non-hockey* objects and individuals because both novices and experts presumably have the same amount of knowledge and experience interacting with such everyday items. However, if experience affects the ties language has to sensorimotor processes, then individuals with hockey experience should show the match-mismatch effect for the hockey-specific items, while hockey novices should not show such an effect.

Both novice and expert hockey players were able to understand the sentences they read (as indicated by high accuracy levels in response to whether the presented items were mentioned in the preceding sentence). Additionally, everyone responded faster to everyday items that matched the action implied in the preceding sentence versus those who did not – suggesting that participants' representations contained information about the sensorimotor qualities of the objects and individuals they read about. However, only those with hockey knowledge and experience showed this effect for the hockey scenarios.

In a second experiment, Holt and Beilock (2006) presented novice and expert American football players with pictures of football players performing actions that either matched or did not match actions implied in preceding sentences. Critically, we manipulated the extent to which the action implied in the sentence was football-specific (an action one would only perform were one a football player – e.g. a quarterback handing off to a receiver) versus non-football-specific (an action performed by a football player, but that everyone should have performed in the past – e.g. a football player sitting down on a bench). Embedding both football-specific actions and non-football-specific (everyday) actions within the domain of football provides a stronger test of the prediction that knowledge and experience performing an action leads one to call upon sensorimotor information when reading about that action. This is because even novices in a given domain should show evidence of this language-sensorimotor link, provided they have experience performing the action in question. Under this view, both novices and experts should respond faster to a picture of a football player performing an everyday action that matches the action implied in a preceding sentence relative to a picture of an action that does not match. In contrast, for football-specific actions, only those who have knowledge and experience performing the action should show the effect. This is exactly what was found. Thus, the ability to differentiate action orientations (suggesting one is representing sensorimotor information associated with the objects and individuals they are reading about) is not just a function of general domain knowledge, but is dependent on the specific experience one has performing the actions and interacting with the objects in question.

The above findings are consistent with the idea that action possibilities are activated when individuals perceive specific objects or events, with this link dependent on the extent to which one has experience with the actions in question. However, it should be noted that these results could be explained by a purely perceptual representation of the sentences that involves no contribution from the motor system at all. Converging methodologies, such as fMRI, are needed to determine precisely which components of the motor system underlie the impact of motor expertise on language comprehension (or if the motor system is involved at all).

Although not related to language comprehension per se, work has been carried out demonstrating expertise differences in brain activation patterns when experts and novices mentally simulate performing an action. Such work may lend insight into how motor experience on the playing field (or ice-rink) impacts the comprehension of action-related text. Milton *et al.* (2007) examined neural activity using fMRI while six professional golfers and seven novice golfers (who had less than two years of golfing experience) mentally simulated their pre-shot routines. Experts showed greater activity than novices in regions closely related to precise visuomotor simulation, namely in the superior parietal lobe (SPL), left dorsal premotor (left PMd) and occipital (OCC) cortices. These regions are part of a broader action-simulation network involved in the perception, representation, and production of action, and their greater recruitment during experts' pre-shot routines suggests that part of what experts may do in shot preparation is to mentally simulate the specific motor sequence about to be performed. Novices, on the other hand, primarily activated posterior limbic and basal ganglion (BG) regions of the brain when mentally simulating their pre-shot routine. BG activation is thought to be indicative of the effortful simulation of shot-related processes and procedures that are not yet fully automatized (see Packard & Knowlton, 2002, for a review of the role of the BG in motor learning). Posterior limbic activation in the posterior cingulate (PC) may reflect the filtering out of non-relevant task information (for a review of the role of the PC in sensory monitoring, see Vogt *et al.*, 1992). Greater PC activation for novices relative to experts then appears to indicate that novices' pre-shot simulations fail to successfully block out details less central to the motor-planning components of the action about to be performed (Milton *et al.*, 2007).

Thus, when expert and novice athletes mentally simulate performing skill-relevant actions, they recruit qualitatively different neural networks to achieve this goal. Moreover, the cognitive and neural operations recruited during motor imagery appear to overlap more closely with the sensorimotor processes governing successful execution itself for experts in comparison to novices. If expertise effects in language comprehension are the result of experience-dependent activation of the neural operations used during actual motor performance, then expertise differences in brain activity during language comprehension should be able to account for the impact of hockey and football skill level on sentence understanding reported above. We are currently exploring this hypothesis in our laboratory.

Preference judgments

Although the idea that we call upon the same sensorimotor operations when we perceive and read about action as when we actually perform a skill is intriguing, at this point one might wonder if the relation between cognition and action is more epiphenomenal than anything else. That is, does motor system activation coinciding with the perception of information in one's environment really have an impact on comprehension and understanding of the stimuli individuals encounter or is it a mere byproduct of such processes?

Recent work demonstrating that our explicit preferences for objects and events are grounded in previous sensorimotor experience supports the former contention. In a clever study, Van den Bergh *et al*. (1990) had skilled and novice typists study pairs of letter strings and indicate which pair they liked better. Unknown to the participants, one letter string in each pair consisted of letters that could be typed with the same finger on a keyboard using standard typing methods, while the other letter string consisted of letters typed with different fingers (e.g. 'GBT' versus 'RCL'). Results showed that expert typists preferred the different-finger letter strings over the same-finger letter strings, whereas novice typists did not show a preference. Furthermore, the typists made this discrimination without conscious awareness that the strings were systematically different.

How can this be explained? From an embodied cognition standpoint, presenting the letter strings may have activated the neural operations involved in actually typing these letters in skilled typists (i.e. perception implicates action, see Prinz, 1997; Rieger, 2004). As typing is thought to involve the overlap of successive key strokes (Rumelhart & Norman, 1982), typing letters with the same finger should result in more motor interference than typing letters with different fingers, as the former case requires that the same digit essentially be in two places at once (or in very close succession). If people prefer to act in ways that reduce motor interference, those who automatically call up motor information about typing the letter strings (i.e. skilled typists) should prefer letters typed with different fingers more so than same fingers.

In an attempt to explicitly test these claims, Beilock and Holt, (2007) presented skilled and novice typists with two separate letter dyads on a screen and asked participants to indicate the dyad they preferred (Beilock & Holt, 2007). Similar to van den Bergh *et al*. (1990), the dyads in each pair fell into one of two categories: Dyads that would be typed with the same finger using standard typing methods (e.g. FV) or dyads that would be typed with different fingers (e.g. FJ). Skilled typists preferred dyads typed with different fingers (i.e. dyads *not* functionally incompatible) significantly more than chance. Novices did not show this preference. Again, participants were unaware of the link between our study and typing, and when asked, could not explicate how the letter dyads typed with the same versus different fingers differed.

Importantly, while making their preference judgments on some trials in a first experiment, participants held a typing pattern in memory that involved the same fingers that would be used to type the presented dyads. If holding this pattern consumes the motor system in such a way that it can no longer inform typists' preference judgments, such preferences should disappear. This is exactly what was observed. A second experiment showed that this motor interference was specific to the digits actually involved in typing the dyads. When expert typists held a motor pattern in memory involving fingers *not* used to type the dyads, the preference remained. Thus, the sensorimotor qualities of the information one is presented with not only has an impact on preference judgments, but this influence is limited to information motorically resonant with the specific effectors involved in the simulated action.

Overtly behaving in ways consistent with positive and negative affective states (e.g. facilitating or inhibiting the muscles typically associated with smiling without requiring subjects to actually pose in a smiling face) has been shown to have an impact on emotional responses in ways congruent with motor behavior (Strack *et al.*, 1988). Such work suggests a link between motor activity and affect. In the above-mentioned typing experiments, we show that such movements are not necessary to impact affective responses or, in this case, preference judgments. Rather, covert sensorimotor simulation of acting on stimuli can provide likeability information – even with no intention to act. This is true as long as individuals have developed relevant associations between what they perceive and how it can be acted on.

Conclusions

In this review, I have presented cognitive science and neuroscience research that supports the notion of cognitive operations that are grounded in action. This embodied viewpoint finds support across multiple levels of psychological inquiry, from behavioral studies of action observation to neuroimaging studies of language comprehension. Although such work supports the notion that the cognitive and neural systems that subserve action are also engaged during cognitive tasks that, on the surface, involve no intention to action, less attention has been focused on how individuals' motor skill experiences modulate the content of their embodied knowledge representations. By turning to sport science work centering around differences in the cognitive operations supporting expert and novice performers (e.g., Beilock & Carr, 2001; Beilock *et al.*, 2002; Beilock *et al.*, 2004), we are able to address such issues. Specifically, the work outlined in this article demonstrates that one's experience on the playing field, ice rink, or computer keyboard fundamentally changes the extent to which cognition is grounded in action. As such, not only does embodied cognition open a new kind of window into sport psychology by predicting the interaction of the mind, body, and environment in ways that conventional information processing theories do not (Niedenthal *et al.*, 2005), but sport science work is able to give back to the embodied movement by demonstrating what experience on the playing field buys one on the pitch and beyond.

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