ABSTRACT

ON THE EMBODIMENT OF EXPERT KNOWLEDGE: WHAT MAKES AN EXPERT?

by Lauren E. Holt

How do experts' representations of knowledge differ from novices'? Traditional views suggest that knowledge is represented as a series of propositional codes. Experts' extensive knowledge may simply result in more or stronger codes than novices. However, recent theories suggest knowledge is embodied: Understanding the world arises from previous experiences interacting with the world rather than from links in a semantic network. Thus, expertise may lead to fundamentally different representations of domain information, containing different traces of perceptual and motor information. Building on embodied theories, two experiments examined the *type* of knowledge supporting novice and expert performance. Experiment 1 asked whether domain knowledge is needed to form embodied representations in ice hockey. Experiment 2 asked whether active football experience, in addition to domain knowledge, is needed to form embodied representations of football-specific action. Results demonstrate that domain knowledge is required. Moreover, motor experience is necessary in forming embodied representations involving domain-specific actions.

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A major topic of interest in the cognitive psychology literature concerns differences between expert performers and their less skilled counterparts. These differences are not just limited to overt performance outcomes, but also extend to the ways in which experts and novices perceive stimuli within a skill domain. For example, in physics problem solving, experts extract higher-level and functional information from situations whereas novices tend to focus on lower-level surface features. When physics experts and novices are asked to sort cards of physics problems by the similarity of their solution, experts tend to sort the cards based on underlying physics principles, whereas novices tend to sort the cards based on surface features of the problems themselves (e.g., whether the problem mentioned the use of an inclined plane, Chi, Feltovich, & Glaser, 1981). Similarly, in the sensorimotor skill of wall climbing, when expert and novice climbers are asked to study a climbing wall and subsequently reproduce the location of its hand and foot grips, expert climbers attend to functional aspects of the wall. That is, experts reproduce the climbing grips based on perceived climbing paths. Novices, on the other hand, attend to structural features of the wall, such as the shape of certain grips (Boschker, Bakker, & Michaels, 2002).

The above work suggests that experts' perceptions of stimuli within their skill domains differ from novices'. Why might this occur? Researchers who approach skill acquisition from a cognitive perspective believe that experts and novices can not only be differentiated in terms of their actual performance outcomes, but can also be distinguished by the cognitive control structures that support planning and drive execution. Specifically, experience in a given domain is thought to lead to an extensive knowledge base and highly organized memory structures that allow for the efficient encoding and retrieval of domain-specific information (Beilock & Carr, 2001; Ericsson & Charness, 1994; Ericsson & Lehmann, 1996). These memory structures enable experts to perceive meaningful relationships among objects in a manner that novices do not (Adelson, 1984; Chase & Simon, 1973; Shafto & Coley, 2003; Vallacher & Wegner, 1987).

Although work in the expertise literature has documented differences in the manner in which experts and novices perceive information within specific skill domains, more work is needed in order gain a complete understanding of the knowledge representations that drive these differences. What, then, is involved in mental representations of knowledge at different levels of learning?

Cognitive Representations of Knowledge

Traditional views of knowledge representation suggest that conscious experience gives rise to amodal propositions that are thought to be arbitrarily related to the objects or concepts they represent (Kintsch, 1988; Newell & Simon, 1972). Essentially, perceptual input interacts with a perceiver's knowledge base, which is conceptualized as a network of connected nodes or concepts in the form of propositions – a semantic network. As stimuli are perceived, concepts in the knowledge base that correspond to the input (as well as related concepts) are activated and the result of this activation is an integrated propositional representation of what one perceives.

More recently, embodied approaches to knowledge representation, such as perceptual symbols theory (Barsalou, 1999), have suggested that amodal propositions may not be the only manner in which knowledge is represented. Perceptual symbols theory states that not only do cognitive representations of objects and events result in a system of activations, but that these activations are based on the brain states that were active during the actual perception and interaction with the objects. That is, conscious experience is thought to lead to perceptual symbols that are analogically related to the perceptual states that produced them. These symbols are believed to be multimodal traces of neural activity that contain at least some of the affordances and motor information present in actual sensorimotor experience (Barsalou, 1999; Glenberg & Kaschak, 2003).

Recent empirical work supports this embodied viewpoint (for a review see Wilson, 2002). For example, when individuals are asked to decide whether a picture was mentioned in a sentence they just read, individuals show faster response times when the picture's shape and orientation match that implied by the sentence than when they do not. After reading the sentence, "John put the pencil in the cup," which implies a vertical orientation of a pencil, individuals were faster to respond to a picture of a pencil in a vertical orientation than to one in a horizontal orientation (Stanfield & Zwaan, 2001). Additionally, after reading the sentence, "The ranger saw the eagle in the sky," which implies an eagle with its wings outstretched, individuals were faster to respond to a picture of an eagle with its wings outstretched than to a picture of an eagle with its wings down (Zwaan, Stanfield, & Yaxley, 2002). These findings suggest that not only were the concepts of "pencil" and "eagle" activated, but sensory information regarding an eagle's perceptual features (e.g., what it looks like when it is flying) was activated as well.

Note that a strictly amodal viewpoint of knowledge representation would have a hard time accounting for the findings mentioned above. Specifically, reading a sentence such as “The ranger saw the eagle in the sky” should be translated into a proposition of the form [[saw[ranger, eagle]], [in[eagle, sky]] that carries no information about the orientation of the eagle. In contrast, perceptual symbols theory would predict that reading such a sentence activates the sensory information and visual experience of seeing an actual eagle in the sky – experiences that would contain information about what an eagle in the sky might look like.

In addition to evidence suggesting that perceptual information is included in cognitive representations of stimuli, embodied approaches suggest that knowledge representations also contain information about the potential interactions and action opportunities that an object may allow in relation to a specific individual (Glenberg, 1997). In the context of language comprehension, it has been demonstrated that the most accurate representations of text are formed when words are associated not only with the objects they represent, but with the objects’ action possibilities as well. Individuals seem to be quicker at learning instructions when those instructions are associated with an actual physical representation. For example, participants more readily learned how to operate a compass when they watched an actor physically mimic the motions required for its operation in comparison to when they simply read about these actions (Glenberg & Robertson, 1999). This suggests that learning the action possibilities associated with objects facilitates later interactions with those objects.

Additional support for the idea that the cognitive representations of objects and events embodies action information comes from work demonstrating that reading sentences that imply specific actions interferes with responses that are incongruent with those actions. Glenberg and Kaschak (2002) asked participants to make sensibility judgments about sentences they read by pushing a button that was either close to their bodies or away from their bodies. When the sentences’ implied actions were away from their bodies (e.g., in the sentence “Close the drawer”), participants’ responses were inhibited when they had to push the button that was close to their bodies (relative to when they responded by pushing the button further away). That is, the implied direction of the sentences interfered with the actual direction of responses. This finding suggests that some type of action-based system is implicated when individuals read about action-related text (see also Creem & Proffitt, 2001). Along similar lines, sensibility judgments of sentences such as “Can you squeeze a tomato?” are facilitated when participants are primed with the associated hand shape (e.g., a clenched hand) relative to when they are primed with an inconsistent hand shape (e.g., a pointed finger, Klatzky, Pellegrino, McCloskey, & Doherty, 1989). Glenberg and Kaschak (2003) suggest that this facilitation occurs because we have experience interacting with these objects and performing specific actions (e.g., squeezing tomatoes), and that language comprehension is interconnected with the same system that is involved in the understanding and planning of actions. The finding that activating the motor system facilitates congruent perceptual activities (and vice versa) has been demonstrated in many laboratories (Borghi, 2004; Chambers, Tanenhaus, & Magnuson, 2004; Craighero, Fadiga, Umilta, & Rizzolatti, 1996; Tucker & Ellis, 1998, 2004), providing support for theories of embodiment and the necessary perception-action link that these theories imply.

Embodiment and Expertise

Thus, it seems that a strictly amodal viewpoint cannot fully account for the richness of one’s knowledge representations. Rather, our cognitive representations of our environments include information about perceptual structure and motor information for carrying out relevant actions. How is this perceptual and motor information acquired? Zwaan (1999) has suggested that “It may depend on the depth of our background knowledge to what extent our representations are embodied,” (p. 86). That is, knowledge embodiment may be one variable that differentiates novice from expert performers.

Although the above mentioned notion has yet to be extensively tested, there is some support for this idea. In a clever study, Van den Bergh, Vrana, and Eelen (1990) investigated differences in the representations of letter strings in novice and expert typists. Skilled and novice typists studied pairs of letter strings and were asked to indicate which pair they liked better. Unbeknownst to the participants, one letter string in each pair consisted of letters typed with the same finger on a keyboard, while the other letter string consisted of letters typed with different fingers (e.g., “GBT” vs. “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 in any way. The authors hypothesized that for the skilled typists, presenting the letter strings activated the motor representation involved in actually typing these letters. Letter strings in which one finger typed more than one letter and incompatibility existed (movements are incompatible here because the finger must complete the action of typing one letter before it commences the action of typing another) were less preferred than strings in which different fingers typed each letter and no such incompatibility occurred (movements are more compatible in this case because the movements made by the different fingers can overlap in time). These findings suggest that (a) motor programs are activated automatically upon perception of stimuli even without intention for physical action, and (b) experience in a given domain affords a different type of motor representation than is present in unskilled individuals. Because of their sensorimotor typing experiences, skilled typists' preference judgments were presumably influenced by the motor representation associated with the letter strings. The judgments of novices, who did not possess this type of sensorimotor knowledge, were not (Van den Bergh et al., 1990)

The Present Experiments

The above work suggests that individuals with different levels of active experience in a given domain possess different representations of stimuli in that domain and the action opportunities that such stimuli offer. Specifically, experience appears to result in an embodied knowledge representation that contains information about the potential interactions and action opportunities that stimuli may allow in relation to a specific individual. The purpose of the current work is to empirically test this notion. Two experiments investigated the hypothesis that one way in which experts in sensorimotor skill domains differ from their novice counterparts is that experts' knowledge structures not only contain declarative knowledge about stimuli in their area of expertise, but that experts represent the action possibilities of those stimuli as well. This latter type of representation arises from active participation in their domain of expertise.

Experiment 1

According to embodied approaches to cognition, and more specifically, perceptual symbols theory, embodied representations are based on actual sensorimotor experiences (Barsalou, 1999; Glenberg & Robertson, 1999). Representing the action-orientation or perceptual qualities of stimuli then, should be limited to those who have experience within a given domain. Experiment 1 examined this notion using the sensorimotor skill of ice hockey as a test bed.

Ice hockey experts and novices were asked to read hockey and non-hockey sentences. Pictures of objects or individuals were presented after each sentence, and participants' goal was to decide whether the picture was mentioned in the preceding sentence as quickly as possible. The sentences either depicted hockey situations (e.g., "The woman watched the hockey player at the face-off”) or non-hockey, everyday situations (e.g., “The woman put the umbrella in the air”). The target object or person that followed each experimental sentence was always mentioned in the sentence, but its shape either matched the shape implied in the sentence or did not. For example, a picture that matches the orientation of the non-hockey sentence, “The woman put the umbrella in the air” is a picture of an umbrella that is open. In contrast, a picture that does not match the shape implied in the sentence is a picture of an umbrella that is closed (because one would not put a closed umbrella in the air). Both pictures are mentioned in the sentence, so the correct response in either case is “yes,” but only the former picture’s shape matches that implied in the sentence.

Embodied theories of knowledge representation suggest that when reading about or viewing objects, individuals form representations of those objects that include information about their physical characteristics and action possibilities (Barsalou, 1999; Glenberg & Robertson, 1999). Thus, in the paradigm described above, the more closely an objects’ physical characteristics and action possibilities resemble those implied by the preceding sentence (i.e., when the picture is a match), the greater amount of overlap there should be between one’s representation of the object and the actual depiction of that object. The subsequent response to that object, then, should be facilitated relative to when the object’s shape and orientation do not as closely resemble the characteristics implied by the sentence – and thus the characteristics of one’s representation (i.e., when the object is a mismatch).

The extent to which individuals exhibit a match-mismatch effect (i.e., the extent to which they respond faster to matches than to mismatches) can inform us of the level and type of detail that is contained in their knowledge representations. For example, if hockey experts possess knowledge within their domain of expertise that differs from that of their novice counterparts - specifically in terms of the representation of perceptual qualities and action possibilities of objects and individuals – then expert ice hockey players should be faster to respond to ice-hockey related stimuli when the shape of that stimuli matches that implied in the sentence in comparison to when it does not. Experts’ first-hand active experience playing hockey and their extensive knowledge of the game should afford them embodied representations of the sentences that allow them to discriminate between hockey-related objects or people whose shapes and actions match that implied by the sentences and those that do not. Novices, on the other hand, should be no quicker to respond to matches than to mismatches when reading about hockey situations. This is due to the fact that novices lack the first-hand hockey experience needed to form embodied representations that are detailed enough to support such a discrimination.

In terms of non-hockey, everyday situations, however, both novice and expert hockey players should respond faster to matches than to mismatches. Presumably, both groups have the same amount of knowledge and experience with everyday, non-hockey objects and situations. Resultantly, both novice and expert hockey players should be able to form embodied representations of the sentences they read that allow them to discriminate between pictures of everyday objects whose shapes match that implied by the sentences and those that do not. Such a result with everyday situations would replicate recent findings by Zwaan and colleagues (Stanfield & Zwaan, 2001; Zwaan et al., 2002).

Method

Participants

Expert participants (all males) were recruited from the Miami University men's varsity and men's club ice hockey teams and the Miami University subject pool provided they had at least two years of boy's high school varsity ice hockey playing experience (*n* = 48). On average, experts indicated that they had played ice hockey for approximately 15 years (*M*= 14.82 years, *SE* =.46 years). Novice participants were male students enrolled in an introductory psychology course at Miami University who had no hockey playing experience (*n* = 59). Participants received either $5 or course credit in exchange for their participation.

Materials

In the current task, individuals read a sentence and then decided, as quickly as possible, if a subsequently-presented picture of an object or individual was mentioned in that sentence. A total of 144 sentence-picture items were used. Forty-eight of these items served as fillers. The filler items all required "no" responses, as none of the pictures were mentioned in their respective sentences. Twenty-four filler items were non-hockey related, and 24 filler items were hockey-related. The remaining 96 items were the main focus of the experiment. All of the 96 experimental items required "yes" responses, as the objects pictured, regardless of their shapes and orientations, were mentioned in their respective sentences.

The 96 experimental items were divided a priori to form 48 groups consisting of two sentences and two pictures each (see Appendix A). Half of these groups were hockey-related and half were non-hockey related. The two sentences in each group described the same object but in a different shape. The two pictures in each group depicted the object described in the sentences, but in different orientations. For example, the two sentences, “The child saw the balloon in the air,” and, “The child saw the balloon in the bag” were paired with a picture of a full balloon (which matches the shape of the balloon implied in the first sentence but is a mismatch for the second sentence) and a picture of a deflated balloon (which matches the shape of the balloon implied in the second sentence but is a mismatch for the first sentence).

Four sentence-picture items were created in each experimental group by crossing each picture and each sentence. For two of the sentence-picture items in a group, the object’s shape *matched* the shape implied by the sentence. For example, the picture of the full balloon was paired with the sentence “The child saw the balloon in the air,” and the picture of the deflated balloon was paired with the sentence “The child saw the balloon in the bag.” For the other two sentence-picture items in a group, the object was a *mismatch*: The full balloon was paired with the “bag” sentence and the deflated balloon was paired with the “air” sentence. Each participant saw only one of these four possible combinations, creating four versions of the experiment. Thus, each picture and each sentence served as a “match” for some participants and a “mismatch” for others. This ensured that any of the results reported below were not due to the specific sentences or pictures used.

Participants were randomly assigned to one of the four versions of the experiment, each containing a total of 96 sentence-picture items. Each version contained the same 48 filler items (half hockey and half non-hockey, each requiring a “no” response). The remaining 48 items were experimental – one sentence-picture item from each of the 48 groups of four sentence-picture items. Half of the experimental items were hockey and half were non-hockey, and each required a “yes” response. Within the experimental items, half of the sentence-picture items were *matches* and half were *mismatches*. Whether sentences or pictures were part of a match or mismatch item was counterbalanced across the four versions of the experiment. All pictures were black and white line drawings either created by the experimenters or obtained from a computer graphics program, various publicly-viewable websites, or a picture list normed for name and image agreement, familiarity, and complexity (Snodgrass & Vanderwart, 1980).

Thus, the design of the experiment was a 2 (expertise: experts, novices) x 2 (domain: hockey, non-hockey) x 2 (picture: match, mismatch) design. Expertise was a between subjects factor; sentence type and picture shape were within subjects factors. Filler sentences were not analyzed as their inclusion was designed to equate the number of “yes” and “no” responses participants made to the sentence-picture items so that individuals would not be biased to respond in any particular way.

Procedure

After giving informed consent, participants were seated in front of a standard computer and introduced to the task via instructions presented on the screen. The instructions informed participants that they would be reading sentences followed by pictures. Participants were told that the goal of the task was to judge whether the pictures were mentioned in the preceding sentences as quickly as possible because their reaction times were being measured by the computer. During an instruction period participants saw two non-hockey related examples followed by feedback as to the correct response. No feedback was given during the main experimental trials.

In each trial, participants were asked to read each sentence and, as soon as they were finished, to press a key marked with a blue square on a button box in front of them. The sentence did not terminate until participants pressed the blue button. When the sentence disappeared a fixation point (“+”) appeared in the middle of the screen for 250 ms. The fixation point was replaced with a 250 ms blank screen, followed by the picture, screen center. Participants judged as quickly as possible whether the picture was mentioned in the sentence by pressing one of two keys on the button box: either a key labeled “Y” for “yes” or one labeled “N” for “no.” Once a response had been made, the picture disappeared. Participants were instructed to rest their fingers on the keys throughout the experiment. All sentences were presented left-justified on the computer screen and occupied no more than one horizontal line of text. Pictures were centered on the screen and occupied a space approximately 3 x 3 inches in size.

Participants completed three blocks of 32 sentence-picture items each and were encouraged to rest between blocks. Within each version of the experiment, the same 32 items were presented in each block (8 experimental hockey, 8 filler hockey, 8 experimental non-hockey, 8 filler non-hockey), but they were presented in a different random order. After the computer task, participants answered questions concerning their perceptions of their performance on the task. Individuals also filled out a demographic sheet detailing familiarity with ice hockey rules and previous experience playing and watching ice hockey, street hockey, and roller hockey. Participants were then fully debriefed and given the appropriate compensation.

Results

Only data from the experimental items were analyzed. Accuracy scores (and corresponding reaction times) were removed from the following analyses for 17 pictures whose overall accuracy was less than 80% correct across one or both of the expertise groups. Low overall accuracy (regardless of whether a picture served as a match or mismatch) suggests that individuals were not able to accurately recognize the presented picture. Thus, including these pictures in the analyses did not seem appropriate. Of the 17 pictures removed, eight were non-hockey related and nine were hockey related. This resulted in following analyses being performed on 39 hockey pictures and 40 non-hockey pictures.

Additionally, reaction times over three seconds and their corresponding accuracy scores were counted as outliers and removed. Across all participants, 24 total reaction times to experimental pictures that were included in the analyses were removed. This was a very low 0.57% of the total data.

Accuracy

Overall, accuracy was extremely high across all sentence and picture types for both novices and experts. This was confirmed by a 2 (expertise: experts, novices) x 2 (domain: hockey, non-hockey) x 2 (picture: match, mismatch) ANOVA on accuracy that revealed no 3-way interaction, $F(1,104) < 1$. There was, however, a marginal main effect of domain, $F(1,104) = 3.46$, $p < .07$, $MSE = 1.79 \times 10^{-2}$, indicating that individuals responded to non-hockey sentences ($M = 95.6\%$, $SE = .6\%$) slightly more accurately than to hockey sentences ($M = 94.3\%$, $SE = .6\%$). A significant main effect of picture type also obtained, $F(1,104) = 31.15$, $p < .01$, $MSE = .17$. Individuals responded more accurately to pictures that matched the shape implied in the sentences - matches ($M = 96.9\%$, $SE = .4\%$) than to pictures that did not match the shape implied in the sentences - mismatches ($M = 92.9\%$, $SE = .8\%$). No other main effects or interactions were significant. Complete accuracy data is presented in Table 1.

Both ice hockey novices and experts showed high levels of accuracy across all pictures and, moreover, accuracy did not differ as a function of hockey skill level. This finding is important because it suggests that everyone was able to perform the task successfully (i.e., determine if a picture of an object or individual was mentioned in a preceding sentence). The lack of any interaction in the accuracy data sets the stage to examine whether the speed with which participants could discriminate between matches and mismatches was dependent on the type of sentence presented (i.e., hockey versus non-hockey) or the skill level of the individual performing the task.

Reaction Time

The central result of the experiment is a 2 (expertise: experts, novices) x 2 (domain: hockey, non-hockey) x 2 (picture: match, mismatch) interaction in RT, $F(1,104) = 6.68$, $p < .02$, $MSE = 4.19 \times 10^4$. RTs to pictures that matched or mismatched their preceding sentences differed, but this difference was dependent on the skill level of the participant and the domain depicted in the sentence-picture items.

To further explore this 3-way interaction, RT data for the non-hockey and hockey sentence-picture items were explored separately. In terms of the non-hockey items, a 2 (expertise: experts, novices) x 2 (picture: match, mismatch) ANOVA revealed only a main effect of picture, $F(1,104) = 50.46$, $p < .01$, $MSE = 3.00 \times 10^5$. Regardless of hockey expertise, all participants responded more quickly to non-hockey matches ($M = 662.59$ ms, $SE = 14.27$ ms) than non-hockey mismatches ($M = 738.19$ ms, $SE = 18.53$ ms). There was no main effect of expertise, $F(1,104) < 1$, and no expertise x picture interaction, $F(1,104) = 1.58$, $p > .2$ (see Figure 1). Participants were able to form embodied representations of everyday objects, as demonstrated by the fact that all individuals, regardless of hockey expertise, responded faster to everyday pictures that matched the orientation implied in the sentence versus those that did not. This finding replicates previous work by Zwaan and colleagues (Stanfield & Zwaan, 2001; Zwaan et al., 2002).

A very different pattern of results was found for hockey-specific items. A 2 (expertise: experts, novices) x 2 (picture: match, mismatch) ANOVA revealed a significant expertise by picture interaction, $F(1,104) = 4.77$, $p < .04$, $MSE = 3.72 \times 10^4$ (Figure 2). Experts responded significantly faster to hockey matches ($M = 714.56$ ms, $SE = 27.45$ ms) than to mismatches ($M = 773.38$ ms, $SE = 26.64$ ms), $t(47) = -3.30$, $p < .01$. Novices showed no difference in RT between hockey matches ($M = 791.56$ ms, $SE = 24.97$ ms) and hockey mismatches ($M = 797.19$ ms, $SE = 24.23$ ms), $t(57) = -.34$, $p > .7$.

Discussion

The expertise by domain by picture interaction in RTs suggests that experts and novices demonstrated different match-mismatch effects as a function of the domain depicted in the sentences–picture items. Participants were able to respond more quickly to matches than to mismatches when they had knowledge of and experience with the domain being described. This was the case for experts for both types of items in Experiment 1 (hockey and non-hockey items), but it was only the case for novices when the sentences and pictures described everyday, non-hockey situations. These differences in the match-mismatch effects across expertise groups allow us to make inferences about differences in expert hokey players' and novices' cognitive representations as a function of the type of stimuli presented. The fact that the experts showed the match-mismatch effect for hockey items suggests that their representations included detailed perceptual information about the domain of ice hockey – a domain within which they had years of experience. The lack of a hockey match-mismatch effect for the novices indicates that the characteristics of their representations were not as detailed as those of the experts. The novices could not represent hockey information in the same way as the experts because they lacked the hockey knowledge and experiences necessary to do so.

Two main conclusions can be drawn from Experiment 1. First, expertise is domain specific in that hockey experts do not look different than hockey novices with respect to how they respond to everyday, non-hockey sentence-picture pairs. This finding is consistent with the notion that expertise is acquired via thousands of hours of practice within a given domain, rather than an innate ability that extends across skill domains (Ericsson, Krampe, & Tesch-Romer, 1993). Second, Experiment 1 suggests that not everyone forms embodied representations of information they are presented with to the same extent. Novices' lack of ice hockey knowledge and experience prevented them from showing the match-mismatch effect for hockey situations. Note that it is not the case that the novices were not forming *any* representations of the hockey situations, as their accuracies were very high. Rather it appears that novices could not form representations in as much detail as experts for hockey-related stimuli. The fact that novices' RTs did not discriminate between ice-hockey matches and mismatches suggests that their representations did not contain information about the perceptual qualities and action possibilities of the hockey-related objects and individuals they were reading about.

According to embodied approaches to cognition, and specifically perceptual symbols theory, the representation of the action possibilities associated with objects results not only from previous declarative knowledge about what the objects are, but from previous experiences interacting with those objects and performing object-relevant actions (Barsalou, 1999; Glenberg, 1997; Zwaan, 1999, 2004). The hockey experts in Experiment 1 possessed both types of knowledge (declarative knowledge and motor experience), while the hockey novices did not. Two possible explanations, then, can account for the above finding in which experts but not novices showed the match-mismatch effect for hockey situations.

First, it may be the case that embodied representations can be formed given general declarative knowledge and passive viewing experience, but our novices did not have the general hockey knowledge or perceptual experience needed to represent the hockey information in this way. Second, it is possible that motor experience in a given domain is needed for one to be able to form embodied representations, and our novices lacked this type of execution experience. If the former possibility is true, then novices with no actual playing experience but a lot of general hockey knowledge and viewing experience *should* show the match-mismatch effect – much like the experts seen above. However, if the latter possibility is correct, then novices with hockey knowledge who lack playing experience should *not* show this effect because they do not possess extensive motor representations relevant to the domain of hockey that allow one to form representations of stimuli that include perceptual detail and action possibilities.

This latter possibility would suggest that motor experience not only carries implications for performance, but it plays a role in the perception and representation of action as well. Although it is no surprise that experts are better performers than novices (indeed this is one criteria of expertise), there is less work demonstrating that motor expertise carries implications for cognitively perceiving and representing information. Such a finding would support the link between perception and action (Borghi, 2004; Chambers et al., 2004; Craighero et al., 1996; Glenberg & Kaschak, 2002; Klatzky et al., 1989; Tucker & Ellis, 1998), and, in addition, advance it by demonstrating that without actual motor experience, such a link may not be as robust.

Support for the idea that the perception-action link may be qualified by actual motor experience comes from recent work driven by the notion that the motor system actually simulates the planning and execution of actions when individuals merely watch those actions being performed (Knoblich & Flach, 2001; Knoblich & Prinz, 2001; Leube, Knoblich, Erb, & Kircher, 2003; Repp & Knoblich, 2004). These authors have hypothesized that if the same or similar systems are involved in planning, executing, and perceiving actions, then the most overlap among these systems should occur when one perceives one's *own* actions relative to another's actions. That is, when people view their own actions, the same system that had once planned that action should also be involved in perceiving the action. Under this view, individuals should be better able to make predictions about the outcomes of their own actions relative to the actions of others because the part of the motor system that had previously executed the action is also being used to simulate the action. These systems, although similar, are not one in the same when one perceives another's actions.

And, indeed, data support these hypotheses. For example, 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 the darts (Knoblich & Flach, 2001). Individuals can also make more accurate predictions about their own versus others' handwriting strokes. When asked to determine whether a stroke was produced alone or before another stroke, individuals' predictions are more accurate for handwriting strokes that they themselves had produced (Knoblich, Seigerschmidt, Flach, & Prinz, 2002). Additionally, these effects obtain even when action perception is non-visual. Pianists can more readily recognize audiotapes of their own performances in relation to other pianists' performances (Repp & Knoblich, 2004).

The above mentioned studies not only reinforce the notion that the perception and action systems interact, but they suggest a mechanism that can account for the results of Experiment 1. Namely, the reason that expert hockey players may have been faster than novices to respond to hockey players and objects whose actions or action possibilities matched that implied by the sentences was because the experts' motor systems were simulating those actions as the sentences were being read. Thus, when the matching pictures appeared, experts were more easily able to respond because the actions being simulated by their motor systems matched that represented in the stimuli. Novices, who lacked the knowledge of the action possibilities or first-hand motor experience, were not able to simulate these actions to the same extent. As a result, novices' responses to matches and mismatches did not differ.

If active experiences give rise to cognitive representations that contain motor information associated with domain-relevant objects and actions (Barsalou, 1999; Glenberg, 1997; Tucker & Ellis, 1998; Van den Bergh et al., 1990; Zwaan, 1999, 2004), and this type of knowledge is accessed or simulated when one reads about such stimuli (Knoblich & Flach, 2001; Knoblich et al., 2002; Repp & Knoblich, 2004), then the ability to form embodied representations for action-based situations will not only differentiate expert from novice performers, but experts from novices with a lot of knowledge in a given domain but no physical experience as well. Experiment 2 was designed to examine this notion.

Experiment 2

Three groups of participants were used in Experiment 2, and the sensorimotor skill of football was used as a test bed. Football *experts* had football-playing experience as well as high levels of general football knowledge. *Novices with knowledge* also had high levels of general football knowledge, but they had no football-playing experience. *Novices* had neither general knowledge nor motor experience.

The setup of Experiment 2 was very similar to Experiment 1. However, only sentences describing *people* performing actions were used in Experiment 2 in order to examine whether experience executing a specific action was necessary to form an embodied representation that contained perceptual and motor information associated with the action described in the sentence. Moreover, an additional variable was included in Experiment 2 that was not manipulated in Experiment 1: The type of action the experimental sentences and pictures described. Half of the sentences and pictures described “football action;” that is, the sentences and pictures portrayed football players doing game-specific movements that occur during official football game play (e.g., the sentence “The quarterback threw the football to the receiver”). The remaining half of the experimental items portrayed “everyday action,” but still in a football setting; that is, football players performing movements that are not specific to the game of football and that do not occur during official football game play (e.g., the sentence “The coach saw the football player on the bench”).

If embodied representations of action rely heavily on having first-hand motor experience performing an action, then only individuals with active football-playing experience should show the match-mismatch effect for sentences describing football-specific actions. However, if individuals can form embodied representations of action merely by being knowledgeable about the actions, then individuals would not need active motor experience to show this effect. Mere knowledge of what these movements entail should be sufficient. In contrast, everyone should show the match-mismatch effect for sentences depicting everyday actions because, despite the fact that these actions are embedded in the domain of football, we all have both knowledge and experience with performing the actions described in the everyday sentences.

Method

Participants

Participants were selected on the basis of their football knowledge and playing experiences: *Experts* had high levels of football knowledge and playing experience while *novices* had low levels of football knowledge and no physical playing experience. A third group of *novices with knowledge* had high levels of football knowledge (similar to the experts), but lacked any playing experience (similar to the novices).

To evaluate participants’ experiences and knowledge, everyone completed a 26-item multiple-choice test of football knowledge developed by the authors with the aid of two local football coaches. Items on this test assessed participants’ knowledge of game rules, player positions, game strategies, football terms, referee signals, and general football field layout. Example items are given in Appendix B. Experts and novices with knowledge were recruited provided they scored high on this knowledge test – above 80% (experts *M* = 97.80%, *SE* = .72%; novices with knowledge *M* = 92.04%, *SE* = 1.22%). Novices were recruited provided they scored low – below 40% (*M* = 25.80%, *SE* = 1.14%).

In addition, all participants completed a demographic form assessing previous organized (e.g., school teams) and unorganized (e.g., backyard football with friends) football playing experiences. Experts were recruited provided they had at least two years of varsity high school or college football playing experience (*M* = 5.29 years, *SE* = .26 years; note that this does not include playing experience that occurred pre-high school). Novices with knowledge and novices were recruited provided they had no experience playing organized football (regular tackle or flag) in high school or college.

Some participants indicated they had experience playing unorganized, backyard-type football with friends, and they indicated how often they played this type of football on a 7-point scale (1 = never; 2 = hardly ever, about 1-3 times in my life; 3 = sometimes, about 4-6 times per year; 4 = every year, about once a month when the weather is nice; 5 = every year, a few times a month; 6 = on a weekly basis; 7 = on a daily basis). To limit any football playing experience whatsoever for the novices with knowledge and novice groups, individuals were only included in these groups provided they indicated a 3 or lower on this scale.

In all, 28 experts, 29 novices with knowledge, and 48 novices were recruited. All participants were recruited from the Miami University subject pool or the Miami University

Intercollegiate Football Team. All participants received either $10 or course credit in exchange for participation. None of these individuals participated in Experiment 1.

Materials

The materials and procedure in Experiment 2 were similar to that of Experiment 1. Just as in Experiment 1, participants read sentences and decided if subsequent pictures were mentioned in the sentences as quickly as possible. However, in Experiment 2 all pictures displayed people: either football players or personnel (e.g., coaches, trainers, cheerleaders, etc.). In addition, all sentences described situations within the domain of football. What differed was the type of action portrayed (either football action or everyday action). All pictures were black and white line drawings created from photographs taken by the experimenters or from non-copyrighted photographs taken from publicly-viewable websites.

A total of 160 sentence-picture items were included in Experiment 2. Half of the items required “yes” responses (i.e., the person in the picture was mentioned in the sentence) and half required “no” responses (i.e., the person in the picture was not mentioned in the sentence). Of the 80 “yes” items, 40 formed the experimental items of interest, with all of the pictures portraying football players (e.g., the sentence, “The quarterback threw the football to the receiver” followed by a picture of a quarterback). Half of the experimental items depicted football players performing game-specific movements (e.g., “The quarterback threw the football to the receiver” followed by a picture of a football player doing an action that either matches or does not). The remaining half of the experimental items depicted football players performing actions that are not specific to the game of football (e.g., “The coach saw the football player on the bench” followed by a picture of a football player doing an action that either matches or does not).

The remaining 40 “yes’ items were fillers, with the pictures portraying football personnel (e.g., the sentence, “The running back saw the coach run down the field” followed by a picture of a coach). All of the 80 “no” items were fillers: Forty of the pictures in the “no” items portrayed football *personnel* who were not mentioned in the preceding sentences, while the remaining forty “no” pictures portrayed football *players* who were not mentioned in the preceding sentences. See Appendix C for examples.

The “yes” and “no” filler items were included so that there were equal numbers of items depicting football players and personnel as well as equal numbers of “yes” and “no” responses. More importantly, the number of times that a “yes” response to a picture of a player was required equaled the number of times that a “no” response to a picture of a player was required. The same held true for responses to pictures of football personnel. Although the only items of interest were the 40 experimental “yes” items whose pictures portrayed football players, including items whose pictures were non-players eliminated any bias to respond to players. Additionally, including items that required “no” responses eliminated any bias to respond “yes.” Finally, counterbalancing the type of response required (“yes” or “no”) and the person depicted in the picture (player or non-player) eliminated any bias towards responding either “yes” or “no” to any type of person.

All items were counterbalanced to create four different versions of the experiment, to which participants were randomly assigned. All four versions included the same 80 “no” filler items (i.e., the same sentences paired with the same pictures). Similarly, all four versions included the same 80 “yes” sentences and pictures (40 experimental, 40 filler), but the manner in which those sentences and pictures were paired differed across the four versions. As in Experiment 1, “yes” items could be either “matches” (i.e., the person in the picture was performing an action that matched the action implied by the sentence) or “mismatches” (i.e., the person in the picture was not performing the action implied by the sentence). All 80 “yes” items were put a priori into groups consisting of two sentences and two pictures. For instance, the sentences “The quarterback threw the football to the receiver” and “The quarterback handed off the football to the receiver” were grouped with a picture of a football player throwing – a match for the first sentence and mismatch for the second sentence, and a picture of a football player handing off to the side – a match for the second sentence and mismatch for the first sentence. Participants saw both items in a group either as matches or they saw both items as mismatches. Both experimental “yes” items and filler “yes” items were grouped in this way. Each of the four versions of the experiment was comprised of a unique set of these sentence-picture pairings.

It should be noted that in Experiment 1, all of the objects of interest in the experimental sentences (i.e., the objects or people to be portrayed in the subsequent pictures) were referred to in the same location in each of the sentences (see Appendix A). Thus, it is possible that participants discovered this pattern over time and were able to anticipate which object would be depicted in the picture. However, this would still not account for the interaction with expertise seen in Experiment 1. Nonetheless, to overcome this limitation, the location of the targets in the sentences in Experiment 2 varied such that roughly half of the targets were mentioned at the beginning of the sentences (e.g., the quarterback is the target in the sentence “The quarterback threw the football to the receiver”) and half were mentioned in the middle of the sentences (e.g., the offensive lineman is the target in the sentence “The trainer saw the offensive lineman protect the ball”). Finally, if only one person was mentioned in each sentence it would have become obvious to participants which person was going to be portrayed in the subsequent picture. So, regardless of responding “yes” or “no,” at least two people were mentioned in every sentence.

Thus, the design of the experiment was a 3 (expertise: experts, novices with knowledge, novices) x 2 (action: football, everyday) x 2 (picture: match, mismatch) design. Expertise was a between subject factor, and action and picture type were within subjects factors.

Procedure

Participants were either given the test of football knowledge and demographic forms assessing background football playing experiences in large sessions prior to the experiment or recruited for the study directly and given the test of football knowledge and demographic forms immediately following the experimental computer task. This difference in protocol across subjects occurred because of how individuals were recruited. All participants from the football team were recruited individually, while many of the novices and novices with knowledge were recruited via the large sessions. Despite this difference however, there were enough novices and novices with knowledge recruited individually (like the experts) to analyze only those participants who took the knowledge test after the computer task. This analysis produced exactly the same pattern of results as that reported below.

The procedure for the computer task participants performed in Experiment 2 was extremely similar to Experiment 1, with three exceptions. First, during the instruction period of the computer task, participants saw a total of eight football action and everyday action examples followed by feedback as to the correct response, in comparison to two non-hockey examples in the first experiment. Second, during the main experiment participants completed 4 blocks of 40 randomly-presented sentence-picture items each, in comparison to 3 blocks of 32 items in the first experiment. Finally, the order of sentence-picture items in Experiment 2 was randomized across all blocks in comparison to within blocks in Experiment 1. As in Experiment 1, participants were encouraged to rest between blocks. At the end of the experiment participants were dismissed and given the appropriate compensation.

Results

As in Experiment 1, only data from experimental items were analyzed. And, as in Experiment 1, accuracy scores (and corresponding RTs) were removed from the following analyses for three pictures whose overall accuracy was less than 80% correct across at least one of the expertise groups. Three pictures were removed, all of which depicted football action. Thus, the following analyses were performed on 17 football action and 20 everyday action items.

Additionally, RTs more than three seconds and their corresponding accuracy scores were counted as outliers and removed. Across all participants, 67 total RTs to experimental pictures that were included in the analyses were removed. This accounted for a very low 1.23% of the total data.

Accuracy

Overall, accuracy was extremely high across all sentence/picture types for all three expertise groups. This was confirmed by a 3 (expertise: experts, novices with knowledge, novices) x 2 (action: football, everyday) x 2 (picture: match, mismatch) ANOVA on accuracy that revealed no 3-way interaction, $F(2,102) < 1$. There was, however, a main effect of action, $F(1,102) = 7.86$, $p < .01$, $MSE = 4.76 \times 10^{-2}$, indicating that individuals responded more accurately to football action items ($M = 96.6\%$, $SE = .6\%$) than to everyday action items ($M = 94.4\%$, $SE = .7\%$). There was also a significant main effect of picture, $F(1,102) = 10.16$, $p < .01$, $MSE = 4.84 \times 10^{-2}$, indicating that individuals responded more accurately overall to matches ($M = 96.6\%$, $SE = .5\%$) than to mismatches ($M = 94.4\%$, $SE = .7\%$). No other main effects or interactions were significant. Complete accuracy data is presented in Table 2.

Reaction Time

As in Experiment 1, the main result of interest is the significant 3 (expertise: experts, novices with knowledge, novices) x 2 (action: football, everyday) x 2 (picture: match, mismatch) interaction with respect to RT, $F(2,102) = 4.76$, $p < .02$, $MSE = 4.66 \times 10^{4}$. This interaction indicates that the expertise groups showed differential responses to matches and mismatches as a function of the action portrayed.

To explore this 3-way interaction, RT data for the football action and everyday action items were explored separately. In terms of the everyday action items, a 3 (expertise: experts, novices with knowledge, novices) x 2 (picture: match, mismatch) ANOVA revealed a main effect of picture, $F(2,102) = 7.91$, $p < .01$, $MSE = 1.20 \times 10^{5}$ (Figure 3). Regardless of football expertise, all participants responded more quickly to everyday action matches (*M* = 903.41 ms, *SE* = 23.58 ms) than to everyday action mismatches (*M* = 952.70 ms, *SE* = 27.90 ms). Because all participants had experience with these types of movements, they were able to form representations of these types of situations as evidenced by their ability to respond more quickly to matches than to mismatches. There was also a main effect of expertise, *F*(2,102) = 3.78, $p <$ .03, *MSE* = 4.41 x 10^5, indicating that experts responded faster overall (*M* = 849 ms, *SE* = 45.66 ms) than novices (*M* = 1006.01 ms, *SE* = 34.87 ms), $p < .01$. The RTs of the novices with knowledge (*M* = 928.69 ms, *SE* = 44.86 ms) did not differ from either the experts ($p > .2$) or the novices ($p > .15$). The RT difference between the experts and novices is most likely due to the fact that football experts had more experience seeing stimuli within their domain. Importantly, however, novices were still able to make the distinction among football players doing everyday actions that matched the sentences versus those whose actions did not match. Moreover, there was no expertise by picture interaction, *F*(2,102) < 1, indicating that the ability to respond faster to matches than to mismatches did not differ across the three expertise groups.

Results look much different for items that depict football-specific action. A 3 (expertise: experts, novices with knowledge, novices) x 2 (picture: match, mismatch) ANOVA revealed a significant expertise by picture interaction, *F*(2,102) = 3.67, $p < .03$, *MSE* = 6.91 x 10^4 (Figure 4). It is the experts who have first-hand active experience executing these types of movements who show the match-mismatch effect for situations depicting football action: They responded significantly faster to football action matches (*M* = 730.27 ms, *SE* = 44.43 ms) than to mismatches (*M* = 847.44 ms, *SE* = 52.28 ms, *t*(27) = -3.49, $p < .01$). However, neither novices with knowledge nor novices showed a significant difference between football action matches and mismatches (novices with knowledge: *M* = 823.74 ms, *SE* = 43.65 ms for matches, *M* = 875.55 ms, *SE* = 51.37 ms for mismatches, *t*(28) = -1.37, $p > .18$; novices: *M* = 897.65 ms, *SE* = 33.93 ms for matches, *M* = 890.65 ms, *SE* = 39.93 ms for mismatches, *t*(47) = .25, $p > .8$).

Although novices with knowledge do not respond significantly faster to football action matches than mismatches, there is a trend for them to do so. It seems that just possessing football knowledge is buying these novices with knowledge something over and above mere novices. However, active motor experience still appears to be buying the experts something more.

Discussion

Experiment 1 demonstrated that individuals lacking ice hockey knowledge and experience could not form representations of hockey-related objects and actions that contained relevant perceptual and motor information to the same extent as ice hockey experts. The findings from Experiment 2 parallel these results and, moreover, suggest what *kind* of knowledge is needed to form these types of representations. Individuals are able to form the most detailed representations of actions only when they have experience performing those actions. In other words, the extent to which individuals have executed domain-specific actions determines the extent to which they can form embodied representations of those actions and make subsequent decisions to sentence-picture items.

It should be noted that the novices with knowledge did show a trend to respond more quickly to football action matches than mismatches (Figure 4). However, they did not show this effect to the same extent as the experts, providing support for the notion that the extent of one's embodied representation depends upon the level of one's motor experiences.

General Discussion

The main goal of this work is to shed light on the question of what makes experts in a domain different from novices. One way to do this is to not only document differences between expert and novice performance, but to explore why these differences occur. That is, understanding expert performance is more than just examining actual performance outcomes, it involves understanding the cognitive control structures or knowledge representations that drive this performance. Embodied theories of knowledge representation suggest that more than just semantic information contributes to our understanding of the world: Embodied representations include information about sensory and motor experiences as well. But, until now, not much work has explored how these representations come about. What type of knowledge or experience is needed to form embodied representations? The two experiments in the current work shed light on this question.

In Experiment 1, expert and novice ice hockey players read sentences about hockey and non-hockey situations and decided if objects or people in the subsequent pictures were mentioned in those sentences. Both experts and novices showed the match-mismatch effect for the non-hockey situations – situations in which they had experience. Only experts showed the match-mismatch effect for hockey situations. These results suggest experts' superior performance with the hockey-specific situations lies in their previous knowledge of and experience with information relevant to those situations.

Experiment 2 employed the same paradigm with football. Experts (who had both domain knowledge as well as sensorimotor experience within this domain), novices with knowledge (who also possessed general football knowledge but lacked motor experience), and novices (with neither knowledge nor experience) read sentences and responded to corresponding pictures that either depicted football players performing football-specific actions, or football players performing everyday actions. All three groups showed the match-mismatch effect for the situations depicting everyday actions. However, only the experts – who differed from the other two groups in terms of their motor experiences – showed the effect for football-specific actions. These results suggest that experts' superior performance with the football-specific action situations lies in their previous motor experience with those actions.

These results are in line with work suggesting that the motor system simulates actions as they are perceived (Knoblich & Flach, 2001; Knoblich et al., 2002; Repp & Knoblich, 2004). Although participants in the current studies did not perceive people performing actions in real time, they perceived stimuli in which actions were implied. Previous work suggests action possibilities are automatically perceived when individuals view stimuli, resulting in low-level motor system activation or priming, which in turn facilitates responses (Glenberg & Kaschak, 2002; Klatzky et al., 1989; Rieger, 2004; Tucker & Ellis, 1998, 2004; Van den Bergh et al., 1990). When participants in Experiments 1 and 2 read the sentences and saw the pictures, their motor systems may have been activated. However, this activation was dependent upon their expertise, resulting in differential performance across groups.

The results of Experiments 1 and 2 are not only consistent with work citing behavioral evidence for embodied knowledge representations (Barsalou, 1999; Glenberg, 1997; Glenberg & Kaschak, 2003; Stanfield & Zwaan, 2001; Zwaan et al., 2002) and associations between perception and action systems (Borghi, 2004; Craighero et al., 1996; Klatzky et al., 1989; Knoblich et al., 2002; Repp & Knoblich, 2004; Rieger, 2004; Tucker & Ellis, 1998; Van den Bergh et al., 1990), but they are also consistent with work indicating differential brain activation as a function of the stimuli used and one's level of experience with the stimuli. For instance, Hauk, Pulvermuller, and colleagues (Hauk, Johnsrude, & Pulvermuller, 2004; Hauk & Pulvermuller, 2004) have shown that when individuals passively read action words associated with the leg, face, and arm (e.g., “kick,” “lick,” and “pick,” respectively), activations occur in brain areas that are implicated in the actual movements of these body parts. In addition, motor and parietal cortex activation occurs when individuals perceive human actions, but when those actions are not humanly possible (e.g., the movement of an arm *through* a leg), the activation disappears, suggesting that the involvement of motor areas differs as a function of how much experience individuals have with different actions (Stevens, Fonlupt, Shiffrar, & Decety, 2000). Similarly, when expert dancers view videotapes of other dancers, motor system activation occurs only when they watch the specific kind of dance in which they are experts. That is, only highly specialized movements that are already a part of an expert’s motor repertoire are simulated when those movements are perceived. Dance moves belonging to a separate domain – even if those movements are muscularly similar to actions within one’s own domain – are not simulated (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, in press).

These brain imaging studies lend further support to embodied theories of knowledge representations as they implicate specific neural structures that underlie the perception of stimuli. Brain activations occur not simply in areas responsible for the representation of semantic information, but they occur in areas responsible for the representation of action. If motor and other sensory areas of the brain are activated upon perceiving stimuli – like reading words or watching videotapes (Gallese & Goldman, 1998; Knoblich & Flach, 2001; Knoblich et al., 2002; Repp & Knoblich, 2004), and these sorts of brain activations depend upon one’s level of expertise (Calvo-Merino et al., in press; Decety & Grezes, 1999; Hauk et al., 2004; Hauk & Pulvermuller, 2004; Stevens et al., 2000), this provides further support for our interpretation of the results obtained in Experiments 1 and 2.

From a theoretical standpoint, the above results suggest that one way in which novices differ from experts in motor skills is in terms of the motor components that accompany one’s representations of objects and events within their skill domain. This is a novel idea in the expertise literature, as traditionally differences in the structure of propositional networks have been used to describe differences in experts’ and novices’ performances (Ericsson & Polson, 1988).

From a practical standpoint, these results carry implications for the way in which motor skills are taught. People without active experience in a domain do not represent domain-specific actions to the same extent as people with active experience. This finding sheds light on when and how active participation should occur in the learning process in order to facilitate skill acquisition and performance. If the reason that expert athletes respond so quickly to other players is due not only to their superior motor capacity but the way in which their actions are represented, then it seems that active experience should occur as early and often in the learning process as possible. Merely watching coaches or other players performing skilled movements may be beneficial. However, actual motor experience may be necessary to form the most comprehensive representation of performance in a given domain. Moreover, these results suggest that a coach or referee who has never played the sport they are involved with may be at a disadvantage in terms of teaching skills to others or interpreting actions in a given domain. Without actual motor experience, these individuals may not have the representations necessary to recognize technique problems or different types of intended actions.

In sum, the current work investigated differences in the cognitive components underlying successful performance across individuals of varying skill levels. One’s previous experiences – experiences in both acquired knowledge and motor execution – not only predict overt performance outcomes, but those experiences are reflected in one’s cognitive representations of the world. Thus, not only does the current work suggest that propositional theories of knowledge representation (Kintsch, 1988; Newell & Simon, 1972) do not account for the richness of our knowledge representations as fully as do embodied theories (Barsalou, 1999; Glenberg, 1997; Zwaan, 2004), but it also suggests how embodied representations come about.

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Appendix A
Example stimuli from Experiment 1

Non-hockey experimental sentence Picture (match)

Group 1:

The child saw the balloon in the air.

The child saw the balloon in the bag.

Group 2:

The ranger saw the eagle in the sky.

The ranger saw the eagle in the nest.

Hockey experimental sentence Picture (match)

Group 1:

The woman watched the hockey player at the face-off.

The woman watched the hockey player at the net.

Note: the hockey player’s hands are in different orientations on the stick here

Group 2:

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

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

Note: in the first sentence the net is knocked over

Non-hockey filler sentence Picture (not mentioned)

The woman watched the bird at the feeder.

Hockey filler sentence Picture (not mentioned)

The fans saw the hockey goalie save the puck.

Appendix B
Example items from football knowledge test in Experiment 2

1. To signal a touchdown, what does a football referee do?
    - A Puts his hands on his hips
    - B Puts his hands out to the side
    - **C Puts his hands in the air above his head**
    - D I don’t know

2. In football, what does the term “bomb” mean?
    - A A really hard hit
    - B A really hard pass
    - **C A really long pass**
    - D I don’t know

3. A safety in football is scored by:
    - **A The defense**
    - B The offense
    - C The quarterback
    - D I don’t know

4. What is the main responsibility of a center in football?
    - A Throws the ball to the receiver
    - **B Snaps the ball to the quarterback**
    - C Tackles the offensive linemen
    - D I don’t know

5. What is the main responsibility of a defensive lineman in football?
    - **A Break through the offensive line**
    - B Try to get a first down
    - C Protect the ball carrier
    - D I don’t know

6. How long is a football field?
    - A 50 yards
    - **B 100 yards**
    - C 150 yards
    - D I don’t know

Notes: Correct answers are shown in boldface. Each item on the tests included option D: “I don’t know.” Participants were encouraged to mark option D and not guess if they were unsure of the correct answer. Responses of “D” were scored as incorrect.

Appendix C
Example stimuli from Experiment 2

Football action experimental sentences	Picture (match)
The quarterback threw the football to the receiver.	
The quarterback handed off the football to the receiver.	

Everyday action experimental sentences	Picture (match)
The coach saw the football player on the bench.	
The coach saw the football player in the huddle.	

“Yes” filler sentences	Picture (match)
The referee signaled the tight end’s touchdown.	
The referee signaled the tight end’s offsides violation.	

“No” filler sentences	Picture (not mentioned)
The coach watched the referee jump over the football.	 (player)
The defenseman tackled the ball carrier near the sidelines.	 (coach)

Table 1

Accuracy of responses to hockey and non-hockey items in Experiment 1.

	Hockey		Non-hockey	
Expertise	Match	Mismatch	Match	Mismatch
Novices	*M* = 95.4%	*M* = 92.6%	*M* = 98.4%	*M* = 94.6%
	SE = .9%	*SE* = 1.3 %	*SE* = .6%	*SE* = 1.3%
Experts	*M* = 96.9%	*M* = 92.2%	*M* = 97.0%	*M* = 92.3%
	SE = .9%	*SE* = 1.5%	*SE* = .7%	*SE* = 1.4%

Table 2

Accuracy of responses to football action and everyday action items in Experiment 2.

	Football action		Everyday action	
Expertise	Match	Mismatch	Match	Mismatch
Novices	*M* = 95.8% *SE* = .9%	*M* = 95.4% *SE* = 1.2%	*M* = 94.6% *SE* = 1.1%	*M* = 91.9% *SE* = 1.5%
Novices with knowledge	*M* = 98.5% *SE* = 1.1%	*M* = 96.5% *SE* = 1.6%	*M* = 96.6% *SE* = 1.4%	*M* = 95.5% *SE* = 1.9%
Experts	*M* = 98.8% *SE* = 1.1%	*M* = 94.8% *SE* = 1.6%	*M* = 95.7% *SE* = 1.4%	*M* = 92.5% *SE* = 1.9%

Figure Captions

Figure 1. Mean reaction times for Experiment 1: Non-hockey items. Error bars represent standard errors of the mean.

Figure 2. Mean reaction times for Experiment 1: Hockey items. Error bars represent standard errors of the mean.

Figure 3. Mean reaction times for Experiment 2: Everyday action items. Error bars represent standard errors of the mean.

Figure 4. Mean reaction times for Experiment 2: Football action items. Error bars represent standard errors of the mean.

Figure 1. Mean reaction times for Experiment 1: Non-hockey items.

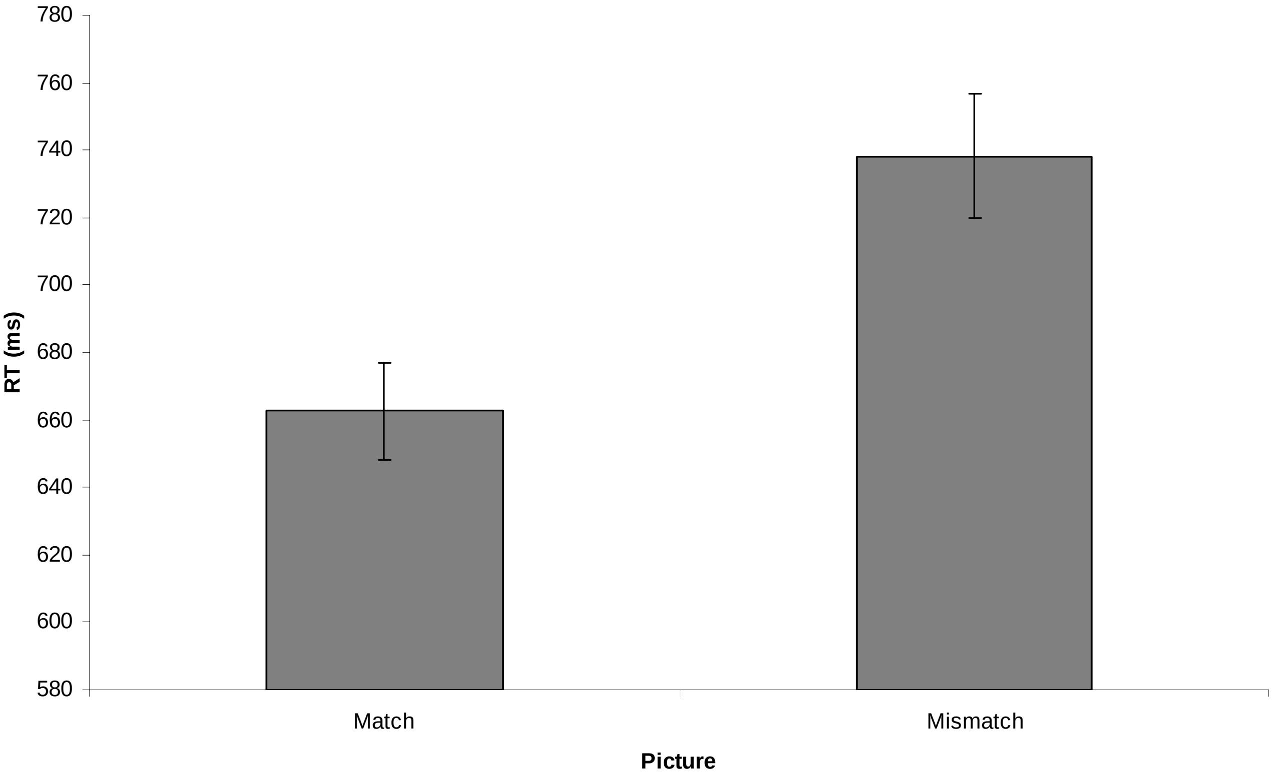

Figure 2. Mean reaction times for Experiment 1: Hockey items.

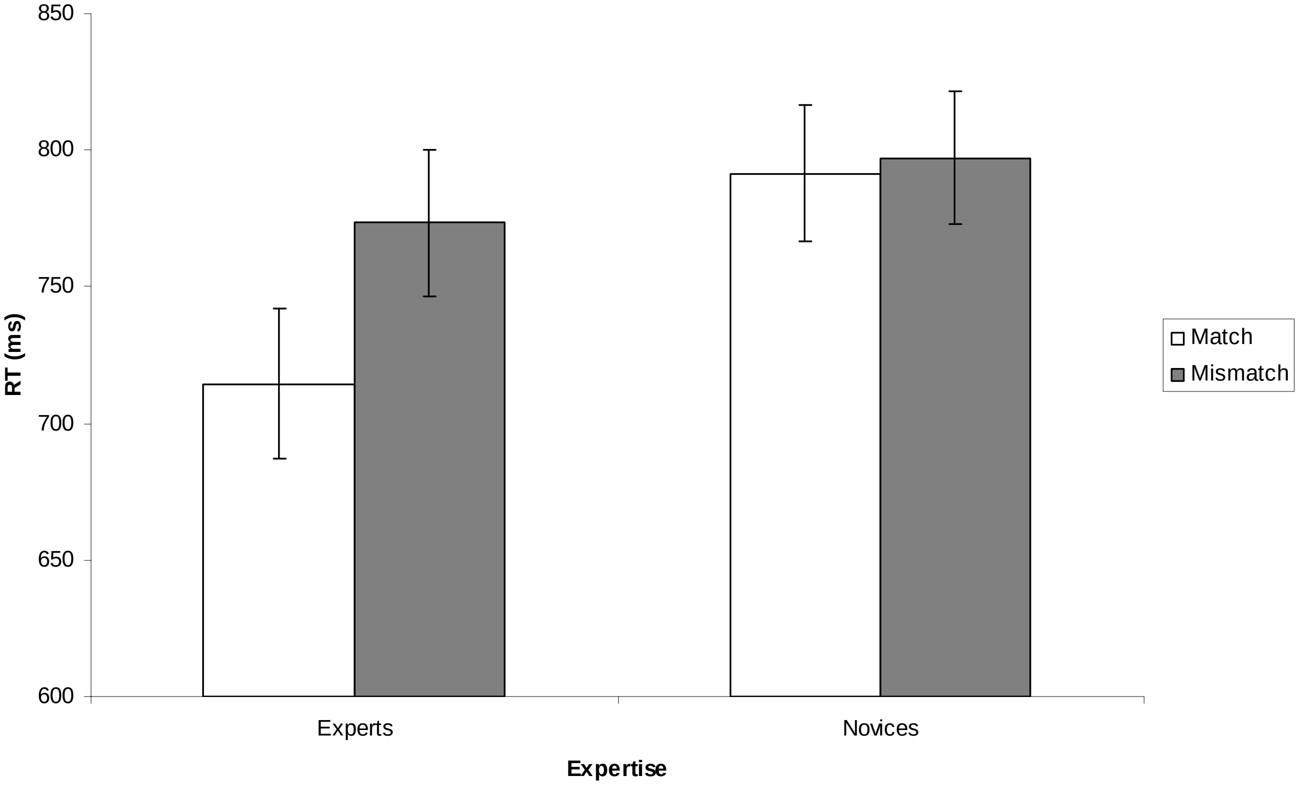

Figure 3. Mean reaction times for Experiment 2: Everyday action items.

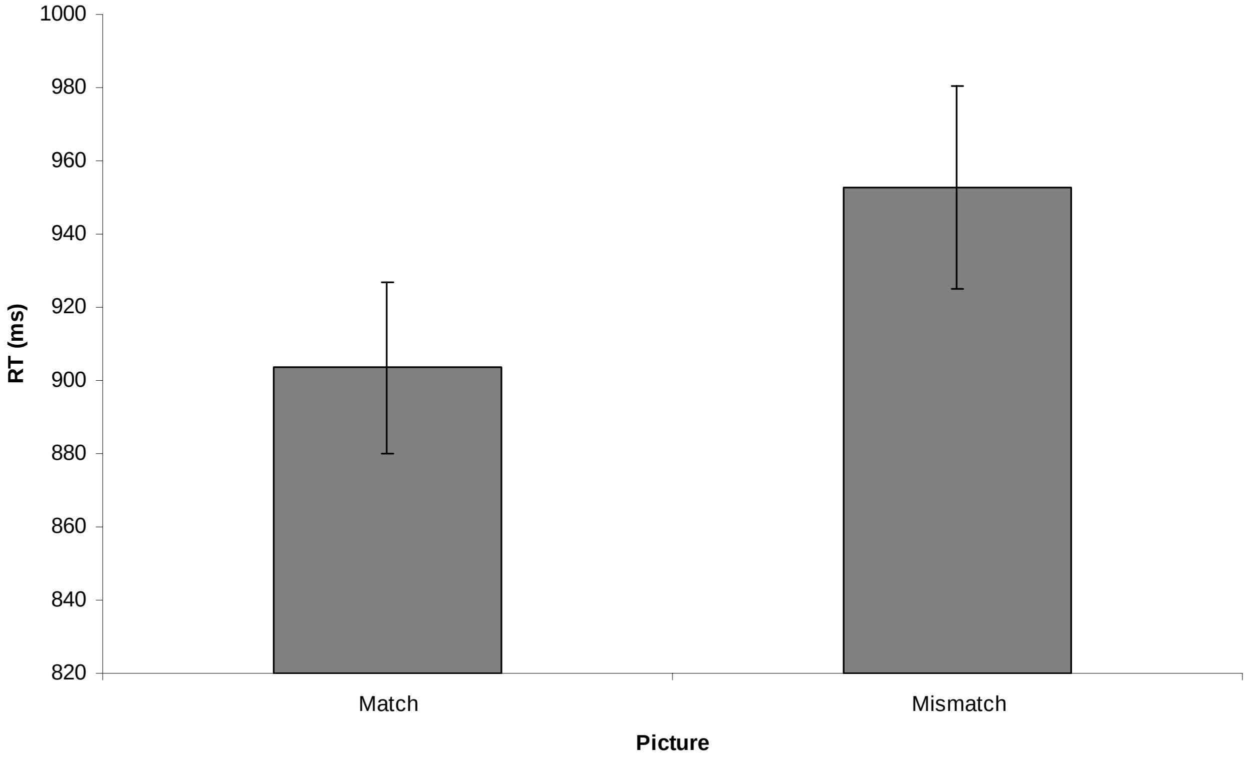

Figure 4. Mean reaction times for Experiment 2: Football action items.