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CHAPTER 1

Grounding cognition in action: expertise, comprehension, and judgment ☆

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Abstract: Recent work demonstrating that both the observation and planning of actions share common neural substrates suggests that merely thinking about action may call upon motor-based neural processes. As a result, higher-level cognitive processes not directly involved with motor production, such as language comprehension or the preference judgments one makes for objects and items in their environment, may be rooted in the sensorimotor systems. In this chapter we not only explore the links between cognition and action, but ask how such cognition–action links may differ as a function of one's experience performing and seeing actions related to the language one hears or the items one is making judgments about. Together, the work presented here suggests that a complete understanding of high-level performance not only requires consideration of how cognition drives action, but vice versa — a bidirectional link between cognition and action.

Keywords: embodied cognition; expertise; judgment; comprehension

Introduction: an embodied perspective

I teach a class at the University of Chicago entitled "Cognitive psychology" and because of this I have the opportunity to examine a majority of the cognitive psychology textbooks that are available for use. Although these text books are rather variable in terms of the topics they cover, one consistency jumps out. Out of the 20 or so cognitive psychology textbooks I own, only one of them has a chapter devoted to motor learning and control. And, it is not just that these books do not devote an entire chapter to the motor system, many of these textbooks do not even mention the word motor at all. It is as if the field of cognitive psychology has — in some sense — proclaimed "Who needs the body in the study of cognition?"

The above point regarding the absence of motor-related topics in cognitive psychology is not limited to my own observations, but has been made by prominent psychologists interested in motor control issues as well (e.g., Rosenbaum, 2005). This lack of motor representation in cognitive psychology is perhaps not surprising given that traditional views of cognitive psychology characterize the mind as an abstract information processor largely divorced from the body and the environment. However, more recent theories of embodied cognition suggest that our ability to represent objects, events, and even abstract concepts (e.g., metaphor) is subserved by the sensorimotor systems we rely on to navigate throughout the world (e.g., Glenberg, 1997;

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Barsalou, 1999; Zwaan, 1999; Wilson, 2002; Gallese and Lakoff, 2005). This embodied viewpoint has roots in ecological psychology's refutation of a distinction between perception and action (Gibson, 1979/1986) and finds support across multiple levels of psychological inquiry.

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; Tettamanti et al., 2005). And, Longcamp et al. (2003, 2005) have found that presenting single English letters to experienced English speakers activated premotor areas involved in writing (i.e., Exner's area) — even though there is no intention to actually write in the perceiver. Moreover, sensibility judgments of sentences such as ''Can you squeeze a tomato?'' are facilitated when individuals are primed with a sentence-associated hand shape (a clenched hand) relative to an inconsistent hand shape (a pointed finger; Klatzky et al., 1989). Thus, rather than our representations of the objects and events we hear, see, or read about being limited to amodal or propositional code arbitrarily related to the concepts they represent (Pylyshyn, 1986), our representations appear to be grounded in action. In other words, our knowledge is embodied in the sense that it consists of sensorimotor information about potential interactions the objects or events we encounter may allow (Wilson, 2002).

Despite recent interest in this embodied cognition viewpoint, less work has focused on how individual differences in visual and/or motor experience (e.g., motor skill expertise) shape embodied knowledge representations. Moreover, little work has examined how embodied representations might affect the explicit choices and judgments individuals make in situations when there is no intention to act. Using both behavioral and neuroimaging techniques, my colleagues and I are currently exploring (a) how motor and visual experience in a particular domain changes language comprehension in that domain — an activity previously thought to be largely amodal in nature (Holt and Beilock, 2006; Beilock et al., 2008) — and (b) how sensorimotor experience gives rise to the automatic simulation of action possibilities associated with the stimuli one encounters which, in turn, can influence preferences and judgments for objects and events (see Beilock and Holt, 2007; Yang et al., submitted). Together, our work suggests that cognition is deeply rooted in action — irrespective of one's intention to act — and that experience operating in particular environments directly affects knowledge representations, preference judgments, and even memory. Below I describe, in more detail, some of the research we have been conducting in an attempt to support this experience-driven embodied viewpoint. Specifically, I describe work examining how activities as diverse as language comprehension and likeability judgments for the objects and items individuals encounter may be driven, at least in part, by the motor system.

Language comprehension

Sport is unlike most human activities, inspiring those who play as well as those who merely watch. For those who aspire to achieve elite performance levels, intensive practice is a must. However, whether athletic experience carries implications beyond the playing field (i.e., beyond action perception and production) is less well understood. Importantly, this issue has been an increasing topic of interest as researchers interested in how one goes about judging the performance of themselves versus others (see Chapter 2: On the relativity of athletic performance: a comparison perspective on performance judgments in sports) and researchers interested in how high-pressure situations might impact the realization of the action possibilities afforded by one's environment (see Chapter 4: Perceiving and moving in sports and other high-pressure contexts) begin to explore the bidirectional link between cognition and action.

Across diverse research areas, investigators of human performance are trying to understand the implications that athletic experience may carry for performance ''beyond the playing field'' by building on the idea that cognition not only drives action, but the other way around as well. Our work has been motivated by the assumption that there is a bidirectional link between cognition and action and we have been especially interested in looking for connections between an individual's action experiences (in terms of both watching others and performing themselves) and their ability to perform activities that, at the outset, appear to be largely amodal and abstract in nature — that is, not heavily dependent on specific sensorimotor systems. One activity that we have been especially interested in is language comprehension.

In a recent study, Beilock et al. (2008) showed that sports experience changes the neural basis of language comprehension — even when there is no intention to act based on the language one hears. As it turns out, people with different motor skill experiences not only rely on different cognitive and neural operations in overt action execution (Beilock and Carr, 2001), but also in the comprehension of action-related language. To demonstrate this, my colleagues and I asked professional and intercollegiate ice-hockey players ($n = 12$), ice-hockey fans with no ice-hockey playing experience but a significant amount of ice-hockey watching experience ($n = 8$), and hockey novices with no ice-hockey playing *or* watching experience ($n = 9$) to passively listen to sentences depicting ice-hockey action scenarios (e.g., "The hockey player finished the stride") or everyday actions scenarios (e.g., "The individual pushed the bell") during functional neuroimaging (functional magnetic resonance imaging, fMRI). Everyone then performed a comprehension task outside the fMRI scanner that gauged their understanding of the sentences they heard inside the scanner.

In this comprehension task (see Fig. 1), participants listened to the sentences describing ice-hockey actions and everyday actions that they had heard in the scanner. Following each sentence, participants were presented with a picture of a target individual who was performing an action that either matched or mismatched the action implied in the sentence. The participant's task was to judge as quickly as possible whether the target individual was mentioned in the sentence (on some trials, pictures of individuals not mentioned in the sentence were presented and the action was not part of the directed decision). If individuals comprehend the perceptual and action qualities described in the sentences they hear (Zwaan et al., 2002; Holt and Beilock, 2006), then responses should be facilitated for pictured individuals whose actions match those implied in the sentence relative to pictured individuals whose actions do not match those implied in the sentence. We termed this index of comprehension the *action-match effect*.

All participants, regardless of hockey experience were able to comprehend the everyday action scenarios (i.e., they all showed a significant action-match effect). This is not surprising given that everyone should have experience viewing and performing everyday actions. However, participants with more hockey experience (i.e., players and fans) were better hockey language comprehenders (i.e., they showed a larger action-match effect; for confirmatory results see Holt and Beilock, 2006). More interestingly, this experience-driven hockey comprehension effect was fully mediated by increased neural activity in the left dorsal premotor cortex [Talairach center-of-gravity = ($\pm$45,9,41)] that occurred while subjects initially listened to the ice-hockey scenarios during fMRI. Put another way, effective auditory comprehension of action-based language was accounted for by experience-dependent activation of the left dorsal premotor cortex, a region thought to support the selection of well-learned action plans and procedures — often in response to learned symbolic associations (Grafton et al., 1998; Wise and Murray, 2000; Schluter et al., 2001; Toni et al., 2002; Rushworth et al., 2003; O'Shea et al., 2007).

Interestingly, facilitated comprehension of hockey action sentences was not limited to our participants with significant hockey motor experience (i.e., hockey players): ice-hockey *fans* also showed increased comprehension of hockey language scenarios. This comprehension effect in fans was accompanied by activation in the left dorsal premotor cortex while listening to the hockey action scenarios that was significantly above baseline. Ice-hockey players showed a similar pattern of neural activation whereas ice-hockey novices did not. Moreover, increased dorsal premotor activation during hockey sentence comprehension was seen bilaterally for the

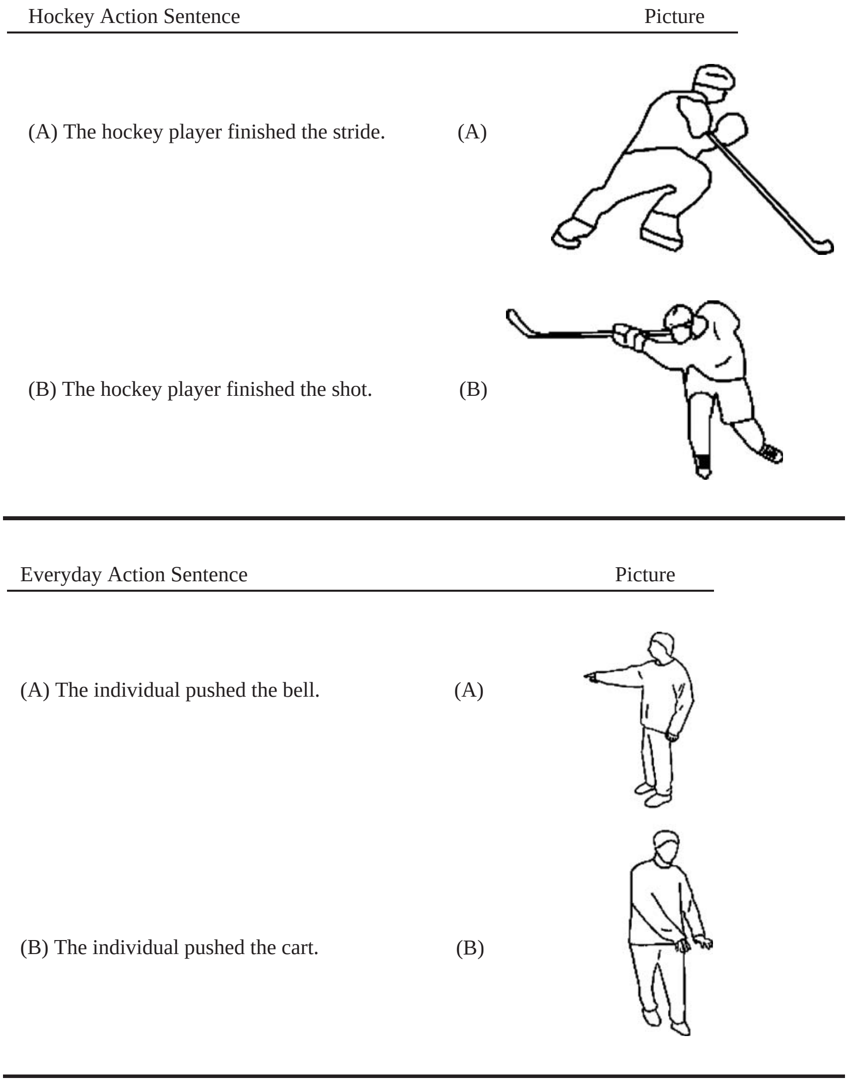

Fig. 1. Examples of the post-scan comprehension task stimuli. Picture A serves as a ‘‘match’’ for Sentence A and a ‘‘mismatch’’ for Sentence B. Picture B serves as a ‘‘match’’ for Sentence B and a ‘‘mismatch’’ for Sentence A. Adapted from Beilock et al. (2008).

fans but not players. This bilateral premotor activation may be indicative of more effortful action selection in fans versus players, which would be generally consistent with the overall longer response times seen in the fans versus players for hockey sentence comprehension. Nonetheless, it is important to point out that only activation in the left dorsal premotor cortex — and not bilateral premotor activation — mediated the impact of hockey experience on language comprehension. The fact that the left (but not right) premotor cortex was the only significant mediator of our experience-language comprehension relation is in line with the finding that the left premotor cortex plays a dominant role in higher-level action selection, regardless of the side of the body involved (Schluter et al., 2001; Haaland et al., 2004; Grafton and Hamilton, 2007).

The relation between hockey experience and hockey sentence comprehension was also fully mediated by bilateral dorsal primary sensory-motor activity [Talairach center-of-gravity = ($\pm$22,–21,53)] while listening to hockey action sentences. Just as with the left premotor region, when activity in these bilateral regions was used to predict hockey language comprehension along with hockey experience, the relation between hockey experience and comprehension was rendered nonsignificant. In this case, however, only a strong *negative* relation between bilateral primary sensory-motor activity and hockey comprehension remained. Primary sensory-motor regions are thought to be heavily involved in instantiating the specific step-by-step movements needed to carry out a novel task (Rizzolatti and Luppino, 2001; Grafton and Hamilton, 2007). Less hockey experience was associated with increased activity in bilateral primary sensory-motor regions during hockey language listening and decreased comprehension. Those without the ability to associate plans for action with linguistic cues — most likely because such actions are not a dominant part of their motor skill repertoires (novices) — instead show increased activity (vs. more experienced counterparts) in neural areas known to be involved in the instantiation of simple movements. Such activation actually hurts comprehension, possibly because it does not embody the higher-level action plans effective comprehension relies on.

In summary, the data presented above show that sports experience enhances the understanding of sports-related language even when there is no intention to act because of the recruitment of neural areas normally involved in action planning and execution (areas outside the purview of traditional language processing). Substantial prior experience viewing or performing ice-hockey actions enhances hockey language comprehension, likely by enabling individuals to associate linguistically described action scenarios with motor plans for execution. This, in turn, gives individuals the type of robust and multimodal representation that is the hallmark of optimal language comprehension.

Explicit judgments

The above findings suggest that we represent language, at least in part, via covert sensorimotor simulation of how we might execute a described behavior and that this representation may be fundamentally different depending on one's experience viewing and performing the actions described in the language in question. But, do these action-cognition links extend beyond understanding? For example, might the covert simulation of action carry implications beyond comprehension, influencing — for example — individuals' explicit judgments about the stimuli they encounter. We have explored this idea in terms of both explicit memory judgments and explicit preferences individuals have for the objects and events they encounter.

Memory judgments

Fluency, or the ease with which an item is processed, is thought to lead individuals to have a subjective feeling of remembering that can often serve as a useful heuristic in recognition. However, fluency does not always result in accurate memory judgments because it can arise independently of whether one has actually seen the item they are judging before. For example, a word such as "test" presented in a semantically predictive sentence (e.g., "the anxious student took a *test*") is more likely to be recognized as old (i.e., having been seen or studied previously) than when this same word is presented in a nonpredictive sentence (e.g., "later in the afternoon he/she took a *test*"). This is because semantic expectancy increases the *conceptual* fluency of this word (Whittlesea, 1993). Similarly, manipulating an item's visual clarity alters its *perceptual* fluency. The easier an item is to visually process, the more likely individuals will say that they have seen it before (Whittlesea et al., 1990).

In a recent series of studies, we (Yang et al., submitted) asked whether memory errors might arise from a source rather different from the semantic or visual context of a given stimulus. Specifically, we examined whether fluency effects might be tied to motor plans that are automatically activated in association with the items individuals encounter — even in situations where there is no actual intention to act.

As mentioned above, recent behavioral and neurophysiological work suggest that we represent our surroundings, at least in part, via covert motor simulation of how we might execute an observed behavior or act on the objects around us. We reasoned that if individuals covertly simulate actions associated with the items they observe, and if this gives rise to information about ease or fluency of action, then this may in turn impact memory judgments for these items. In other words, fluency might not only arise from the conceptual context in which an item is viewed or the visual qualities of the item itself, but also from the automatic activation of motor plans for action associated with the stimuli one is making memory judgments about.

To test this idea, we turned to the domain of typing. Recent work has shown that an integral part of letter processing — at least for experienced typists — is the motor simulation of typing the letters themselves. Specifically, in a Stroop-like task, Rieger (2004, 2007) found that typing experts' manual responses were faster when the finger used to indicate the color of a letter the typists were presented with was congruent with the finger typically used to type the letter using standard touch-typing conventions. Such work suggests that when typing experts perceive letters, they automatically activate motor plans for typing them. If this motor simulation carries information about how easy it would be to produce such letters, then individuals' propensity to recognize letters as previously studied items in a memory judgment task might be a function of how easy it would be to actually type the letters. This would be the case despite the fact that the individuals have no intention to type.

Skilled and novice typists studied a list of letter dyads and then took a subsequent recognition memory test. To manipulate the typing ease of the dyads, we varied whether the presented letter dyads would be typed, using standard touch-typing methods, with the same finger (e.g., FV) or different fingers (e.g., FK). The interval between typing consecutive letters using the same finger is longer than the interval between typing consecutive letters with different fingers (Viviani and Laissard, 1996). This is because typing is a parallel process in which consecutive letters are programmed simultaneously and a given finger can only be in one place at a time. Thus, letter dyads typed by the same finger should cause more motor interference or be harder to type than dyads typed with different fingers because, the latter case can be planned and performed more so in parallel than the former (Rumelhart and McClelland, 1982; Rumelhart and Norman, 1982).

If dyad recognition memory judgments are driven by motor fluency, individuals' propensity to recognize a dyad as old should be higher for those dyads that would be easier (i.e., different-finger dyads) versus harder (i.e., same-finger dyads) to type. However, this should only hold for skilled typists who have extensive typing experience and have thus formed consistent mappings between specific letters and the fingers used to type them. This is exactly what was found. Skilled typists made more *false recognition errors* (i.e., indicting they had studied a dyad when in fact they had not) for same-finger dyads in comparison to different-finger dyads.

Preference judgments

The above findings suggest that explicit memory judgments can be influenced by the motor associations individuals have with the items being judged. But, can we take this a step further? If (a) individuals mentally simulate acting on the objects they perceive in their environment, and (b) if this mental simulation of action differs as a function of skill level, and (c) if people prefer to act in ways that create less motor interference (i.e., are more fluent), then individuals should report higher ratings of *liking* for objects that are easier versus harder to act on — even though these individuals have no intention to act. In other words, the fluency associated with covertly simulating typing letter dyads may not only impact one's memory judgments, but one's preferences for one dyad over another.

To explore this idea, we (Beilock and Holt, 2007) again turned to the domain of typing. Skilled and novice typists were simultaneously presented with two separate letter dyads on a screen and asked to indicate the dyad they preferred. Specifically, participants were informed that they would see two letter dyads and that they should verbally indicate which of the two dyads they preferred, using their first impressions of the letters while avoiding choosing dyads based on their associations with any initials or abbreviations. As in the memory judgment study, the dyads 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). Each dyad pair presented to participants always involved one dyad from each category — a paradigm first introduced by Van den Bergh et al. (1990). As mentioned above, because typing is thought to involve the overlap of successive key strokes (Rumelhart and Norman, 1982), typing two letters with the same finger should result in more motor interference than typing two 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).

Results demonstrated that skilled typists preferred dyads typed with different fingers (i.e., dyads that would be easier to type) significantly more than chance (note that chance is 0.5 because half of the letter dyads that were judged involved the same finger and half different fingers). Novices showed no preference (see Fig. 2,

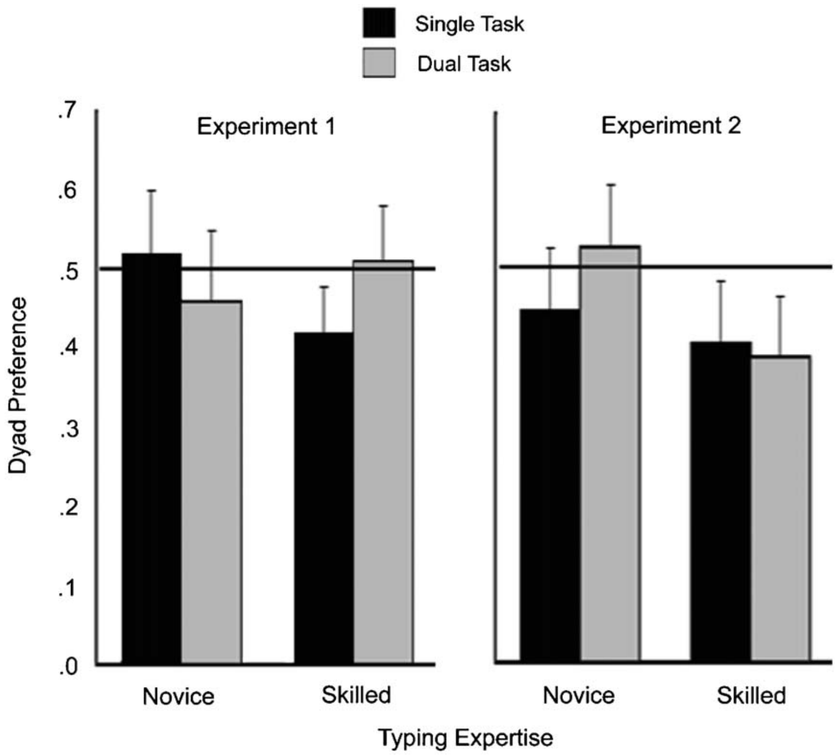

Fig. 2. Letter dyad preferences in the single-task and dual-task blocks for novice and skilled typists in Experiment 1 and Experiment 2. Dyad preference: To create a dependent variable indicating preferences for same-finger or different-finger dyads, a score was calculated such that every time a same-finger dyad was preferred, a 1 was assigned to that trial. A different-finger dyad preference received a 0. These values were summed and divided by the total number of trials in each block. Thus, a score of 0.5 indicates no preference, less than 0.5 indicates a preference for different-finger (easier to type) dyads, and greater than 0.5 indicates a preference for same-finger (harder to type) dyads. Error bars represent 95% confidence intervals. Adapted from Beilock and Holt (2007).

experiment 1, black bars). Importantly, participants were recruited for a study examining "cognitive task performance" to minimize associations with the study and typing. It was only when the study was completed that individuals were categorized as skilled or novice typists. As a result, participants were unaware of the link between the study and typing, and when asked, could not explicate how the letter dyads typed with the same versus different finger differed.

Why might skilled typists show the letter dyad preference that novices do not? If typing experience results in the association between specific letters and the motor programs used to type them, and perceiving letters automatically activates these motor plans (Rieger, 2004; see also Prinz's common coding theory, 1997), then such covert simulation of typing should provide information about the relative interference involved in acting on the letters one is presented with. And, if individuals prefer to act in ways that reduce interference, one should prefer letter dyads that, if acted on, would result in the least amount of motor interference.

To explicitly test these claims, while making their preference judgments on some trials, participants held a finger press pattern in memory that involved the same fingers that would be used to type the presented dyads. If holding this pattern utilizes motor system resources that could otherwise be used to inform typists' preference judgments, such preferences should disappear — exactly what occurred (see Fig. 2, experiment 1, gray bars). 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 (see Fig. 2, experiment 2, gray bars — note black bars replicate experiment 1's single-task effect). Thus, covert mental simulation of acting on the information one is presented with not only impacts preference judgments, but this influence is limited to information motorically resonant with the specific effectors involved in the simulated action.

Conclusions

In conclusion, the embodied viewpoint finds support across multiple levels of psychological inquiry from behavioral studies of memory 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. Our work demonstrates that one's experience on the playing field, ice rink, or even computer keyboard fundamentally changes the extent to which (and how) cognition is grounded in action.

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