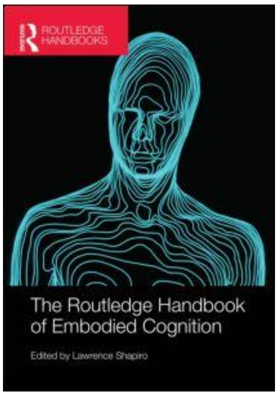

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MEMORY AND ACTION

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Introduction

Traditional theories viewed memory as the "great storehouse of information." Since the late 1960s, researchers have begun thinking of information as stored in the form of semantic networks. The general idea was that concepts were stored in nodes and that the links between nodes indicated an association between the concepts. Several decades later, it became clear that there is a fundamental problem with this view. The problem is that the concepts are merely labels in the network, for example the label "whale" or "tree." The network is merely a connection of linked labels. The labels have no meaning to the network; they only have meaning to the user. As Harnad (1990) put it, the network is parasitic on us. He dubbed this the *grounding problem*. The grounding problem suggests that semantic networks as just described cannot be a model of human memory.

A great deal of research since the publication of Harnad's influential paper has tried to solve the grounding problem. Mental representations need to be grounded in perception and action; they cannot be a free-floating system of symbols. A research tradition has emerged that tries to investigate how cognition is grounded in perception and action. Sometimes this research tradition is called "embodied cognition" but others, like the authors of this chapter, prefer the term "grounded cognition."

The first publications in this emerging field addressed the question of how language processing is grounded in action and perception (Glenberg and Kaschak, 2002; Tucker and Ellis, 1998; Zwaan, Stanfield, and Yaxley, 2002). These studies suggested that there are interactions between language and perception and action. Over the years, convergent evidence on these mutual interactions of action and perception with cognitive processes have given rise to a promising line of research that explored ways in which different domains of cognition are grounded in various action and perception patterns (Barsalou, Simmons, Barbey, and Wilson, 2003; Borghi and Cimatti, 2010; Price, Peterson, and Harmon-Jones, 2012).

Theoretical discussions on the groundedness of cognition were initially of a general nature. They dealt with the intricate relations between body and brain (Damasio, 1994), perceptual symbol systems (Barsalou, 1999; Barsalou *et al.*, 2003), views on embodied cognition (Glenberg, 1997; Wilson, 2002) and simulation (Gallese, 2003). What they have in common is a disagreement with the traditional view of cognition that is burdened with the grounding problem

(Fodor, 1975, 1983). They also share a focus on the central role of the body in shaping the mind (Wilson, 2002).

This chapter will review embodied cognition perspectives and examples of empirical research within the context of a memory and action domain. Relevant insights on memory systems, the role of the body in cognitive processes, and neural substrates will be discussed here. This is followed by a more in-depth discussion of empirical research that relates to the memory and action theme with a focus on different motor domains, memory systems, and tasks involved. Expertise is addressed as a special form of action-cognition interaction and relates to memory-bias issues that are the result of motor fluency. The chapter continues with an exploration of new directions in memory and action research in the psychology of economics, law and collective remembering, and concludes with the evaluation of boundary issues and limitations of the embodied cognition approach that have been brought up recently (Mahon and Caramazza, 2008).

Theoretical perspectives on memory and action

Various perspectives on grounded cognition (Barsalou, 1999; Glenberg, 1997; Wilson, 2002), episodic memory (Rubin, 2006), and the neural architecture underlying recall and recognition (Damasio, 1989, 1994) converge on the idea that memory processes have specific neural underpinnings. Rubin considers episodic memory to be a collection of interacting basic systems, including vision, emotion, language, search and retrieval, explicit memory, narrative and motor systems in which each basic system has its own neural substrate (Rubin, 2006). For example, the search and retrieval system has its neural substrate in the frontal lobes, whereas explicit memory systems are based in the medial temporal lobe. The hippocampus and surrounding structures are relevant for binding aspects of a memory (Squire, Stark, and Clark, 2004). This notion of a neural basis of the basic systems is supported by research showing activation of different brain areas in the time course of retrieving an autobiographical memory (Daselaar *et al.*, 2005). At the start of the retrieval process, activation of areas associated with explicit memory and search and retrieval (hippocampus and prefrontal cortex) increases, whereas activity in the visual cortex reflects the re-experience or maintenance of an event once it is retrieved. This corresponds to increases in amygdala activation and higher subjective ratings of reliving the event during the retrieval process. The notion of interacting brain systems underlying memory retrieval and of memories being distributed across brain systems is a way of conceptualizing the grounding of cognition. In other words, the experience of an event and the reconstruction of an event when it is being retrieved occurs in a similar way and with the same brain activation and same systems involved as during the original experience. This is consistent with Damasio's theory of the neural architecture underlying recall and recognition (1989), in which activity occurs in multiple brain areas near the sensory portals and motor output regions. Thus, instead of a single place for the integration of sensory and motor processes, multiple ones exist that are also recursive and iterative. The integration occurs in "convergence zones," zones that bind features of a sensory or motor activity into single entities and then bind entities into events or sets of events. This process of binding causes the integration of features and events at both perceptual and cognitive levels.

Components of Damasio's theory of a neural architecture underlying recall and recognition are also reflected in Barsalou's theory of grounded cognition (1999; Barsalou *et al.*, 2003). Cognition is grounded through the process of simulation. When retrieving an experience, neural states are re-enacted from action, perception and introspective systems. Perception covers the sensory modalities, the motor modality includes movement and proprioception, and introspection is a modality that is comprised of affective states, mental models, and motivation. Together, these modalities are responsible for different aspects of experience. For example, when a stimulus (a horse) is being perceived visually, neural feature detectors are active in the visual system. Conjunctive neurons that are located in an association area nearby in the brain combine these active features to store them in memory for later retrieval. When there is no more visual input, these neurons can reactivate the original set of features to a certain extent in order to make a similar visual representation of the horse that was seen before. This is considered a simulation. Simulations are rich in detail because of their multimodal nature; they do not contain only the visual (or other sensory) state when the stimulus was first perceived or the event was first experienced but also encompass the relevant motor and mental states that were part of the original experience. The result is an experience of reliving the situation during the re-enactment phase. A second idea that embodied cognition perspectives have in common is adherence to a central role of the body in cognitive processes. Applied to the memory domain, cognitive processes are a way to support appropriate action for a certain situation not by remembering what the situation is but by remembering the relevance of the action for that situation (Wilson, 2002). For example, visual memory can prime appropriate subsequent motor activity in tasks where perceiving the size and dimensions of a certain shape, such as a rectangle, aids performance on a subsequent task that requires a motor action, such as grasping an object that is the same shape or orientation as the shape observed before (Craighero, Fadiga, Umiltà, and Rizzolatti, 1996). Other types of memory are similarly embodied. Verbal rehearsal and counting on one's fingers are action patterns to facilitate short-term memory. Episodic memory retrieval, such as describing yesterday's party, is related to the body because relevant sensorimotor aspects of the event are reconstructed along with details of what the party was about (Bietti, 2012). Implicit memory is also based on action patterns of the body because motor skills that are difficult to learn initially (such as riding a bike) become automatized with practice and can bypass the representational bottleneck that is encountered when learning new things under time pressure.

Glenberg's view on grounded cognition (1997) also focuses on the relationships between memory and action. Specifically, memory can be defined in terms of integrated sets of action patterns that are constrained by our bodies. When a new instance of an action is undertaken, for example cooking a meal on a stove, previous cooking experiences with certain foods that have been left on the stove for too long come into play. New action patterns (setting a timer while cooking) may be an adjustment of earlier ones and be incorporated into memory for these actions. Conscious recollection is therefore a form of action pattern completion that is reconstructive by nature. These action patterns are constrained by how an individual can move his body and manipulate objects in a particular environment. For example, reaching for a cup on the other side of the table requires a different kind of movement and grip than reaching for a pencil that is right in front of you. In general, grounded and embodied cognition views action preparedness to be a basic function of cognition. Memory is especially important in offline tasks where actions do not take place in the "here and now" but involve remembering action patterns and information from the past, anticipating or planning things in the future, or imagining events that may never take place. The mutual relatedness between the body and the mind, or, more specifically, between memory and action and perception, implies that manipulations of the body and movement may result in memory changes, and vice versa. Motor fluency and expertise in complex motor movements may facilitate and enhance memory performance but might also lead to memory errors when motor fluency overrules decision-making processes. In the next section, empirical support for these assumptions is reviewed.

Empirical support for memory and action

Effects of the body and action patterns on memory processes have been demonstrated in a variety of studies in different domains and for various tasks (e.g. Dijkstra, Kaschak, and Zwaan, 2007; Casasanto and Dijkstra, 2010; Seno, Kawabe, Ito, and Sunaga, 2013; Yang, Gallo, and Beilock, 2009). These studies show that manipulations to the body result in changes in memory performance, or vice versa, that manipulations in the task result in bodily changes, suggesting mutual relationships between the body and memory processes.

The effect of body position on the ease of retrieval was examined in an autobiographical memory study (Dijkstra *et al.*, 2007). Participants assumed a body position either congruent or incongruent with the original body position during a memory-retrieval event ("Tell me about a time you were at the dentist office?" – congruent: lying down on a recliner; incongruent: standing with feet wide and hands on the hips). Response times for the retrieval of the memories were calculated from the video-recording of the experimental session. Two weeks later, participants were asked which memories they remembered from the experimental session in a free recall task. The results indicated faster responses for memories that were retrieved during the experimental session in congruent compared with incongruent body positions. Moreover, participants demonstrated better free recall later of congruent than incongruent memories. Adopting a congruent body position apparently helped to reconstruct the earlier experience, which resulted in better memory access and a stronger memory trace over a long period of time. The findings suggest that memory retrieval involves an embodied simulation of the original experience that includes body position. Having relevant sensorimotor aspects from the original experience available for memory retrieval facilitates the ease and durability with which this happens. Can body movements in contrast to position have an impact on autobiographical memory retrieval as well? A study by Casasanto and Dijkstra (2010) assessed the effect of motor actions on access to and content of autobiographical memories by examining how positive and negative emotions were expressed in the context of spatial metaphors of verticality, such as cheering when our favorite soccer team wins or sitting slumped with our head in our hands when it loses. During the experiment, participants deposited marbles upward or downward from one box into another, creating a movement that was by itself unrelated to the task of retrieving memories to positive or negative prompts ("Tell me about a time you were proud/ashamed of yourself") but tapped into the association of the spatial metaphor and matching emotion: up = positive, and down = negative. In the first experiment, participants were faster recounting memories during schema-congruent (up = positive, down = negative) than schema-incongruent movements. In the second experiment, participants retrieved memories to valence-neutral prompts while making the same upward or downward movements with the marbles. After recounting the memories, they evaluated the memories as either positive or negative, based on their emotional content. The results indicated that participants evaluated the memories more positively after they were initially retrieved during upward movements and more negatively after they were initially retrieved during downward movements with the marbles. Motor actions did not only seem to facilitate access to one's memories when these actions are congruent with the valence of the memories but they also affected the emotional content of the memory if a neutral retrieval cue was provided. These findings underscore the effect of body movement in a memory task, influencing both access and content via schematic representations of up-down and positive-negative associations. A similar association between body position and emotion content was examined in a study that looked at the activation of emotion concepts on changes in posture (Oosterwijk, Rotteveel, Fischer, and Hess, 2009). Participants generated words that were associated with positive and negative emotions, such as "pride" and "disappointment," based on the idea that this generation task should tap into the conceptual system in which associations of certain emotion concepts with action patterns are stored (pride = positive = upward position, disappointment = negative = downward position). At the same time, their posture height was measured with a hidden camera. This way, changes in posture due to the generation of pride or disappointment words could be measured. The results indicated that when participants generated disappointment words, their posture became more slumped, making their height lower than it was when they generated pride words. The results support the embodied cognition perspective that conceptual knowledge arises from action patterns and bodily states.

The link between the body and autobiographical memory retrieval has been examined in a motorically more indirect manner as well by manipulating the illusion of self-motion perception, or "vection" (Seno *et al.*, 2013). Vection occurs when someone is observing upward- or downward-moving stimuli and having the illusion of self-motion in an opposite direction to the motion of the observed stimuli. Such a manipulation provides a way to disentangle possible visual effects of motion direction (watching up-down movements) from self-motion direction effects (making up-down movements) and to address the question whether this illusion can affect the emotional valence of autobiographical memories. If visual direction motion is important, upward vection would yield the generation of memories classified as positive. However, if self-motion direction is important, upward motion vection would result in the generation of memories classified as negative because the illusion is created that one moves downward. The results supported the prediction that both actual self-motion (Casasanto and Dijkstra, 2010) and illusory self-motion (Seno *et al.*, 2013) can modulate the emotional valence of recollected memories.

These studies illustrate how body position and (illusory) body movement facilitate access to autobiographical memories and may affect the emotional content of the memory. The effects are the result of the reconstruction of relevant aspects of the initial experience by virtue of body and action patterns that facilitate the reconstruction process and by the activation of concrete experiences associated with abstract concepts for which a mapping of action patterns (up-down) with concepts (emotions) exists. According to Barsalou, this reconstruction process can be biased due to selective attention and re-enactment of only a subset of represented features (1999). For example, overlearned action patterns may hinder the ability to differentiate between patterns that were or were not observed previously. A bias in reconstruction and motor fluency may therefore have the potential to create memory errors.

Yang and colleagues examined such an effect of an overlearned ability of motor movement, "motor fluency," on later recognition (Yang *et al.*, 2009). Based on the phenomenon that an item's visual clarity can alter its perceptual fluency, the idea was that the same could happen with regard to motor fluency. If observing the letter "p" leads to a covert simulation of the action of typing the letter "p" (with the little finger on your right hand if you are a typist), then this motor simulation should cause a feeling of familiarity. The activation of action plans associated with the stimuli could then impact memory judgments, resulting in decision errors on a recognition task. In the experiment, skilled typists and novices studied a list of letter dyads that would normally be typed with the same finger (reflecting lower motor fluency because the same finger cannot be at more than one place at a time) or with different fingers (reflecting higher motor fluency). Skilled typists were expected to falsely recognize the letter that would be easier to type (have higher motor fluency). The results supported this assumption. Expert typists, who have more consistent mappings between specific letters and motor plans to type them, made more false recognition errors to different-finger letter dyads than non-fluent dyads. In contrast, typing novices did not show motor-fluency effects in recognition memory.

Recognition memory seems to be affected by the covert simulation of actions associated with the dyads being evaluated. Motor fluency as a result of expertise development can lead to a reconstruction bias and makes experts more vulnerable to false recognition. Expertise in complex motor movements can also have beneficial effects on memory, however, which has been demonstrated in other studies conducted within the embodied cognition domain.

Boschker and colleagues demonstrated benefits of expertise built up from motor fluency of complex movements in combination with affordances in the environment (Boschker, Bakker, and Michaels, 2002). They wondered whether expert climbers would perceive climbing affordances to a greater extent than structural features of a climbing wall and remember climbing routes of wall elements better than less-experienced climbers. A climbing wall offers affordances for climbing if a hold affords grasping and is not too far away from another hold in order to afford reaching by hand or foot. Experts were expected to remember climbing routes as possible action movements based on their earlier climbing experiences and recollect this route in a way that reflects these affordances. This was exactly what was found. Expert climbers also directed their attention to the important aspects of the climbing wall more than less-experienced climbers. Differences in skill level thus coincided with corresponding differences in visual perception and memory. Experts' superior climbing experience would therefore, not only help them climb faster and more efficiently, but also enhance their memory performance on climbing-related tasks.

Benefits of expertise for complex movements was also demonstrated in expert dancers. Calvo-Merino and colleagues (Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard, 2005) speculated that the human mirror system might be sensitive to the degree of correspondence between the observed action and motor capability of the observer. They accordingly assessed whether expertise in performing dance movements that belonged to their action repertoire would yield a difference in brain activity compared with dance movements that did not belong to their action repertoire. During the experiment, expert ballet and capoeira dancers watched the same videos of ballet and capoeira movements while in an fMRI scanner. They had motor experience with one set of movements but not the other. The results indicated stronger BOLD (blood-oxygenation-level-dependent) responses in mirror areas of the brain when they observed dance movements from their own motor repertoire than when observing kinematically comparable dance movements they could not perform themselves. Thus, as expected, participants responded according to their own motor expertise. The mirror system in the brain, typically active when observing others, does not seem to respond simply to visual kinematics of body movement but transforms visual inputs into the specific motor capabilities of the observer. This supports simulation theories in which action perception involves covert motor activity.

The studies discussed above support the "memory is for action/action is for memory" assumption deriving from the embodied cognition perspective. Action patterns in these studies were relevant for a certain situation, activated existing mappings between abstract concepts and concrete experiences, and evolved to complex, automatic patterns with specific neural underpinnings among experts. Access to and retention of memories can be facilitated, and memory content can be affected, when appropriate action patterns are executed that facilitate the reconstruction process of a previously experienced event. Under certain circumstances, cognitive bias may occur when motor fluency overrules the decision process, but action expertise with complex movements also produces brain activation of related areas and recall of relevant information in the environment. Overall, these research findings are consistent with the thesis that memory is embodied in the sense that it interacts with action systems and shares a common neural basis with action.

Other approaches

Our focus in this discussion so far has been on the relationship between memory and the motor system. Presenting all of the existing research in this domain exceeds the purpose of this chapter. Many other studies have supported the neural basis of cognitive processes and relationships between memory and action in other memory domains (Crawford, 2009; McNorgan, 2012). Our focus has been on the motor system but many other studies have been conducted focusing on other modalities. A study on the role of body scaling in memory when action is not immediate (Twedt, Crawford, and Proffitt, 2012) showed that participants were most accurate in judging target height from memory when it was closest to their own height. Davoli and colleagues conducted a study on the role of the body within the visual memory domain (Davoli, Brockmole, and Witt, 2012). They tested the adaptivity of changes in cognitive processing of direct and remote interactions. Participants judged and remembered the distance of a target 30 meters away to be closer when they illuminated the target with a laser pointer than when they pointed at it with a baton. Previous interactions with these tools resulted in a distorted perception of how far away the object was (Davoli *et al.*, 2012). A new trend in embodied cognition research is to examine the groundedness of cognition in action and perception from an interdisciplinary perspective. Embodied perspectives have informed investigations in clinical psychology and in the psychology of law, discourse processes and collective remembering. In each case, researchers pursue novel combinations of current themes involving contributions of action and perception patterns in cognitive processing. Several applications of embodied cognition in different disciplines were proposed by Davis and colleagues (2012). One possible application of embodiment in the legal system involves study of the interactions between the body and cognitive processes in legal contexts as they may affect the outcome of judges' and jurors' decision making. Such studies examined the relationship between hand-washing (a form of physical purity) and moral purity (Schnall, Benton, and Harvey, 2008), and the potential bias of eyewitnesses as a result of (suggestive) gestures (Broaders and Goldin-Meadow, 2010). Other possible applications of embodiment in relatively unexplored fields extend an embodied approach to reading, art perception and music cognition (Davis *et al.*, 2012; Naveda and Leman, 2010).

A more theoretical interdisciplinary approach to embodied cognition has been articulated by Bietti (2012) who makes a case for the interdependencies of cognition and embodied discourse practices in the process of collective remembering. Cognitive, embodied, discursive and pragmatic processes all contribute to the reconstruction and communication of memories in social environments through intricate interactions that develop from the construction of situation models when processing information. Situation models integrate information from different modalities and provide memory traces in episodic memory that may be updated when new situation models are created. Conversations allow for a reconstruction of individual and shared memories and a natural means to communicate them. Eye gaze and body posture may support a conversational alignment of the communication partners by expressing interest (leaning toward the other) or disinterest (leaning away from the other) in what the communication partner conveys. New interdisciplinary approaches in embodied cognition can be entirely different as well. A clinical application was conducted by Marangolo and colleagues (Marangolo, Cipollari, Fiori, Razzano, and Caltagirone, 2012), who included patients with aphasia in a study on the role of action observation treatment on verb recovery. These patients had a selective deficit in verb retrieval and participated in a training program that included observation of action video clips after which they had to indicate the appropriate verb with the clip. The training worked for the video clips of human actions (eating) but not for non-human actions (barking). Because the human action verbs are grounded with sensorimotor features, and are part of the motor repertoire of the person observing them, performing and observing the action interacts with the semantic system and therefore enhances the activation of the corresponding representation and the retrieval of the relevant verb.

These approaches explore new ways and domains of investigating embodiment by looking beyond potential barriers of the embodied cognition view. The interdependencies between action, perception and cognition are well known by now within the field of cognitive psychology. This is not yet true in clinical or legal psychology or in the arts, despite the possibility that embodied approaches could fuel a promising line of research to reveal other ways in which the body affects cognition and perception. A different development within the current theoretical debate regarding embodied cognition goes in the opposite direction, revealing a need to define the boundaries and limitations of the embodied cognition approach and to develop alternative explanations for the available evidence.

One alternative view postulates that actual cognitive processing is performed by abstract amodal symbolic systems and that activation cascades down into sensorimotor systems (Mahon and Caramazza, 2008). Thus, this *interactive view* takes an intermediary position between the traditional "disembodied" view and the grounded view. It will be a major challenge to distinguish empirically between the interactive and the grounded view because the two views make very similar predictions. Another major challenge is to develop a convincing account of how abstract information is processed. Barsalou and Wiemer-Hastings (2005) provide an interesting start. In their view, abstract concepts are not fundamentally different from concrete ones. They are both mental representations of situations. In the case of concrete concepts, the representation has a focal entity (the object), whereas the focus is more diffuse in the case of abstract concepts. However, the focus becomes clear once the concept is situated. For example, a concrete concept like BRIDGE has a focal entity that is in a situation (e.g. it is situated across an expanse of water), whereas an abstract concept like DEMOCRACY does not have a focal entity, although one can be constructed in a specific instantiation of the concept (e.g. a voting booth). As yet, there is not a great deal of evidence that speaks to this view.

In conclusion, although the grounded view of memory has received a considerable amount of empirical support, the extant empirical evidence is limited in that it pertains mostly to concrete concepts. In addition, alternative accounts have emerged that are a hybrid between the traditional view and the grounded view. The viability of the grounded view will depend on efforts to differentiate it empirically from other views (and vice versa) and on its ability to deal with abstract concepts, both theoretically and empirically. An interdisciplinary perspective may be the best hope to overcome current barriers to the embodied cognition view and to articulate where the interplay between memory and action ends.

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