# The Movement of Eye and Hand as a Window into Language and Cognition

Michael Spivey
Dept. of Psychology, Cornell University, Ithaca, NY 14853
email: spivey@oconell.edu

Daniel Richardson
Dept. of Psychology, UC Santa Cruz, Santa Cruz, CA 95064
email: dcr@ucsc.edu

Rick Dale
Dept. of Psychology, Cornell University, Ithaca, NY 14853
email: rad28@cornell.edu

Abstract

We review a variety of new results indicating that actual motor movements (not just mental representations of them) are also intimate components of linguistic and cognitive processes. Everywhere from spoken word recognition to sentence comprehension to visual memory to problem solving to video games to everyday conversation, motor movements often appear to be the very stuff of which cognitive operations are made. Rather than treating language and cognition as modular systems that are independent of perception and action, this dynamic embodied view of mental activity treats them as contiguous with the rest of the brain and body.

> "Man has no Body distinct from his Soul,
> for that called Body is a portion of the Soul …"
> -William Blake (1790)

**Introduction**

As William Blake suggested so long ago, "the soul" -- or in today's terminology, "the mind" -- does indeed appear to be inextricable from the body.  For example, research on the embodiment of cognition has been accumulating considerable evidence that cognitive processes routinely depend on "perceptual simulations" (e.g., Barsalou, 1999a; Richardson, Spivey, Barsalou, & McRae, 2003; Pecher & Zwaan, 2005; Zwaan, Stanfield, & Yaxley, 2002).  Interestingly, decades of experimental research in the ecological psychology tradition (e.g., Gibson, 1979; Tucker & Ellis, 1998; Turvey & Carello, 1981) and in the ideomotor framework (Greenwald, 1970; Sebanz, Knoblich, & Prinz, 2003) have shown that the senses themselves are inextricable from motor processing.  Therefore, if cognition is entangled with the senses, and the senses are entangled with motor processing, perhaps we should not be surprised to observe the mind itself inextricable from action.

Having a body plays an undeniable role in how perception and cognition function. Some have even suggested that perception and cognition could not carry out "normal processing" with out a functioning body (Noë, 2005).  This could perhaps be a slightly overzealous way of putting it, as it might unrealistically suggest that a man who is paralyzed has lost his intelligence (cf. Pylyshyn, 1974; see also Edelman, 2006).

Nonetheless, irrespective of what might be defined as "normal processing," differently-abled bodies, and thus differently-trained motor cortices, are likely to have significantly different perceptual-motor routines, and therefore different "perceptual simulations," and therefore at least subtly different cognitive processes. Imagine a very tall person who is accustomed to having to duck through doorways. Such a person surely has slightly different perception-action cycles for indoor navigation compared to people of average height, and perhaps this alters the way he distributes his visual attention as he locomotes, as well as his conceptualization of 3-D spatial layout and his use of affordances in the environment (cf. Warren & Whang, 1987; see also Bhalla & Proffitt, 1999).

The role of action in real-time cognitive processing is considerably more prominent than is generally assumed in the mainstream of the cognitive sciences. In this chapter, we review a variety of studies demonstrating the influence of a person's own movements (and potential movements) in perceptual and cognitive performance. We then focus on eye movements and reaching movements as particularly informative measures of real-time processing. Not only do eye and hand movements function as convenient *indicators* of continuous cognitive processes (for the experimenter), they can also function as *manipulators* of those very same cognitive processes (for the subject). That is, where you look and what you touch can influence how you think. Finally, this chapter concludes with a discussion of studies that examine the cognitive processes of two people engaged in coordinated actions. If two people's coordinated actions are describable as "joint action," and action is fundamental to cognition, does this suggest that they temporarily share, to some degree, a "joint cognition?"

**Thinking and moving**

A great number of studies have shown that cognitive processes rely heavily on perceptual and motor mechanisms. From imagination relying on perceptual systems to visual recognition relying on motor systems, the literature is replete with examples of cognition not being anything like the suite of encapsulated computational modules that traditional cognitive psychology once promised. Rather than being a separate stage of information processing that takes place on its own in between perception and action, cognition appears instead to be composed of complex dynamic mixtures of anticipated percepts and prepared actions, i.e., perceptual-motor simulations.

A familiar notion in cognitive psychology is that although visual imagery occurs in the absence of any sensory input, it is closely related to sensory mechanisms (Kosslyn, Behrmann, & Jeannerod, 1995; Kosslyn & Ochsner, 1994; Mellet et al., 2000). Similarly, there is evidence that motor imagery engages the same systems that control action in the world (Jeannerod, 1994). These motor systems also appear to influence how we perceive and interpret stimuli. Moreover, motor activity has a close, productive relationship to certain types of cognitive activity, such as groping for a word (Krauss, 1998) or turning something over in one's mind (de'Sperati, 2003).

For example, our tacit knowledge of physical constraints on our own limb movement influences how we perceive biological motion. When we trace a wide circle with our hand, the velocity changes as a result of the constraints of arm motion. Observers watching a moving dot will judge velocity to be constant when it is actually changing velocity in a pattern of biomechanical motion (Cohen, 1964). Viviani, Baud-Bovy and Redolfi (1997) found that similar visual illusions hold for kinematic perception

when subjects' hands are moved by a robot arm. Similarly, Babcock and Freyd (1988) found that subjects can recover information about the dynamics of the movement production from the perception of static handwritten forms. Tse and Cavanagh (2000) showed subjects animations of Chinese characters being produced stroke by stroke. Although a whole line appeared at once, subjects perceived apparent motion: each appeared as a line drawn from one point to another. Interestingly, subjects raised in China perceived the direction of the stroke in accordance with how they would draw the figure, whereas non-Chinese subjects, driven only by bottom-up cues, perceived apparent motion in the opposite direction.

Human observers are easily able to detect human forms in a dynamic point light display (Johansson, 1973), and even pick up gender and recognize friends (Cutting & Kozlowski, 1977). This perceptual ability employs motor control systems: we recognize biological motion via our own ability to produce it. For example, Shiffrar and Freyd (1993) looked at the apparent motion of limbs that was induced by two static photographs of human forms in slightly different postures. Usually, apparent motion is perceived along the shortest path between two locations. At rapid rates of presentation then, subjects reported seeing a limb move from behind the back to in front of the chest, along a path that went through the body. However, as the delay between the images increased, subjects perceived motion along a biologically plausible path, around the body, as constrained by the natural movements of joints. Moreover, it has been shown that exactly at the presentation rate where subjects switch from seeing the shortest path through the body to the biologically plausible motion around the body, motor cortex becomes activated (Stevens, Fonlupt, Shiffrar, & Decety, 2000). In this way, motor areas

controlling our own bodies are involved in a specifically biological interpretation of visual input (cf. Knoblich, Thornton, Grosjean, & Shiffrar, 2005)

In fact, subtle deviations in sensory-motor experience can influence our perception of others (cf. Hamilton, Wolpert, & Frith, 2004). For example, when ballet dancers watch other ballet dancers, or when capoeira dancers watch other capoeira dancers, they exhibit activation in the premotor cortex and related areas (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). Thus, while simply watching the dancers, they seem to be generating their own motor simulations of the movements being carried out. However, when ballet dancers watch capoeira, or when capoeira dancers watch ballet, this mirror system is not active. And this is not due solely to amount of visual exposure. Female ballet dancers, who are of course visually exposed to a great deal of male ballet movements, but do not include many of them in their own movement repertoire, also *do not* show activation of premotor cortex when watching male ballet dancers.

We use motor systems not just to perceive the actions of others, but also to make predictions regarding perceptual events. Knoblich and Flach (2001) had participants throw darts at a dartboard, and later showed them video clips of themselves and others throwing these darts (from a side-view perspective). Without being allowed to see the trajectory of the dart itself, only the dynamics of the arm movement (and in some conditions the body as well), participants were asked to predict whether each thrown dart would land in the upper third, middle, or lower third of the dartboard. Participants were reliably better at making these predictions when they were watching video clips of themselves than when they were watching video clips of others. Thus, even though these

participants had never before watched themselves (from a third-person perspective) throw darts, their perceptual anticipation of action effects (such as where the dart would land) was more accurate when the observed movement had been produced by the same motor system now performing the perceptual-motor simulation.

The importance of one's own sensory-motor routines for judgments about *observed* motor movements becomes especially relevant when one considers the cases of two individuals whose somatosensory input, across the entire surface of the body (except the head), has been eliminated due to a degenerative neural disease when they were young. They are the only two such patients in the world. These gentlemen can walk, very slowly and carefully, purely due to the fact that they can *watch* when each foot lands and looks stable, and then can command the next leg to step and find stable footing. They get no tactile or proprioceptive feedback from their limbs as to whether the foot is evenly supported, or whether the weight that is being put on it is evenly balanced, or whether their fingers have adequately grasped a drinking glass before lifting it. They must rely entirely on visual feedback to tell them these things. Here are two persons whose somatosensory-motor feedback loops have been inactive for many years. Does this significant limitation in their degree of embodiment impair their ability to make cognitive judgments (or construct perceptual simulations) regarding someone else interacting physically with their environment?

Bosbach, Cole, Prinz, and Knoblich (2005) gave these two patients the task of watching an actor lift a box and judging whether the box is heavy or light depending on the actor's posture and limb dynamics. For this simple task, these two de-afferented patients did as well as non-impaired control participants. But what about when the actor

occasionally lifted the box in a manner suggesting that he had been deceived as to the weight of the box?  Are the postural and limb dynamics in such a case readily perceivable by an observer?  Though control participants were quite good at this task, the two de-afferented patients performed far worse.  This result suggests that one's own perceptual-motor routines play a significant role in cognitively simulating the mental state of someone else interacting with their environment.

By mentally simulating our physical interactions with objects, motor systems take part in representing and reasoning about those objects.  Our knowledge about objects – mugs, cars, musical instruments – is clearly rich with both perceptual and motor information.  We can produce (Klatzky, Pellegrino, McClosky, & Lederman, 1993) and recognize (Wang & Goodglass, 1992) mimes of objects with ease.  Brain imaging has revealed that this information is not only relevant to charades and actual physical interactions with objects, but that motor representations are also active when we remember or imagine objects.  Functional neuroimaging has revealed somatotopically organized activation of pre-motor cortex when humans observe object and non-object related actions (Buccino et al., 2001). During action observation, an internal replica of that action appears to be generated in premotor cortex. If that action involves any objects, additional activation is observed in posterior parietal regions, as if the observer himself were actually using that object.

Behavioral evidence also suggests that when we passively observe an object, there is latent activation of motor systems. Tucker and Ellis (1998) showed participants images of household objects (e.g. a mug), and asked them to judge whether they were presented in their usual orientation or were upside down. Responses were faster when they were

made with the hand that was on the same side as the object's affordance (e.g. the handle

of the mug).  Moreover, even the shape of a person's hand, while they manually respond

to visual images in an object categorization task, affects their response times as a function

of the graspability of that object with that hand-shape.  Tucker and Ellis (2001) had

participants categorize visual images of objects as natural or manufactured, either by

squeezing a response handle with a full-hand power grasp in one condition, or by

pinching a response manipulandum with thumb-and-forefinger precision grasp in the

other condition.  When people were responding to the natural/manufactured task with a

power grasp, larger objects (that afforded a power grasp for lifting) were categorized

more quickly.  When they were responding with a precision grasp, smaller objects (that

afforded a precision grasp for lifting) were categorized more quickly.  Thus, the cognitive

task of determining the category membership of an object was automatically recruiting

current manual grasping parameters, and being affected by their match or mismatch to the

affordances of that object.

Beyond imagined actions and thinking about objects, action representations

appear to permeate all sorts of cognitive activities. Research in social psychology shows

that the implicit activation of a stereotype can directly affect motor behavior. In a

remarkable study that has now been replicated in several different laboratories, the

concept of an elderly person was primed in participants, and they were observed leaving

the laboratory (Bargh, Chen, & Burrows, 1996). In accordance with the 'slow'

component of the elderly stereotype, participants walked away at a significantly slower

rate than those of a control group.  Here, a primed concept affected motor behavior, but

the reverse direction of influence has also been demonstrated: motor actions can affect

cognitive judgments.  Cacioppo, Priester and Berntson  (1993) instructed participants to view and evaluate various ideographs, while using their hands and forearms to pull toward themselves, or while using their hands and forearms to push away from themselves. The pulling-toward-the-self motion was hypothesized to unconsciously activate a concept of affiliation or acceptance. The pushing-away motion was hypothesized to unconsciously activate a concept of avoidance or rejection. When later reviewing the same images, these participants were instructed to rate the ideographs on a likeability scale.  The images that had been viewed during a pulling motion received significantly higher ratings than those that had been viewed during a pushing motion.  In these ways, both motor actions and cognitive processes appear to influence each other.

Such arguments are compelling for these "perceptiony" skills, such as making judgments about visual objects and events.  However, for many theorists, the prime example of a *disembodied* cognitive activity, which should be encapsulated from perceptual and motor processes, is language.  A key property of language is that it can describe things that are not present, that have never been seen or done by the speaker or listener.  And yet, in a range of linguistic tasks, we nonetheless find motor participation. Even relatively high-level linguistic and conceptual representations appear to be deeply rooted in perceptual-motor components (e.g., Barsalou, 2002; Mandler, 1992; Zwaan, Madden, Yaxley, & Aveyard, 2004).  For example, activation of motor cortex can result from just hearing an action verb (Hauk & Pulvermüller, 2004; Pulvermüller, 1999; Tettamanti et al., 2005).  Electro-muscular activity in the hands and feet themselves is modulated by reading sentences about hand and foot actions (Buccino et al., 2005). In fact, even the comprehension of a sentence about movement can be affected by the

direction of the motoric response being used. Glenberg and Kaschak (2002) had participants push or pull a lever to respond to sentences that described away-from-self or toward-self events, and they found a reliable stimulus-response compatibility effect such that participants were faster to push (than pull) the lever in response to sentences about away-from-self events and faster to pull (than push) the lever in response to sentences about toward-self events.

Actions play a role in language *learning* as well. When two-year-olds are learning new names for objects, they tend to associate objects that they've moved along a particular axis (vertically or horizontally) with objects that exhibit spatial elongation along that same axis (Smith, 2005). For example, if the toddler is told that a certain round-ish object is a "wug," and then encouraged to move the wug up and down in space, she will associate vertical extendedness to wugs. Later, the toddler is presented with two wug-like objects, one of them wider than it is tall and the other taller than it is wide, and asked, "Which one of these is a wug?" The toddler will tend to choose the tall thin object as the wug. Other toddlers, who had moved their first wug left and right in space, and are now presented with the exact same choice, tend to choose the short and wide object as the wug.

In these examples, one can see the wide-ranging ubiquity of motor representations in cognitive and perceptual tasks. Along with Wexler, Kosslyn, and Berthoz (1998), Goldstone and Barsalou (1998), and others, we suggest that these perceptual-motor effects on cognitive processes are not just accidental peripheral intrusions onto higher cognition, but instead are a crucial part of the workings of the whole cognitive system. As a result, when we measure action, we are thereby also measuring cognition. In the

sections to follow, we focus particularly on hand movements and eye movements as not only *indicators* of real-time cognitive processes but also *manipulators* of cognitive processes.

**The Eye Is Quicker Than The Hand**

In this chapter, much of our discussion will revolve around (semi-)continuous measures of eye movements and hand movements as integral components of real-time cognitive processing.  Eye movements have a long history of being used as an unusually informative measure of perceptual-cognitive processing in a wide range of tasks (cf. Richardson & Spivey, 2004). In contemporary cognitive psychology, eye-tracking has produced important experimental findings in a variety of areas, including visual search, scene perception, visual imagery, visual memory, driving, reading, spoken language processing, video games, chess, and problem solving (for reviews, see Rayner, 1998; Underwood, 2005).

Many of the disadvantages of outcome-based measures, such as reaction time and accuracy, are avoided when using eye-movement data as a measure of cognitive processing.  As eye saccadic movements naturally occur 3-4 times per second, eye-movement data provide a semi-continuous record of regions of the display that are briefly considered relevant for carrying out whatever actions are at hand.  Crucially, this record provides data *during* the course of cognitive processing, not merely as an *outcome* of the cognitive processing.  Moreover, saccades take only about 150-200 milliseconds to program once the target has been selected (Matin, Shao, & Boff, 1993; Saslow, 1967), so they are a rather early measure of cognitive processing, and they tend to be resistant to

strategic influences. Perhaps most importantly, eye movements exhibit a unique sensitivity to partially active representations that may not be detected by other experimental methods. Essentially, if one thinks of it in terms of thresholds for executing motor movement, eye movements have an exceptionally low threshold for being triggered, compared to other motor movements. Since they are extremely fast, metabolically cheap, and quickly corrected, there is little cost if the eyes fixate a region of a display that turns out to be irrelevant for the actual action that is eventually chosen. Therefore, briefly partially-active representations -- that might never elicit reaching, speaking, or even internal monolog activity, because they fade before reaching those thresholds -- can nonetheless occasionally trigger an eye movement that reveals this otherwise-undetectable momentary consideration of that region of the visual display as being potentially relevant for interpretation and/or action.

This early and quite sensitive semi-continuous measure of cognitive processing can also frequently be used in ways that do not interrupt task processing with requests for metacognitive reports or other overt responses that may alter what would otherwise be normal uninterrupted processing of the task. Thus, in addition to providing evidence for partially active representations throughout the course of an experimental trial, and not just at it its outcome, eye-tracking also allows for a certain degree of ecological validity in task performance, as the "responses" it collects are ones that naturally happen anyway.

Similarly, while moving a computer-mouse toward a to-be-clicked object on a computer screen, the mouse cursor traverses intermediate regions of space that allow the trajectory to reveal spatial attraction effects that also "naturally happen anyway." Just as the eyes may occasionally fixate a distractor object before finally landing on the target

object, computer-mouse movements will routinely curve toward a distractor object on their way toward the target object. That said, mouse movements are a less immediate measure of cognition than eye movements for several reasons.  They are initiated later than eye movements.  They are slower than eye movements.  And they are considerably more voluntary than eye movements.  Amidst these relative drawbacks, the advantage of mouse movements over eye movements is that they are *anything but* saccadic.  That is, since arm movements are often *not* ballistic, each individual movement of the mouse can reveal a graded effect of spatial attention being partially allocated to a distractor object on the screen, manifested as a trajectory that curves somewhat toward the distractor on its way to the target object.  In contrast, individual saccadic movements of the eyes can only provide a dichotomous variable of whether the distractor object attracted overt spatial attention (was fixated) or not.

Another way to describe this key advantage of computer-mouse movements is that the smooth and often nonlinear movement of the arm can be sampled at 60Hz with the mouse (faster with optical measures), and each 17 millisecond time slice carries new information about what objects in x,y space might be "attracting" the movement of the mouse cursor.  Whereas, with most eye-movement tasks, even when the eyetracker is sampling at 250 Hz or higher, the eye movement pattern usually only gives new information about what objects are "attracting" attention about 3-4 times per second, i.e., when a saccade moves the eyes to a new fixation (but cf. Theeuwes, Olivers & Chizk, 2005; Doyle &Walker, 2001, for very subtle curvatures of saccadic eye movements). Importantly, the commensurate strengths and weaknesses of eye-tracking and mouse-tracking are certainly not mutually exclusive, and the interrelation of eye and hand is a

quite fertile topic of much research (e.g., Ballard, Hayhoe, & Pelz, 1995; Flanagan & Rao, 1995). To treat these two methods as adversarial would be counter-productive, since they can be easily combined as simultaneous measures of real-time cognitive processing in the same task (for discussion, see Magnuson, 2005; Spivey, Grosjean, & Knoblich, 2005). Eye movements and reaching movements each provide quite special windows into the mind, often revealing continuous competition between mental representations during the course of recognizing objects, words, scenes, and sentences.

**Hands and Eyes as Real-Time Indicators of Cognition**

A number of studies have examined the temporal dynamics of hand movements and eye movements to provide a semi-continuous record of where in space overt visual attention has been applied over the course of one or two seconds surrounding the response to a stimulus. Substantially more informative than a reaction time collected solely at the onset of a response, these temporally drawn-out measures of oculometrics and manual kinematics can reveal aspects of cognitive processing that take place both before and after the point in time at which a reaction time is collected.

For example, Abrams and Balota (1991) reported a study in which they gave participants a lexical decision task (i.e., "is this a word or a non-word?") and had them respond with a leftward movement of a slidebar for "non-word" responses, and with a rightward movement for "word" responses. (Half of the subjects had the reverse regime.) Higher frequency words elicited not only faster initiation of the rightward movement, but also greater force and acceleration of the sliding movement (see also Angel, 1973, and Mattes, Ulrich, and Miller, 1997, for related results). Thus, they argued that the

kinematics of an entire response movement, not just the latency of its initiation (as with reaction times), can provide rich information about real-time cognitive processes.

In addition to studying the kinematics over time of a single movement, competition between multiple response options can also be informative. Coles, Gratton, Bashore, Eriksen, and Donchin (1985) gave participants two response handles (dynamometers) that recorded the force and timing of the squeeze performed on them. The left handle was used for responding to one type of target stimulus and the right handle was for responding to another type of target stimulus. On some trials, the target stimulus for the left handle was surrounded by irrelevant stimuli that actually corresponded to a right-handle response. On these trials, the onset of the left-handle response was delayed, not surprisingly. However, there was also a significant graded increase in force applied to the *right handle*, when compared to non-competition control trials. That is, the response competition typically purported to take place in those kinds of trials was not resolved in a cognitive stage which then issued a single lateralized movement command to the motor system. Rather, the two possible responses (squeezing the left handle and squeezing the right handle) were both partially active and competing, as indicated by bilateral activation in motor areas of the brain (from their converging electroencephalography evidence), as indicated by electrical activity in the muscles of both arms (from their converging electromyography evidence), and as indicated by the actual force that was physically applied to the handles themselves. Findings like these have sparked a long-standing debate over whether activation from perceptual and cognitive representations continuously flows into response selection and motor execution processes or whether such activation is transmitted in completed packets from isolated

stage to isolated stage (e.g., Balota & Abrams, 1995; McClelland, 1979; Meyer, Osman, Irwin, & Yantis, 1988; Miller, 1988; Ratcliff, 1988; see also Gold & Shadlen, 2001).

Another way to track the real-time flow of sensory input all the way through to motor output is to record the trajectory of natural reaching movements. Goodale, Pélisson, and Prablanc (1986) instructed participants to reach for a target object and made it shift location while the arm was in motion. Even when the participant could not see their arm, and even when they claimed not to have consciously perceived the target object shifting its location, the arm smoothly adjusted its trajectory mid-flight in order to arrive at the target's new location. Tipper, Howard, and Jackson (1997) extended this experimental design to cases where distractor objects were present in addition to the target object. They observed that, under various circumstances, the distractor object could either attract the movement path toward itself or repel the movement path away from itself.

This graded spatial attraction of the movement path toward distractor objects becomes particularly useful under conditions where a temporarily ambiguous stimulus could potentially be mapped onto either the target or distractor objects. For example, when a virtual reaching movement, via a computer-mouse, is directed toward a target object, distractor objects with similar features can exert a kind of "pull" of the movement toward themselves. Spivey, Grosjean, and Knoblich (2005) presented pictures of objects on a computer screen and gave participants pre-recorded spoken instructions such as "Click the carriage," and "Click the tower." With the mouse cursor starting at the bottom center of the screen, and the objects displayed in the upper left and right corners, participants generally moved the mouse upward and curving leftward or rightward.

Interestingly, when the distractor object's name shared phonetic features with the target object's name (e.g., a carrot opposite the carriage, or a towel opposite the tower), the mouse-movement trajectory tended to be conspicuously curved. When the distractor object's name did not share phonetic features with the target object's name (e.g., a raccoon opposite the carriage, or a crayon opposite the tower), there was significantly less curvature in the mouse-movement trajectory.

-------------------------

Figure 1 about here

-------------------------

Figure 1A shows raw data from an individual trial, where a participant was instructed to "Click the carriage," and the mouse-movement trajectory gravitated somewhat toward the carrot on its way to landing on the carriage.  Figure 1B shows raw data from a different trial with a different participant, but the same instruction, and the mouse-movement trajectory showed essentially no spatial attraction toward the raccoon on its way to landing on the carriage. (Related findings with saccadic eye movements were reported by Allopenna, Magnuson, & Tanenhaus, 1998, and by Spivey-Knowlton, Tanenhaus, Eberhard, & Sedivy, 1998.)

This graded spatial attraction toward a competitor object is also visible with semantic categorization tasks.  Dale, Kehoe and Spivey (in press) presented taxonomic classes as the response options at the top of the screen, such as MAMMAL and FISH, and presented the picture of an animal at the bottom of the screen (where the mouse cursor started).  When the animal was a typical member of its category, such as a horse, the computer-mouse trajectory was relatively direct to the correct category.  In contrast,

when the animal was an atypical member of its category, such as a whale, the trajectory

was significantly more curved in the direction of the competing category (which shared

several perceptual features with the animal).  Even the very first timestep of the mouse

trajectory showed significantly different angles of movement for the typical and atypical

animals, indicating that the degree of feature-match with the competing category was

affecting the earliest portion of the movement.  These results share much in common with

attractor-network simulations that treat categorization as a temporally dynamic process in

which the presentation of an exemplar initiates a trajectory through a high-dimensional

state space that eventually settles into an attractor basin (McRae, 2004; Spivey & Dale,

2004).  Thus, performance in this mouse-movement task can be thought of projecting that

high-dimensional mental space onto the two-dimensional action space of the computer

screen to provide a data visualization of the trajectory in question.

In contrast to the slow curving trajectories of hand movements, most cognitive

studies of eye movements examine fast ballistic saccades (but cf. Krauzlis & Adler, 2001,

for cognitive influences on smooth pursuit eye movements).  Nonetheless, even saccades

can, under certain circumstances, exhibit a blending of two competing movement

commands.  For example, Gold and Shadlen (2000) showed that an voluntary saccade

based on a perceptual decision can blend with an involuntary saccade elicited by

microstimulation to produce an intermediate direction of saccade. First, they had also

inserted a microelectrode into the monkey's frontal eye fields, a brain area in frontal

cortex that controls saccadic eye movements, and found a region where microstimulation

of those neurons would elicit an involuntary saccade in an upward direction.  Then, they

presented displays of randomly moving dots to the monkey, which had been trained to

detect small portions of coherent unidirectional (leftward or rightward) motion amidst the randomly moving dots, and to respond with a voluntary saccade to a left-side or right-side response target. When only a small proportion of the dots exhibited coherent motion, the monkey would take considerable viewing time to accumulate this partial information before producing his voluntary response saccade. If the involuntary microstimulated saccade was elicited early on during this period, the resulting eye movement would be almost perfectly upward (consistent with the involuntary saccade direction). However, across numerous trials, as the involuntary microstimulated saccade was elicited later and later during that period of accumulation of perceptual information, the direction of the voluntary response saccade was more and more evident in the resulting elicited saccade. That is, with longer and longer delays between the onset of a barely-leftward-moving random dot display and elicitation of the involuntary saccade, the microstimulation would produce a saccade that was less and less upward and more and more a combination of upward and leftward. Essentially, as time went by, the gradually emerging perceptual decision was coextensive with the gradually emerging voluntary saccade, and this partially-active motor signal would "leak into" the saccade resulting from the microstimulation. Thus, Gold and Shadlen (2000, 2001) argued that perceptual decisions are not discretely achieved in perceptual areas of the brain and only then shunted to motor areas who wait like dumb pencil-pushers to execute a unitary instruction without informed nuance. Rather, the gradual microevolution of a perceptual decision over hundreds of milliseconds continuously cascades into motor areas of the brain that are thus part and parcel of the decision process.

Although a saccadic eye movement to an empty region in between two competing objects is a rare event, it has been shown that fast *sequences* of saccades do correspond to the gradual unfolding of competing interpretations of a spoken sentence (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). For example, when instructed to "pick up the large red rectangle," participants often make anticipatory eye movements to a variety of large red objects in the display before the noun, "rectangle" is even spoken (Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995). This finding indicates that the incrementality of spoken language comprehension allows listeners to use adjectives to infer reference to objects in the display, even before the noun (conventionally assumed to be what performs the referencing function) is heard. Moreover, temporary mis-parsing of the structure of syntactically ambiguous sentences, often called "garden-path" effects, is also detectable in the real-time scanpath elicited by spoken instructions. For example, eye-movement patterns have demonstrated that the motor affordances availed by the set of real objects in front of the participant immediately constrain syntactic parsing processes (Chambers, Tanenhaus, & Magnuson, 2004). Consider a display like Figure 2, containing a liquid egg in a bowl, another egg in a glass, an empty bowl, and a pile of flour. Eye-movement patterns revealed that a listener initially pursues different syntactic parses of the temporarily ambiguous instruction "pour the egg in the bowl onto the flour," depending on whether the alternative egg in a glass is also in liquid form or in shell form. When the alternative egg is in liquid form (Figure 2A), listeners immediately parse "in the bowl" as discriminating which egg is being referenced, and therefore pursue the correct syntactic structure. However, when the alternative egg is in shell form (Figure 2B), and thus does not afford *pouring*, "in the bowl" is not naturally interpreted as

distinguishing which egg is being referenced.  Instead, scanpaths indicate that listeners

briefly consider "in the bowl" as denoting the goal of the pouring event, i.e., participants

briefly look at the empty bowl as though it may be where the egg is to be poured.

------------------------------------

Insert Figure 2 about here

------------------------------------

Interestingly, these kinds of eye movements in response to spoken language input

can even be informative when what's being "looked at" isn't really there.  Richardson

and Matlock (in press) presented static drawings of scenes with various kinds of paths,

roads, and fences, and played pre-recorded stories that included sentences like "The fence

is next to the coastline," and "The fence follows the coastline."  Although these two

sentences essentially convey the same information, the latter of the two carries with it an

implicit form of metaphorical movement, called fictive motion.  Richardson and Matlock

found that, while participants viewed these static scenes, fictive motion sentences

induced more eye movements along the length of the fence (or path or road) than did the

meaning-equivalent literal sentences.  In fact, when a context sentence described the

terrain as rocky or otherwise difficult to traverse, participants looked even longer at the

fence (or path or road) when the target sentence exhibited fictive motion, as if the fence's

"following" of the coastline involved movement that the eyes could actually pursue.

These results are consistent with the claim that the understanding of motion events (even

metaphorical motion) involves a mental animation of visual representations (cf. Zwaan,

Madden, Yaxley, & Aveyard, 2004; see also Hegarty, 1992; Kourtzi & Kanwisher, 2000;

Rozenblit, Spivey, & Wojslawowicz, 2002).

In fact, even when the visual display is completely blank, eye movements to different blank regions can reveal structure in the mental representations being constructed during spoken language comprehension and during memory. Participants who thought the eyetracker had been turned off during a putative "break" between experiments, listened to stories about a skyscraper and about a canyon, and naturally made eye movements on a blank wall in the (upward or downward) direction of the verbally described motion (Spivey & Geng, 2001; see also Altmann & Kamide, 2004, for related findings). And in memory tasks, people tend to treat the location in space where information was delivered as a kind of spatial marker for memory retrieval, even when that information is obviously no longer there. For example, when four talking faces deliver arbitrary facts from four corners of the display and then disappear, and then the participant is presented with a statement to verify with respect to those facts, he or she will often spontaneously look at the original location in space (now empty) that used to contain the talking face that delivered the fact in question (Richardson & Spivey, 2000; see also Richardson & Kirkham, 2004). In a sense, the spatial environment is so routinely relied upon as an external memory that indexes to locations in space are called upon, via eye movements, even when the information once held in that region is long gone.

Across these many examples of eye movements and hand movements revealing the real-time processes of cognition, the common observation that rings true throughout this section is that perceptual systems appear to continuously transmit their evolving representations to motor systems. When a partially active perceptual representation is associated with a particular motor representation, the resulting partially active motor

representation will often find a way to influence or control behavior. Thus, rather than imagining that there may be some intermediate cognitive system that functions in a stage-based manner independently of perception and action, cognition itself may be better conceived of as a set of emergent properties that result from the continuous interaction between perceptual processes and motor processes (Kelso, 1995; Port & Van Gelder, 1995; Spivey, in press).

**Hands and Eyes as Real-Time Manipulators of Cognition**

In their memory task, Richardson and Spivey (2000) did not find improved memory on trials where participants fixated the original location compared to trials where participants did not fixate the original location. However, this could have been due to participants occasionally producing the correct answer before needing to make any eye movements at all. When eye position is converted into an independent variable (instead of a dependent variable), with participants being allowed to look at the original location or being explicitly instructed to look elsewhere, looking at the original location improves memory for the now-absent information by about 20% (Laeng & Teodorescu, 2002; see also Sacks & Hollingworth, 2005). Thus, movements of the eyes to particular locations in space not only *provide a measure* of cognitive processing, they *influence* cognitive processing.

But the eyes aren't the only effectors that treat the external environment as a place where cognitive operations can take place. In the case of mental rotation tasks, Kirsh and Maglio (1994) demonstrated that expert Tetris video-game players relied far more on actual external rotations of objects on the screen (elicited by button-presses) than on

mental rotations of internal representations of those objects. Essentially, in these experts, motor cortex had learned to take up the job of overtly carrying out the rotations of objects for determining their fit into slots at the bottom of the display, as it was faster and more accurate than trusting cognitive processes to perform those rotations covertly.

In fact, there is extensive behavioral and neurological evidence that motor representations naturally assist in mental rotation tasks. Wohlschläger and Wohlschläger (1998) demonstrated that when subjects mentally rotated a 3D object, performance was better if the manual response used a rotational motor action that was in the same direction to the mental rotation. Transcranial magnetic stimulation of primary motor cortex disrupts mental rotation (Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000), neuroimaging reveals activation of motor areas when humans perform a mental rotation task (Richter et al., 2000), and gradual angular translations of neuronal population vectors in motor cortex are observed when monkeys perform mental rotation tasks (Georgopoulos, Lurito, Petrides, Schwartz,& Massey, 1989). This should not be surprising, given that there are basically two ways to find out what an object will look like at a different orientation: physically rotate the object, or mentally rotate an internal image of the object. Wexler et al (1998) contend that these two strategies are linked, that *mental* rotation is a perceptual-motor simulation of *manual* rotation.

Manual gestures during conversation are another case where hand movements not only *reveal* something about cognition (McNeill, 1992), but they *influence* the gesturer's cognitive processes. Sometimes gestures appear to be part of the communicative signal, intended to aid the listener's comprehension (for review, see Kendon, 1994). However, there are other circumstances where they appear be used to aid the speaker's own speech

production processes (Krauss, 1998). In either case, they clearly contain informational content. For example, gestures are more common when the speaker is trying to retrieve lexical items that are spatial, concrete, and imageable. In fact, electromyography measures even show greater amplitude of electro-muscular activity in the dominant arm during gestures co-occurring with the retrieval of lexical items that are more spatial and more concrete (Morsella & Krauss, 2005). It may very well be that, during a laborious lexical retrieval event, recruiting manual motor processes to act out some of the semantic properties of that not-yet-found lexical item facilitates the pattern completion process of retrieval.

This physically externalized "acting out" process is also helpful for spatial reasoning tasks. Schwartz and Black (1999) presented evidence that, in some cases, human subjects can more successfully carry out a reasoning task if they physically simulate perceptual and motor experiences, rather than "thinking it through." (Note, if the reader has not come across this particular reasoning problem before, then it might be instructive to try and solve the problem "rationally" or "mathematically" first). The question was this: There are two glasses of the same height, filled to an equal height with water. One glass is narrow, and one is wide. Which glass would have to be tilted to a greater angle for the water to pour out? It was found that most subjects gave the incorrect answer, replying that the wider glass would have to be tilted more. However, Schwartz and Black asked another group of subjects to mime holding either a narrow or a wide glass filled to a certain level, and slowly to tilt their hands, stopping when they imagined water would start pouring. It was found that subjects tilted the narrow glass to a greater

degree.  In this case then, an externalized perception-action simulation gave a more accurate judgement than cognitive reasoning did on its own.

Even *accidental* "actings out" can have fortuitous results for cognitive reasoning. Glucksberg (1964) carefully watched participants as they attempted to solve Duncker's (1945) candle problem.  With the real objects in front of them (a candle, a box of tacks, and a book of matches), participants were given the task of mounting the candle on the wall using only those objects.  Glucksberg recorded how many times they touched the cardboard box of tacks (which solves the problem by being emptied and tacked to the wall as the mounting platform itself), and found that participants who managed to come up with the correct solution happened to touch the box, well before their "Aha!" moment, more times than those who did not solve the problem.  This suggests that, before their seemingly-instantaneous insight to use the box as the solution, something inside their nervous system was paying a little extra attention to the box.  Moreover, right before that "Aha!" moment, the object that these participants had most recently touched was always the box -- and in most cases that touch had been adventitious and non-purposeful.  It is almost as if the participant's *hands* suspected that the box itself would be useful before the participant *himself* knew.

A related example of perceptual-motor subsystems partially suspecting the correct solution to an insight problem, well before the explicit language subsystems have managed to verbalize it to themselves, comes from a study by Grant and Spivey (2003).  Eye movements were recorded while participants attempted to solve a diagram-based version of Duncker's (1945) classic tumor-and-lasers radiation problem.  "Given a human being with an inoperable stomach tumor, and lasers which destroy organic tissue at sufficient intensity,

how can one cure the person with these lasers and, at the same time, avoid harming the

healthy tissue that surrounds the tumor?" A schematic diagram was provided, composed

simply of a filled oval, representing the tumor, with a circumscribing oval representing the

stomach lining (which must not be injured). Nothing else in Duncker's problem

description was depicted in the schematic diagram. As this problem is a very difficult

insight problem, only a third of the participants solved it without needing hints. Although

the eye-movement patterns were very similar for successful and unsuccessful solvers, one

difference stood out. During the 30 seconds before encountering their "Aha!' moment,

successful solvers tended to look at the stomach lining, the circumscribing oval, more than

unsuccessful solvers did (during the corresponding 30 thirty seconds just before they gave

up and requested a hint). A bit like Glucksberg's (1964) successful candle-problem solvers

idly touching the box before discovering its usefulness, Grant and Spivey's successful

solvers were making frequent eye movements inward toward the tumor and back outward

again, stopping regularly on the stomach lining, almost *sketching* the solution (of multiple

low-energy lasers converging on the tumor) with their scanpath. Thus, the eye-movement

patterns in Grant and Spivey's first experiment provided an *indicator* of the parts of the

diagram that seemed to be associated with achieving the correct solution. In a second

experiment, Grant and Spivey tested whether attracting attention (and eye movements) to

that part could *manipulate* cognition into achieving the insight necessary for solving the

problem.

In the second experiment, the schematic diagram was animated (with a single

pixel increase in diameter pulsating at 3 Hz) to subtly increase the perceptual salience of

the stomach lining, in one condition, or the tumor, in a control condition. A second

control condition had no animation at all. In the two control conditions, one third of the participants solved the problem without hints, as expected. However, in the pulsating stomach lining condition, *two thirds* of the participants solved the problem without hints. Grant and Spivey (2003) hypothesized that the increased perceptual salience of the stomach lining helped elicit patterns of eye movements and attention that were conducive to developing a *perceptual simulation* (Barsalou, 1999a) of the correct solution, involving multiple weak lasers passing harmlessly through the stomach lining at different locations and converging their energies at the tumor. Thus, a perceptual-motor process -- an eye-movement pattern characterized by saccades into and back out of the stomach region, including a conspicuous proportion of fixations of stomach lining itself -- appears to play an important role in high-level cognition.

Clearly, eye movements and hand movements are more than just convenient indicators of real-time cognition, to be used by an experimenter for measuring cognitive processes. Eye movements and hand movements are also real-time manipulators of cognition, used by the individual to perform cognitive operations on objects in the environment via the perception-action cycle (cf. Neisser, 1976). And, to be sure, these are not the only kinds of movements that can perform this "jump-starting" of cognitive processes. In fact, when people are instructed to imagine various smells, they tend to spontaneously sniff the air (though odor-free), and they do so longer when they are imagining a pleasant scent than when they are imagining an unpleasant scent (Bensafi, Pouliot, & Sobel, 2005). Apparently, *all* of our effectors can participate in cognition. The many motor actions available to us are not just the feedforward results of perceptual

and cognitive processing; sometimes perceptual and cognitive processes are the results of motor actions.

**Coupled Action**

In the previous section, we reviewed evidence that action does not just *reflect* cognitive and perceptual processes, but appears to *influence* them as well. This suggests a rich dynamic between perception-action systems on one hand and cognitive processes on the other. So far, this review has been limited to two themes. First, each direction of influence, whether from or to action, has been considered separately. Second, such influence has been considered only within an individual person. The perspective that perception, cognition, and action interact suggests an extension on each of these themes. As for the first, these interacting systems generate a closed-loop in which there is continuous interplay between them, suggesting that a rich dynamic emerges from their functioning. Numerous researchers have thus explored dynamic *coordination* between perception, cognition, and action. As for the second theme, we may depart from focusing on the individual. If perception and action are coordinated within an individual, then perhaps perceptual feedback from others in the context of one's actions can lead to coordinative dynamics between multiple individuals.

Coordination within persons has been extensively studied. Well-known research on manual action demonstrates this dynamic perception-action interplay. For example, work on bimanual coordination shows that rhythmic, stable action patterns emerge within an individual. Yaminishi, Kawato, and Suzuki (1980) showed that bimanual finger tapping tends towards in-phase patterns, where the muscles for the two index fingers are

moving in the same way at the same time. Even when the fingers start out in non-matching phases, especially if they are moved rapidly, they involuntarily transition into this stable coordinative pattern. Haken, Kelso, and Bunz (1985) famously showed that a dynamical systems model perfectly predicts this behavior by employing the notion of an attractor landscape (see Kelso, 1995, for a review). The dynamic visuo-haptic information during action produces a closed-loop system that engenders stable attractors – regions in the space of possible movement patterns that are highly stable. While the previous sections show cognition and perception flowing into action, or action influencing perception and cognition, this coordination reveals the dynamic interplay between the two systems – producing, as a consequence, stable, coordinative behavioral sequences.

Interestingly, this perception-action coordination occurs between individuals as well. Schmidt, Carello, and Turvey (1990) showed that the same dynamical description of Haken et al. (1985), predictive of within-person coordination in such stable manual action shown by Yaminishi et al. (1980), also describes coordination that emerges between the leg movements of two individuals. Two participants sat side by side and each swung one leg to the left and right. Participants viewed each other's movements, and leg movements between the individuals exhibited all the hallmark characteristics of the perception-action dynamic of within-person coordination: stable, in-phase attractors. This result reveals that the flow of perceptual information during continuous leg movement creates a coupled system *between individuals*, producing similarly coordinative behavior. Perception-action cycles therefore extend from the cognitive system of one individual to behavior in two or more cognitive systems.

It turns out that *perceiving* actions of others is not the only means by which two individuals may become a coupled perception-action system.  In fact, the ability to process *potential* actions by a task partner can come to influence one's actions.  Sebanz, Knoblich, and Prinz (2003) show that the action of one person can be influenced by perceiving an irrelevant stimulus that cues a possible action by her partner. In stimulus-compatibility experiments, they had participants respond to one color with a left button, or another color with a right button.  Participants were placed in individual or joint conditions.  When alone, participants had either a two-choice or go-nogo task, in which they responded with right and left buttons appropriately, or in the go-nogo condition, just to one of the colors. In the joint condition, with a partner, each participant would be responsible for responding to one color. An irrelevant stimulus was included with the color cues. As in other stimulus-compatibility tasks, the irrelevant stimulus could potentially impede responding: The color cue was presented as a ring on a pointing finger. This pointing finger, while having a color cue for participant A, may be directed towards participant B. This irrelevant stimulus may be processed as a potential cued action for the task partner. As evidence that participants were indeed actively processing their partner's possible actions, reaction times were significantly influenced by the incompatible finger direction. These results were similar to two-choice incompatibility effects observed *within one* participant.

How might this influence of a partner's actions come into play in a coordinative task between two people? In a study by Knoblich and Jordan (2003), individuals or pairs of participants had to actively keep a tracking stimulus on top of a moving target as the target moved back-and-forth across the computer screen. In the paired condition, one

participant controlled leftward changes in tracking velocity, and the other controlled the rightward changes. In order to perform the task well, participants would have to compensate and anticipate changes in the target's movement – e.g., the reliable prediction that the target would begin to move to the left, then stop at the edge of the display, and proceed to move across to the right, and so on. Some pairs of participants received auditory feedback about the key presses of their partners, and some did not. Pairs of participants who received feedback about the action of their partner gradually came to resemble individual participants in their ability to follow target movement with the tracking stimulus. These results reveal that environmental cues that help participants process their partner's actions permit the development of anticipatory control strategies: They were able to actively coordinate their key presses with their partner's.

These studies show that the perception-action cycle reveals very similar coordination patterns when occurring between two people as when occurring within one person. How does the individual cognitive system succeed at this cross-individual coordination? One suggestion is that we engage in perceptual-motor- simulation (Barsalou, 1999a) or prediction (Wolpert & Flanagan, 2001): When watching a motor action, we implicitly generate the action internally. As recent evidence for this, Flanagan and Johansson (2003) had participants perform or observe a sequential manual action of stacking blocks. Participants who observed the action did not passively follow the movements, but rather seemed to "simulate" the motor activity itself with anticipatory eye movements that in fact matched the eye movements of the actor. The authors suggest that the cognitive system actively predicts and simulates action, even when just observing the actions of others.

This perspective on motor simulation and prediction resonates with the recent discoveries of a mirror neuron system (Decety & Grèzes, 1999; Rizzolatti, Fadiga, Gallese, Fogassi, 1996). A subset of neurons in both nonhuman primate and human premotor cortex seems to fire *both* when performing an action and when observing others perform the same action (see Rizzolatti & Craighero, 2004, for a review). This shared mechanism for perceiving and predicting action may be an important component for coordinating one's behavior with others.

These examples of perception-action coordination across individuals in fact resonate with a wide variety of findings in even higher order cognition, such as language. Language behavior induces coupling of various processes, including eye movements (Richardson & Dale, 2005), posture (Shockley, Santana, & Fowler, 2003), and language structures (Dale & Spivey, in press; see also Bernieri & Rosenthal, 1991; Bock, 1986; Branigan, Pickering, & Cleland, 2000; Sokolov, 1993), actively coordinated in dialogue. These various processes together likely guide the complex conversational behavior we exhibit, such as maintaining common ground (Clark, 1996). Coordinative patterns in conversation can also come in seemingly irrelevant forms. For example, in social cognition research, seemingly pointless gesticulations and movements are often unknowingly adopted by task partners (see Bargh & Chartrand, 1999, for review).

These variables influencing coordination of perceptual-motor processes, from fingers wagging to legs swinging to shared syntactic structures to social cognitive influences, all may interact across multiple time scales. As a result, one becomes tempted to describe cognition not in terms of domain-specific mental operations taking place in an individual's brain, but instead in terms of domain-general interactions that

emerge between individuals during their coordinated actions. Rather than continue

searching for various "boxes in the head" (Bechtel, 1998), cognitive scientists may need

to start searching for the "shared manifold of intersubjectivity" (Gallese, 2003; see also

Spivey, Richardson, & Fitneva, 2004).


**From "Cognition *for* Action" to "Cognition *as* Action"**

From this broad array of examples, it should be abundantly clear that action plays

a fundamental role in our understanding of cognition and language. Action is no longer

seen as the lonely caboose at the end of a train of sequential modular stages, as once

assumed by the traditional information-processing approach in cognitive psychology.

Action, in its simulated, preparatory, and executed forms, is coextensive with a wide

variety of real-time cognitive processes, including visual object recognition, biological

motion perception, language comprehension, semantic categorization, and natural

conversation. As argued by ecological psychologists (e.g., Gibson, 1979; Turvey, 1992),

part of understanding a visual scene necessarily involves mapping one's potential

behaviors onto the actions afforded to your body by that environment. And as argued by

proponents of embodied cognition (Barsalou, 1999b; Glenberg & Kaschak, 2002), part of

understanding a sentence necessarily involves perceptual-motor simulations of the events

described in that sentence.

Essentially, our brains cannot help but *act out*, at least implicitly, what we are

thinking. And when those thoughts are multifarious or mixed, due to temporary

uncertainty or ambiguity, the "acting out" that manifests itself is likewise multifarious or

mixed. For example, we reach initially toward the midpoint of two competing objects

(Spivey et al., 2005), or we look at multiple objects in quick succession (Tanenhaus et al., 1995). The flow of information from cognitive processes to motor processes is sufficiently continuous and unabated that evidence for simultaneously-active and competing interpretations of perceptual input can be observed not only in the activation of motor cortex and of peripheral muscles (Coles et al., 1985), but even in the actual motor output that is executed (Dale et al., in press; Gold & Shadlen, 2000).

Given this inseparability of cognition from action, certain bodily movements in the environment can begin to be seen as performing cognitive functions themselves (Kirsh, 1995). The fluidity of the perception-action cycle allows physical manipulations of the environment, such as manually rotating a real object, to proxy for certain neural processes, such as mentally rotating the visual representation of that object. The result is a blurring of the line between body-internal cognitive processes and body-external cognitive processes, which in turn makes for a particularly interesting treatment of joint action between two coordinated agents (see Sebanz, Bekkering, & Knoblich, 2006, for a review). From your automatic anticipation of your partner's movements, coupled with the planning of your own movements, emerges a dance of concepts and actions that appears at times to no longer harbor any concern for which body they belong to.

The future of cognitive psychology is being profoundly influenced by the mountains of evidence (of which we have barely scratched the surface in this review) against the putative separation of action from cognition. In fact, just as the accumulation of evidence for the role of motivation in perceptual processing reinvigorates the "New Look" in perception (Bruner & Goodman, 1947) every couple of decades (Erdelyi, 1974; Niedenthal & Kitayama, 1994), a similar accumulation of evidence for the role of action

in cognitive processing regularly bolsters the embodied view of cognition (e.g., Barsalou, 1999a, A. Clark, 1997; Dreyfus, 1972; Lakoff & Johnson, 1980; Ryle, 1949; Steels & Brooks, 1995; Wilson, 2002). The field of cognitive psychology can no longer go about its business treating its favorite dependent measures as though they were tapping pure cognition, without any influence from the motor component in the task. Even just the act of pressing a button carries with it dynamic kinematic properties that can reveal more cognitive complexity than the mere reaction time does by itself (cf. Mattes et al., 1997). If this dynamic embodied cognition (that is also embedded in the environment and entrained with other agents by way of a continuous perception-action cycle) continues to reshape the way we view how the mind works, and even what the mind *is*, then this dramatic makeover will not only give cognitive psychology a brand "new look", it will give it a brand new body.

**References**

Abrams, R., & Balota, D. (1991).  Mental chronometry: Beyond reaction time. *Psychological Science*, *2*, 153-157.

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998).  Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models.  *Journal of Memory and Language*, *38*, 419-439.

Altmann, G., & Kamide, Y. (2004).  Now you see it, now you don't: Mediating the mapping between language and the visual world.  In J. Henderson, & F. Ferreira (Eds.), *The interface of language, vision, and action: Eye movements and the visual world*.  New York:  Psychology Press.

Angel, A. (1973). Input-output relations in simple reaction time experiments. *Quarterly Journal of Experimental Psychology, 25*, 193-200.

Babcock, M. K., & Freyd, J. J. (1988). Perception of dynamic information in static handwritten forms. *American Journal of Psychology, 101(1)*, 111-130.

Baldissera, F., Cavallari, P., Craighero, L., & Fadiga, L. (2001). Modulation of spinal excitability during observation of hand actions in humans. *European Journal of Neuroscience, 13(1)*, 190-194.

Ballard, D., Hayhoe, M., & Pelz, J. (1995).  Memory representations in natural tasks. *Journal of Cognitive Neuroscience*, *7*, 66-80.

Balota, D., & Abrams, R. (1995).  Mental chronometry:  Beyond onset latencies in the lexical decision task.  *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1289-1302.

Bargh, J.A., & Chartrand, T.L. (1999). The unbearable automaticity of being. *American Psychologist, 54*, 462-479.

Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology, 71(2)*, 230-244.

Barsalou, L. (1999a). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577-660.

Barsalou, L. (1999b). Language comprehension: Archival memory or preparation for situated action. *Discourse Processes, 28*, 61-80.

Barsalou, L. (2002). Being there conceptually: Simulating categories in preparation for situated action. In N.L. Stein, P.J. Bauer, & M. Rabinowitz (Eds.), *Representation, memory, and development: Essays in honor of Jean Mandler*. Mahwah, NJ: Erlbaum.

Bechtel, W. (1998). Representations and cognitive explanations: Assessing the dynamicist's challenge in cognitive science. *Cognitive Science*, *22*, 295-318.

Bensafi, M., Pouliot, S. & Sobel, N. (2005). Odorant-specific Patterns of Sniffing during Imagery Distinguish 'Bad' and 'Good' Olfactory Imagers. *Chemical Senses, 30,* 521-529.

Bernieri, F.J. & Rosenthal, R. (1991). Interpersonal coordination: Behavior matching and interactional synchrony. In R.S. Feldman and B. Rime (Eds.), *Fundamentals of nonverbal behavior* (pp. 401-432). Cambridge University Press.

Bhalla, M. & Proffitt, D. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1076-1096.

Blake, W. (1790). *The marriage of heaven and hell*. Pierpont Morgan Library (electronic edition).

Bock, J. (1986). Syntactic persistence in language production. *Cognitive Psychology, 18*, 355-387.

Bosbach, S., Cole, J., Prinz, W., & Knoblich, G. (2005). Inferring another's expectation from action: The role of peripheral sensation. *Nature Neuroscience, 8*, 1295-1297.

Branigan, H.P., Pickering, M.J. & Cleland, A.A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-25.

Bruner, J. & Goodman, C. (1947). Value and need as organizing factors in perception. *Journal of Abnormal and Social Psychology, 42*, 33-44.

*Buccino, G., Binkofski, F., Fink, G., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R., Zilles, K., Rizzolatti, G. & Freund, H. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study.* European Journal of Neuroscience, 13(2)*, 400-404.*

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study *Cognitive Brain Research, 24*, 355-363.

Cacioppo, J., Priester, J., & Berntson, G. (1993). Rudimentary determinants of

attitudes: II Arm flexion and extension have differential effects on attitudes. *Journal of*

*Personality and Social Psychology, 65*(1), 5-17.

Calvo-Merino, B., Glaser, D., Grèzes, J., Passingham, R., & Haggard, P. (2005).

Action observation and acquired motor skills: An fMRI study with expert dancers.

*Cerebral Cortex*, *15*, 1243-1249.

Chambers, C., Tanenhaus, M., & Magnuson, J. (2004). Actions and affordances in

syntactic ambiguity resolution. *Journal of Experimental Psychology: Learning, Memory*

*and Cognition, 30*, 687-696.

Clark, A. (1997).  *Being there: Putting brain, body and world together again*.

Cambridge, MA:  MIT Press.

Clark, H. (1996). *Using Language*. Cambridge University Press

Cohen, A. L. (1964). *Problems in motion perception*. Uppsala, Sweden:

Lundequistska Bokhandeln.

Coles, M., Gratton, G., & Donchin, E. (1988).  Detecting early communication:

Using measures of movement-related potentials to illuminate human information

processing.  *Biological Psychology*, *26*, 69-89.

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait

perception without familiarity cues. *Bulletin of the Psychonomic Society, 9*, 353-356.

Dale, R., & Spivey, M. (in press).  Unraveling the dyad: Using recurrence

analysis to explore patterns of syntactic coordination between children and caregivers in

conversation.  *Language Learning*.

Dale, R., Kehoe, C., & Spivey, M. (in press).  Graded motor responses in the time

course of categorizing atypical exemplars. *Memory and Cognition*.

de'Sperati, C. (2003). Precise oculomotor correlates of visuospatial mental rotation and circular motion imagery. *Journal of Cognitive Neuroscience*, *15*, 1244-1259.

de'Sperati, C., & Stucchi, N. (2000). Motor imagery and visual event recognition. *Experimental Brain Research, 133*, 273–278.

Decety, J., & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences*, *3*, 172-178.

de'Sperati, C., & Stucchi, N. (1997). Recognizing the motion of a graspable object is guided by handedness. *Neuroreport: An International Journal for the Rapid Communication of Research in Neuroscience, 8*, 2761-2765.

Doyle, M., & Walker, R. (2001). Curved saccade trajectories: Voluntary and reflexive saccades curve away from irrelevant distractors. *Experimental Brain Research*, *139*, 333-344.

Dreyfus, H. (1972). *What computers can't do: A critique of artificial reason*. New York: Harper and Row.

Duncker, K. (1945). On problem solving. *Psychological Monographs*, 58(5, Whole No. 270).

Eberhard, K., Spivey-Knowlton, M., Sedivy, J., & Tanenhaus, M. (1995). Eye movements as a window into real-time spoken language comprehension in natural contexts. *Journal of Psycholinguistic Research*, *24*, 409-436.

Edelman, S. (2006). Mostly harmless: Book review of Noë's 'Action in Perception'. *Artificial Life, 12*, 183-186.

Erdelyi, M. (1974). A new look at the new look: Perceptual defense and vigilance. *Psychological Review, 81*, 1-25.

Flanagan, J.R. & Johansson, R.S. (2003). Action plans used in action observations. *Nature, 424*, 769-771

Flanagan, J. & Rao, A. (1995). Trajectory adaptation to a nonlinear visuomotor transformation: evidence of motion planning in visually perceived space. *Journal of Neurophysiology, 74*, 2174-2178.

Gallese, V. (2003). The manifold nature of interpersonal relations: The quest for a common mechanism. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *358*, 517-528.

Ganis, G., Keenan, J. P., Kosslyn, S. M., & Pascual-Leone, A. (2000). Transcranial magnetic stimulation of primary motor cortex affects mental rotation. *Cerebral Cortex, 10*(2), 175-180.

Georgopoulos, A., Lurito, J., Petrides, M., Schwartz, A., & Massey, J. (1989). Mental rotation of the neuronal population vector. *Science, 243*, 234-236.

Gibson, J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Glenberg, A., & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin and Review*, *9*, 558-565.

Glucksberg, S. (1964). Functional fixedness: Problem solution as a function of observing responses. *Psychonomic Science*, *1*, 117-118.

Gold, J., & Shadlen, M. (2000). Representation of a perceptual decision in developing oculomotor commands. *Nature, 404*, 390-394.

Gold, J., & Shadlen, M. (2001).  Neural computations that underlie decisions about sensory stimuli.  *Trends in Cognitive Sciences*, *5*, 10-16.

Goldstone, R., & Barsalou, L. (1998). Reuniting perception and conception. *Cognition, 65(2-3)*, 231-262.

Goodale, M., Pélisson, D., & Prablanc, C. (1986).  Large adjustments in visually guided reaching do not depend on vision of the hand or perception of target displacement. *Nature*, *320*, 748-750.

Grant, E., & Spivey, M. (2003).  Eye movements and problems solving: Guiding attention guides thought.  *Psychological Science*, *14*, 462-466.

Greenwald, A. (1970).  A choice reaction time test of ideomotor theory.  *Journal of Experimental Psychology*, *86*, 20-25.

Haken, H., Kelso, J., & Bunz, H. (1985).  A theoretical model of phase transitions in human hand movements.  *Biological Cybernetics*, *51*, 347-356.

Hamilton, A., Wolpert, D., & Frith, U. (2004).  Your own action influences how you perceive another person's action.  *Current Biology*, *14*, 493-498.

Hauk, O., & Pulvermüller, F. (2004).  Neurophysiological distinction of action words in the fronto-central cortex.  *Human Brain Mapping*, *21*, 191-201.

Hegarty, M. (1992).  Mental animation: Inferring motion from static displays of mechanical systems. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 1084-1102.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences, 17(2)*, 187-245.

Jeannerod, M. (1995). Mental imagery in the motor cortext. *Neuropsychologia, 3311.*

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics, 14*(2), 201-211.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge, MA: MIT Press.

Kendon, A. (1994). Do gestures communicate?: A review. *Research on Language and Social Interaction, 27*, 175-200.

Kirsh, D. (1995). The intelligent use of space. *Artificial Intelligence, 73*, 31-68.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science,18*, 513-549.

Klatzky, R. L., Pellegrino, J. W., McClosky, B. P., & Lederman, S. J. (1993). Cognitive representations of functional interactions with objects. *Memory and Cognition, 213*, 294-303.

Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: Interactions of perception and action. *Psychological Science, 12*, 467-472.

Knoblich, G., & Jordan, J. (2003). Action coordination in groups and individuals: Learning anticipatory control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 1006-1016.

Knoblich, G., Thornton, I., Grosjean, M. & Shiffrar, M. (Eds.) (2005). *Human body perception from the inside out*. Oxford, UK: Oxford University Press.

Kosslyn, S. M., & Ochsner, K. N. (1994). In search of occipital activation during visual mental imagery. *Trends Neurosci, 17*(7), 290-292.

Kosslyn, S. M., Behrmann, M., & Jeannerod, M. (1995). The cognitive

neuroscience of mental imagery. *Neuropsychologia, 33*(11), 1335-1344.

Kourtzi, Z. & Kanwisher, N. (2000). Activation in human MT/MST by static

images with implied motion. *Journal of Cognitive Neuroscience, 12*, 48-55.

Krauss, R. (1998). Why do we gesture when we speak. *Current Directions in

Psychological Science, 7*, 54-59.

Krauzlis, R. & Adler, S. (2001). Effects of directional expectations on

Laeng, B., & Teodorescu, D. (2002). Eye scanpaths during visual imagery

reenact those of perception of the same visual scene. *Cognitive Science*, *26*, 207-231.

Lakoff, G. & Johnson, M. (1980). *Metaphors we live by*. Chicago: The University

of Chicago Press.

Magnuson, J. (2005). Moving hand reveals dynamics of thought. *Proceedings of

the National Academy of Sciences, 102*, 9995-9996.

Mandler, J. (1992). How to build a baby: II. Conceptual primitives.

*Psychological Review*, *99*, 587-604.

Matin, E., Shao, K., & Boff, K. (1993). Saccadic overhead: Information-

processing time with and without saccades. *Perception and Psychophysics*, *53*, 372-380.

Mattes, S., Ulrich, R., & Miller, J. (1997). Effects of response probability on

response force in simple RT. *Quarterly Journal of Experimental Psychology: A, 50*, 405-

420.

McClelland, J. (1979). On the time relations of mental processes: An

examination of systems of processes in cascade. *Psychological Review*, *86*, 287-330.

McNeill, D. (Ed.) (1992). *Language and gesture*. Cambridge, UK: Cambridge University Press.

McRae, K. (2004). Semantic memory: Some insights from feature-based connectionist attractor networks. In B. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory, Vol. 45* (pp. 41-86). San Diego, CA: Elsevier Academic Press.

Mellet, E., Tzourio-Mazoyer, N., Bricogne, S., Mazoyer, B., Kosslyn, S. M., & Denis, M. (2000). Functional anatomy of high-resolution visual mental imagery. *Journal of Cognitive Neuroscience, 12*(1), 98-109.

Meyer, D., Osman, A., Irwin, D. & Yantis, S. (1988). Modern mental chronometry. *Biological Psychology, 26*, 3-67.

Miller, J. (1988). Discrete and continuous models of human information processing: Theoretical distinctions and empirical results. *Acta Psychologica*, *67*, 191-257.

Morsella, E. & Krauss, R. (2005). Muscular activity in the arm during lexical retrieval: Implications for gesture-speech theories. *Journal of Psycholinguistic Research, 34*, 415-427.

motion perception and pursuit eye movements. *Visual Neuroscience, 18*, 365-376.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology*. San Francisco, California: W. H. Freeman.

Niedenthal, P. & Kitayama, S. (1994) *The heart's eye: emotional influences in perception and attention*. Academic Press.

Noë, A. (2005). *Action in perception*. Cambridge, MA: MIT Press.

Pecher, D. & Zwaan, R. (Eds.) (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge, UK: Cambridge University Press.

Port, R., & van Gelder, T. (Eds.). (1995). *Mind as motion: Explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences*, *22*, 253-279.

Pylyshyn, Z. (1974). Minds, machines and phenomenology: Some reflections on Dreyfus' "What computers can't do." *Cognition*, *3*, 57-77.

Ratcliff, R. (1988). Continuous versus discrete information processing: Modeling accumulation of partial information. *Psychological Review*, *95*, 238-255.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, 124, 372-422.

Richardson, D. & Kirkham, N. (2004). Multi-modal events and moving locations: Eye movements of adults and 6-month-olds reveal dynamic spatial indexing. *Journal of Experimental Psychology: General*, *133*, 46-62.

Richardson, D. & Matlock, T. (in press). The integration of figurative language and static depictions: An eye movement study of fictive motion. *Cognition*.

Richardson, D. & Spivey, M. (2000). Representation, space and Hollywood Squares: looking at things that aren't there anymore. *Cognition*, *76*, 269-295.

Richardson, D. & Spivey, M. (2004). Eye tracking: Research areas and applications. In G. Wnek & G. Bowlin (Eds.) *Encyclopedia of Biomaterials and Biomedical Engineering*. (pp. 573-582). New York: Marcel Dekker, Inc.

Richardson, D., Spivey, M., Barsalou, L., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science, 2*7, 767-780.

Richardson, D.C. & Dale, R. (2005). Looking to understanding: The coupling between speakers' and listeners' eye movements and its relationship to discourse comprehension. *Cognitive Science*, *29*, 39-54.

Richter, W., Somorjai, R., Summers, R., Jarmasz, M., Menon, R., Gati, J., Georgopoulos, A., Teger, C., & Ugurbil, K. (2000). Motor area activity during mental rotation studied by time-resolved single-trial fMRI. *Journal of Cognitive Neuroscience, 12*, 310-320.

Rizzolatti, G. & Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience, 27*, 169-192.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*, 131-141.

Rozenblit, L., Spivey, M., & Wojslawowicz, J. (2002).  Mechanical reasoning about gear-and-belt systems: Do eye movements predict performance?  In M. Anderson, B. Meyer, & P. Olivier (Eds.), *Diagrammatic representation and reasoning* (pp. 223-240).  Berlin:  Springer-Verlag.

Ryle, G. (1949).  *The concept of mind*.  New York:  Barnes & Noble.

Sacks, D. & Hollingworth, A. (2005). Attending to original object location facilitates visual memory retrieval. *Journal of Vision, 5(8)*, 443a.

Saslow, M. G. (1967) Effects of components of displacement-step stimuli upon latency of saccadic eye movements. *Journal of the Optical Society of America*, *57*, 1024-1029.

Schmidt, R., Carello, C., & Turvey, M. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 227-247.

Schwartz, D., & Black, J. (1996). Analog imagery in mental model reasoning: Depictive models. *Cognitive Psychology, 30(2)*, 154-219.

Schwartz, D., & Black, T. (1999). Inferences through imagined actions: Knowing by simulated doing. *Journal of Experimental Psychology: Learning Memory and Cognition, 25*(1), 116-136.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Science, 10,* 70-76.

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition*, *88*, B11-B21.

Shiffrar, M., & Freyd, J. J. (1993). Timing and apparent motion path choice with human body photographs. *Psychological Science, 4(6)*, 379-384.

Shockley, K., Santana, M. V. & Fowler, C.A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 326-332.

Smith, L. B. (2005) Action alters shape categories. *Cognitive Science,* 29, 665-679.

Sokolov, J. (1993). A local contingency analysis of the fine-tuning hypothesis.

*Developmental Psychology*, *29,* 1008-1023.

Spivey, M. & Dale, R. (2004).  On the continuity of mind: Toward a dynamical account of cognition.  In B. Ross (Ed.), *The Psychology of Learning and Motivation*. Vol. 45. (pp. 87-142) San Diego, CA:  Elsevier Academic Press.

Spivey, M. (in press). *The continuity of mind*.  NY, NY: Oxford University Press.

Spivey, M., & Geng, J. (2001).  Oculomotor mechanisms activated by imagery and memory: Eye movements to absent objects.  *Psychological Research, 65,* 235-241.

Spivey, M., Grosjean, M., & Knoblich, G. (2005).  Continuous attraction toward phonological competitors.  *Proceedings of the National Academy of Sciences*, *102*, 10393-10398.

Spivey, M., Richardson, D., & Fitneva, S. (2004).  Thinking outside the brain: Spatial indices to linguistic and visual information.  In J. Henderson and F. Ferreira (Eds.), *The Interface of Vision Language and Action*.  New York: Psychology Press.

Spivey-Knowlton, M., Tanenhaus, M., Eberhard, K., Sedivy, J. (1998). Integration of visuospatial and linguistic information in real-time and real-space.  In P. Olivier & K. Gapp (Eds.), *Representation and Processing of Spatial Expressions*. (pp.201-214). Mahwah, NJ: Erlbaum.

Steels, L. & Brooks, R. (1995). *The artificial life route to artificial intelligence: Building embodied, situated agents*.  Hillsdale, NJ: Erlbaum.

Stevens, J. A., Fonlupt, P., Shiffrar, M., & Decety, J. (2000). New aspects of motion perception: Selective neural encoding of apparent human movements. . *Neuroreport: For Rapid Communication of Neuroscience Research, 11(1)*, 109-115.

Tanenhaus, M., Spivey-Knowlton, M., Eberhard, K. & Sedivy, J. (1995). Integration of visual and linguistic information during spoken language comprehension. *Science*, *268*, 1632-1634.

Tettamanti, M., Buccino, G. Saccuman, M., Gallese, V., Danna, M., Scifo, P., Fazio, F., Rizzolatti, G., Cappa, S., Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, *17*, 273-281.

Theeuwes, J., Olivers, C., & Chizk, C. (2005). Remembering a location makes the eyes curve away. *Psychological Science*, *16*, 196-199.

Tipper, S., Howard, L., & Jackson, S. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition*, *4*, 1-38.

Tse, P. & Cavanagh, P. (2000). Chinese and Americans see opposite apparent motions in a Chinese character. *Cognition, 74*, B27-B32.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24(3)*, 830-846 .

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, *8*, 769-800.

Turvey, M. & Carello, C. (1981). Cognition: The view from ecological realism. *Cognition, 10*, 313-321.

Turvey, M. (1992). Affordances and prospective control: an outline of the ontology. *Ecological Psychology, 4*, 173-187.

Underwood, G. (Ed.) (2005). *Cognitive processes in eye guidance*.  Oxford, UK: Oxford University Press.

Viviani, P., Baud-Bovy, G., & Redolfi, M. (1997). Perceiving and tracking kinesthetic stimuli: Further evidence of motor-perceptual interactions. *Journal of Experimental Psychology: Human Perception and Performance, 23(4)*, 1232-1252.

Wang, L., & Goodglass, H. (1992). Pantomime, praxis, and aphasia. *Brain and Language, 42(4)*, 402-418.

Warren, W. & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 371-383.

Wexler, M., Kosslyn, S., & Berthoz, A. (1998). Motor processes in mental rotation. *Cognition, 68(1)*, 77-94.

Wilson, M. (2002). Six views of embodied cognition.  *Psychonomic Bulletin and Review, 9*, 625-636.

Wohlschläger, S., & Wohlschläger, A. (1998). Mental and manual rotation. *Journal of Experimental Psychology: Human Perception and Performance, 24*(2), 397-314.

Wolpert, D.M. & Flanagan, J.R. (2001). Motor prediction. *Current Biology, 11*, R729-R732.

Yaminishi, J., Kawato, M., & Suzuki, R. (1980). Two coupled oscillators as a model for the coordinated finger tapping by both hands. *Biological Cybernetics, 37*, 219-225.

Zwaan, R., Madden, C., Yaxley, R., & Aveyard, M. (2004).  Moving words: Dynamic representations in language comprehension.  *Cognitive Science*, *28*, 611-619.

Zwaan, R., Stanfield, R. & Yaxley, R. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science, 13*, 168-171.

# Figure Captions

Figure 1. When instructed to "click the carriage," individual computer-mouse movements will often exhibit graded spatial attraction toward objects in the display whose names share some phonetic features with the spoken word, e.g., the carrot. (Panel A).  In control conditions, where the alternative object's name is not similar to the spoken word, movement trajectories tend to be more direct (Panel B).

Figure 2.  Although each display contains two eggs, in the instruction "Pour the egg in the bowl onto the flour," a referential ambiguity occurs only in panel A, since panel B's alternative egg is not pourable.  As a result, the visual context in panel A encourages listeners to initially parse "in the bowl" as discriminating between the two eggs, producing a correct syntactic analysis of the sentence.  In panel B, however, "Pour the egg," can clearly only refer to the upper-right egg, and therefore listeners often initially parse "in the bowl" as denoting the goal of the pouring event (and thus briefly, incorrectly, look at the other bowl).