The Cinderella of Psychology

The Neglect of Motor Control in the Science of Mental Life and Behavior

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One would expect psychology—the science of mental life and behavior—to place great emphasis on the means by which mental life is behaviorally expressed. Surprisingly, however, the study of how decisions are enacted—the focus of motor control research—has received little attention in psychology. This article documents the neglect and considers possible reasons for it. The hypotheses considered include three that are raised and then rejected: (a) no famous psychologists have studied motor control, (b) cognitive psychologists are mainly interested in uniquely human functions, and (c) motor control is simply too hard to study. Three other hypotheses are more viable: (d) cognitive psychologists have been more interested in epistemology than in action, (e) psychologists have disfavored motor control because overt responses were the only admissible measure in behaviorism, and (f) psychologists have felt that neuroscientists have the market cornered when it comes to motor control research. There are signs that motor control's Cinderella status is changing.

Keywords: motor control, history of psychology, perception and action, cognitive control of movement, cognitive neuroscience

A newcomer to psychology—for example, a student taking an introductory psychology course—would probably be unsurprised to learn that a major aim of psychological research is to understand how decisions are enacted. Psychology, this student would learn, is the science of mental life and behavior, so he or she would find it natural that many psychologists study how people reach for and manipulate objects, walk around obstacles, and control movements required for speaking, writing, smiling, and gesturing. The work of such investigators, presented under the rubric of motor control, would complement other topics in psychology such as perception, learning, emotion, and development.

This scenario is nothing like the reality of what is taught in introductory psychology courses, nor, for that matter, other psychology classes. Ironically, psychology has paid little attention to motor control, which may be defined as the "set of processes that enables creatures (living or artificial) to stabilize or move the body or physical extensions of the body (tools) in desired ways" (Rosenbaum, 2002, p. 315). What accounts for this neglect? Why have psychologists given short shrift to the translation of intentions into overt behaviors? In this article, I consider several possibilities. Other authors have commented on the neglect of motor control in behavioral science (Gazzaniga, Ivry, & Mangun, 1998; Jeannerod, 1985; Schmidt & Lee, 1999; Wiesendanger, 1997), but no one, to my knowledge, has provided a full-length treatment of the source of the neglect in psychology. The main contribution of this article is to ask why motor control has had the status of a Cinderella in psychological research. The answers to which I have been led are informative about the factors that motivate psychologists.

The article has four parts. First, I briefly present the main questions that are pursued by psychologists interested in motor control. Second, I document psychology's neglect of motor control. Third, I consider the possible reasons for the neglect. Fourth, I comment on the future of motor control in psychology.

Psychological Issues in Motor Control

To describe psychology's neglect of motor control, I will first clarify the aims of research in this domain. The main question concerns the necessary and sufficient conditions for the generation of voluntary movements. One way of posing the question is to ask how, of all the movements that could possibly be performed given an actor's intentional state, a particular movement is carried out? Consider the act of picking up a pen. Although this act is simple, it requires many decisions. Where along the length of the pen should the pen be grasped? Which hand should be used? What should the orientation of the hand be? How should the grasp depend on what will be done with the pen? Should the pen be grasped the same way if it will be used for writing or for poking a hole?

Distinguishing between movement possibilities and intentional states implies a distinction between asking how and why a task is performed. The separation of the two

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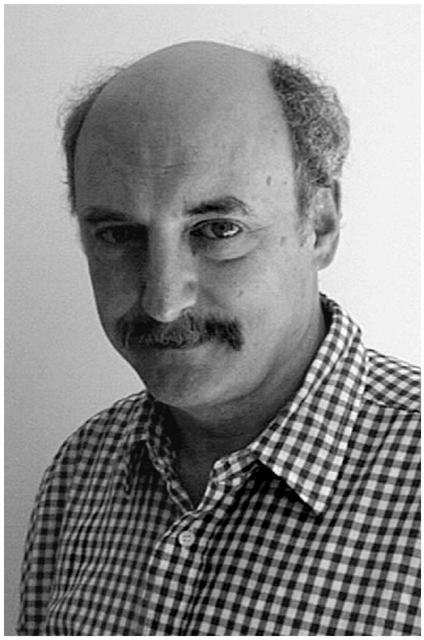

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need not imply that intention formation and intention enactment are unrelated. Knowledge of how one can perform affects what one intends to do, just as what one intends to do affects how one acts. Still, it has proven useful to take for granted that when an actor performs some voluntary action, he or she has some goal in mind. Insofar as there are different means of achieving that goal, the question of interest for students of motor control is how the performed movements are selected and controlled.

Researchers interested in the translation of intentions into physical actions have largely focused on anticipatory phenomena. The logic of the approach is straightforward. If the activity of the nervous system prior to the performance of some motor act differs from the activity of the nervous system prior to the performance of some other motor act, it is reasonable to suppose that the state of the nervous system played a role in differentiating the two acts. Said another way, the state of the nervous system is a necessary, if not sufficient, condition for performing any particular act. By this way of thinking, changes in the nervous system prior to performance of a motor act reflect the history of the act's genesis (e.g., Jeannerod, 1988).

The analysis of the precursors of voluntary motor acts is not restricted to studies of neural activity. Behaviors, too, betray their histories. Errors in performance provide clues into the nature of plans for forthcoming actions, whether for speech (e.g., Dell, 1986; Fromkin, 1973, 1980; Lashley, 1951), typewriting (Cooper, 1983; Rosenbaum, 1991, chap. 8), or other kinds of performance (Norman, 1981; Reason, 1990). Reaction times to begin production of motor sequences also provide information about the processes underlying movement generation (Henry & Rogers, 1960; Klapp, 1977; Rosenbaum, 1987; S. Sternberg, Monsell, Knoll, & Wright, 1978).

Studies of motor control have also focused on learning. Through learning, motor acts are performed more quickly, automatically, and consistently (Schmidt & Lee, 1999). An insight from the study of motor learning is that, as practice continues, actors achieve greater flexibility in the way they perform. One way they do so is by unlocking biomechanical degrees of freedom. Thus, novice pistol shooters tend to keep their elbows and wrists locked, but with practice they allow these joints to counterrotate so extension of one joint compensates for flexion of the other (Arutyunyan, Gurfinkel, & Mirsky, 1969). Learners can also acquire the ability to decouple joint motions. Thus, skilled pianists can achieve greater independence of the two hands than can novice piano players (Shaffer, 1976). Similarly, experienced percussionists can generate more complex polyrhythms than can new drummers (Pressing, Summers, & Magill, 1996).

Studies of motor control have also focused on the connection between perception and performance. What one perceives affects how one acts, just as how one acts affects what one perceives. Thus, one's capacity to tune one's actions to the perceptual environment depends on one's opportunity to actively explore the relations between one's actions and the perceptions those actions afford (Held, 1965). Such exploration permits prediction of the perceptual consequences of behavior, and such predictions help one determine whether perceptual changes originate from changes in the external environment or from one's activity in the environment. As a result, if the image of the visual world shifts across the retina and the eye has been commanded to move, the retinal shift can be ascribed to motion of the eye rather than to motion of the external environment (von Helmholtz, 1909/1911).

Predicting perceptual consequences of motor acts plays a key role in motor planning. As James (1890) wrote, "If I will to write 'Peter' rather than 'Paul,' it is the thought of certain digital sensations, of certain alphabetic sounds, of certain appearances on the paper, and of no others, which immediately precedes the motion of my pen" (p. 500).

The idea that plans for motor action include perceptual goals has received a great deal of support in recent years (for reviews, see Hommel, Musseler, Aschersleben, & Prinz, 2001). That plans for motor activity are partly perceptual makes sense from the perspective of feedback processing. To respond adaptively to movement-related feedback, one needs to have a goal against which the feedback can be compared.

Documenting the Neglect

Having summarized some of the concerns of motor control research, I turn to psychology's neglect of this field. I document the neglect with reference to two main sources: (a) coverage in textbooks and (b) coverage in journals.

Coverage in Textbooks

Insofar as textbooks reflect the paradigm of a field (Kuhn, 1970), the coverage of motor control in psychology textbooks gives an indication of the level of interest in this area of study. It is fitting in this connection to look at the table of contents of one of the most influential textbooks in behavioral science, Neisser's (1967) *Cognitive Psychology*. This volume helped establish cognitive psychology as the preeminent approach to experimental psychology. Scanning the contents of Neisser's book (see Appendix A), one sees what cognitive psychology entailed for Neisser, at least in 1967: perceiving, attending, and remembering visual and auditory information, including verbal information.

Surprisingly, the picture has not changed much in the ensuing years. Appendix B lists the table of contents of another successful textbook in cognitive psychology, Ashcraft's (2002) *Cognitive Psychology* (3rd ed.). The organization of Ashcraft's book is typical of cognitive psychology textbooks on the market today (e.g., Anderson, 2005; Matlin, 2002; Medin, Ross, & Markman, 2005; R. J. Sternberg, 2003). The main difference between Ashcraft's and Neisser's (1967) tables of contents is that Ashcraft's contents include a chapter on decisions, judgments, and reasoning as well as a chapter on problem solving. The presence of these chapters highlights the growth of knowledge about higher-level aspects of cognition in the last 40 years or so.

Coverage in Journals

Because textbooks may not be the best indicators of research activity, it is useful to ask whether research journals provide a different picture of the level of activity in motor control research. To find out, I used Web of Science to obtain counts of articles on selected topics from the Social Sciences Citation Index. The period I used was as inclusive as possible on the date of the inquiry, August 11, 2004. The topics I searched for were the ones Ashcraft (2002) included in his table of contents, although I trimmed or combined words for purposes of the search (see Table 1). The one term I queried from Web of Science that was not included in Ashcraft's list was *motor*. I did not use the term *movement* because this can include studies of visual movement perception as well as political or social tides. As shown in Table 1, coverage of motor-related topics was lower than coverage of topics that comprise the standard fare of cognitive psychology textbooks. This outcome indicates that journals are similar to textbooks in the extent to which they reflect research activity.

Table 1
Citations of Selected Topics in the Social Science Citation Index From 1986 to 2004

Topic	Occurrence
Attention	51,946
Cognitive	65,039
Decision or judgment or reasoning	54,367
Language	42,205
Memory	48,867
Motor	17,424
Perception or pattern recognition	34,328

Note. All topics except for *Motor* are referred to in Ashcraft's (2002) *Cognitive Psychology* (3rd ed.; see Appendix B).

Possible Reasons for the Neglect

Why has motor control been neglected in psychology? Several explanations come to mind.

The No-Celebrity Hypothesis

One possibility is that no famous psychologists have studied motor control. This hypothesis is worth considering because luminaries attract acolytes, and if no psychologists of note have studied movement, it stands to reason that few psychologists, famous or otherwise, have gravitated to this topic. In fact, the list of psychologists who have studied motor control is notable for its celebrity. Robert Woodworth, the author of some of the most masterful reviews of experimental psychology (Woodworth, 1938; Woodworth & Schlosberg, 1954), wrote his doctoral dissertation on manual aiming (Woodworth, 1899). This work became a classic (for a review, see Elliott, Helsen, & Chua, 2001) and inspired subsequent influential studies of eye–hand coordination by other well-known psychologists, including Paul Fitts (1954), Steven Keele and Michael Posner (1968), and David Meyer, Keith Smith, Sylvan Kornblum, Richard Abrams, and Charles Wright (1990). Other well-known psychologists have also made major contributions to the study of motor control. Among them are Frederic Bartlett (1932); Karl Lashley (1951); Saul Sternberg, Stephen Monsell, Ronald Knoll, and Charles Wright (1978); and Michael Turvey (1990). As this list of names indicates, established investigators have indeed contributed to the study of motor control.

The Only-Human Hypothesis

Another hypothesis is that psychologists—and especially cognitive psychologists—are mainly interested in human mental life and behavior. Motor control is not very interesting, according to the only-human hypothesis, because the way humans move does not seem very different from the way animals move. Thought and language are what distinguish humans from animals. Consequently, if a cognitive psychology textbook discusses any form of motor control in detail, it is usually speech production.

Counterarguments can be made to the only-human hypothesis. One is that a number of uniquely human forms of action receive little or no coverage in most cognitive psychology texts. Handwriting and typing are rarely mentioned, for example, though both topics are distinctly human and have received quite a bit of attention from psychologists (Cooper, 1983), including famous ones (Logan, 1983, 2003; Rumelhart & Norman, 1982). A second counterargument is that aspects of perception and cognition that are not uniquely human are covered in considerable detail in cognitive psychology textbooks as well as in contemporary psychology journals (e.g., pattern recognition). Third, plenty of psychological research is done with nonhuman species.

The Dumb-Jock Hypothesis

Another possible reason for the neglect of motor control in psychology is that motor activity does not appear to reflect much intelligence. According to the dumb-jock hypothesis, one does not have to be highly intelligent, as measured by IQ tests, to move well. Hence motor control is not very interesting.

The dumb-jock hypothesis may have more to it than first meets the eye, or at least reviewing evidence bearing on it provides information about previous findings that may be unfamiliar to many psychologists. It turns out that several well-known studies have shown that when it is plausible to expect motor factors to be a limiting factor in some task or other, intellectual factors actually limit performance. One example is Tolman's (1948) classic demonstration of cognitive maps. Tolman coined the term *cognitive maps* after finding that animals learned the spatial layouts of the mazes they occupied, not the movements they made within the mazes. Similarly, studies of stimulus–response compatibility have shown that the relation between locations of stimuli and responses mainly determine reaction times, not which hand makes the response (Proctor & Reeve, 1990). Mirror neurons, which fire both when animals perform actions or observe the same actions performed by other individuals (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), appear to code the goals of actions rather than the movements that are made (Rizzolatti, Fogassi, & Gallese, 2001). Even the interactions between two hands that arise when one tries to carry out different movements with the two hands simultaneously (e.g., drawing a curve with one hand while drawing a straight line with the other; Franz, Zelaznik, & McCabe, 1991) turn out to be due primarily to the difficulty of perceiving the positions of the two hands, not the difficulty of moving the two hands at the same time (Mechsner, Kerzel, Knoblich, & Prinz, 2001). These examples suggest that motor behavior is not, so to speak, where the action is.

Despite these examples, I doubt the dumb-jock hypothesis. One source of doubt is that psychologists have devoted a great deal of attention to many functions that are not intellectually intensive. Hunger, thirst, sex, and the visual perception of texture are examples. The second source of doubt is that although movement may not take much intelligence in the conventional sense, current technology, as reflected in robotics, is unable to achieve what most normal 4-year-olds can do quite easily—peel a banana, climb a tree, or put on a shirt. It may be that movement does not require the kind of intelligence that is required to run a company or play chess, but our ignorance of the intelligence underlying everyday movement is more vast than our ignorance of "white-collar" forms of intelligence. This disparity was apparent when IBM's Big Blue computer beat Gary Kasparov, the world's best chess player, in a highly touted match. A human operator moved the pieces for Big Blue.

The Too-Hard-to-Study Hypothesis

Perhaps motor control is the Cinderella of psychology because it is too hard to study. This hypothesis has been publicized by at least two notable contributors to behavioral and neural science. Donald Broadbent (1993), a pioneer in applied and experimental psychology, wrote that

> motor performance has always been a neglected and deprived area of psychology. There are technical reasons for that; it is much harder to control what a person does than what stimulates them, and therefore harder to produce scientific laws of the type "A is followed by B." (p. 864)

Edward Evarts (1973), a pioneer in neurophysiology, made a comparable claim in his description of early neural recording techniques:

> One difficulty in studying volitional movement arose from the necessity of having the active participation of the experimental subject; that precluded the use of an anesthetized animal. Research on sensory processes moved ahead rapidly because sensory functions could be tested in such an animal. For example, the physiology of visual receptors could be studied in anesthetized animals, but the physiology of eye movement could not since such studies required animals capable of perception, attention, and coordinated motor function. (p. 96)

The methodological difficulties that Evarts (1973) described were later overcome, thanks in part to his own refinement of microelectrode technology. A great deal of research has subsequently been done on the brain activity of awake, moving animals. Still, the range of movements that is possible while brain activity is being recorded remains small compared with what is possible in the everyday environment because the technology used for recording brain activity in awake subjects (e.g., functional magnetic resonance imagery) requires the use of scanners that significantly limit mobility.

In addition to the technical difficulties of studying motor control, the processes underlying movement planning and generation are relatively immune to conscious inspection. As James (1890) wrote, "For many actions, we are aware of nothing between the conception and the execution. All sorts of neuromuscular processes come between . . . but we know absolutely nothing of them. We think the act, and it is done" (p. 790).

The fact that psychologists seem to have no sense of motor innervation—a topic discussed at length by James (1890)—may have put the study of motor control at a disadvantage, compared, say, with the study of visual perception, where visual images can be formed in one's mind.

There are problems with the too-hard-to-study-hypothesis, however. One is that much of what psychologists know about motor control was discovered with techniques that are no more complex than the techniques used to study other psychological phenomena. Psychologists have learned about the planning and control of movements by recording mistakes that people make, by recording how long it takes to initiate and perform predetermined motor sequences, and by using other methods that are common in experimental psychology. For example, using a simple video recording system, Cohen and Rosenbaum (2004) showed that when people took hold of a vertically oriented rod to move it from one position to another, they took hold of the rod at a height that was inversely related to the height to which it would be brought. This result corroborates the hypothesis that people anticipate final body positions when carrying out voluntary movements (Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001). The fact that this principle could be supported with little more than a stick and a camcorder shows that motor control is not too hard to study so long as one is interested in studying it.

The other problem with the too-hard-to-study hypothesis is that problems of measurement rarely dissuade people from developing solutions to those problems when they are curious enough. An example is the movie camera, whose invention was spurred by the desire to see individual frames of rapid movements so that, among other things, one could determine whether a galloping horse had all its hooves off the ground at any time—a hotly debated topic in the 19th century (Muybridge, 1887/1957). The commercial potential of cinema only came to be recognized later (Newhall, 1999).

The Think-Before-You-Act Hypothesis

All the hypotheses considered so far were ones I raised and then dismissed. Now I consider three hypotheses that strike me as more viable. The first is the think-before-you-act hypothesis. The idea is that the core question in cognitive psychology—What is knowledge?—is not one that naturally inspires work on the question, How do people move? Scientific psychology originated in philosophy, many of whose long-standing questions had to do with epistemology: How do people come to know the world? Can people know the world as it really is or only as they imagine it? and so on. Inheriting these concerns, psychologists were naturally inclined to investigate the topics listed in most cognitive psychology textbooks today: perception, attention, learning, and memory. Reasoning, decision making, and problem solving also fit in because they may illuminate how and what people learn.

If perceiving and knowing have higher priority than motor control, one would expect a boost in the study of movement when such study can provide new insights into perceiving and knowing. Just such a boost occurred in the past few years because of research concerning a woman who suffered damage to the ventral pathway of her visual system (Milner & Goodale, 1995). When asked to report the seen size or orientation of a bar, the woman typically performed at chance, but when she reached for the bar, her hand approached it as if the bar's visual size and orientation were available to her. Her inability to use vision for recognition contrasted sharply with her ability to use vision for movement. The disparity suggested that she could see for the sake of action but not for the sake of identification.

On the basis of these and other observations, Milner and Goodale (1995) proposed that there is a "how" visual system and a "what" visual system. For students of perception, this provocative claim made the study of hand movements attractive for investigating visual perception. Consequently, many studies have since been done on visual factors affecting manual control (for a review, see Glover, 2002). Such studies have been useful not just for shedding light on Milner and Goodale's how–what distinction; they have also permitted new insights into the control of hand movements per se (e.g., Glover & Dixon, 2001).

Other studies of motor control have been similarly inspired by perceptual questions. For example, to explore the possibility that spatial attention depends on the actions carried out in space, Tipper, Lortie, and Baylis (1992) showed that hand movements directed to visual targets were affected by the presence of visual distractors. This work inspired further research on action-related attention (Humphreys & Riddoch, 2003). Similarly, to test Piaget's (1936/1952) assertion that, for babies, "out of sight" means "out of mind," Clifton, Rochat, Litovsky, and Perris (1991) studied babies' reaches to sounding objects that first were visible but then were plunged into darkness. The babies' reaches were well directed to the objects, including to parts of the objects that were removed from the sound source, indicating that out of sight does not mean out of mind, contra Piaget. In much the same vein, Smith, Thelen, Titzer, and McLin (1999) challenged Piaget's claims about the immaturity of infants' understanding of objects as permanent entities. The challenge was made possible by carefully investigating babies' reaches to seen and hidden objects.

The Baby-With-the-Bathwater Hypothesis

I turn now to the penultimate hypothesis concerning psychology's neglect of action—the baby-with-the-bathwater hypothesis. According to this hypothesis, when mainstream psychology rejected behaviorism—an approach that treated the response as the only admissible source of psychological data—it eschewed response measures more sweepingly than would have occurred otherwise. The study of motor control was guilty by association. Motor behavior was associated with mindlessness, and a mindless response-centered program of research was anathema to psychologists basking in the glow of cognitivism.

If the baby-with-the-bathwater hypothesis is correct, one would expect the study of action to fare better when and where behaviorism has not held sway than when and where it has. Consistent with this expectation, the study of movement prospered in America at the end of the 19th century and early in the 20th century, before the advent of John B. Watson. Important contributions to motor control research were made in this period. For a review, see Schmidt and Lee (1999).

Concerning the where of action research, in England and continental Europe, where behaviorism never took hold as it did in America, there have been long-standing programs of research on movement. A reflection of the healthy state of motor control research in England is that a textbook by a team of British cognitive psychologists (Smyth, Collins, Morris, & Levy, 1994) entitled *Cognition in Action* has chapters with names like "Reaching for a Glass of Beer" (chap. 4) and "Tapping Your Head and Rubbing Your Stomach" (chap. 5). In Germany and Holland, university students majoring in psychology are invited to take courses in motor control. Such classes are rare in America.

These points notwithstanding, a predilection of America's foremost behaviorist had the surprising effect of turning psychologists away from movement. When B. F. Skinner promoted operant conditioning, he downplayed the importance of body movements per se, stressing instead the instrumental effects of muscle activity. Thus, whether a pigeon pecked a key or kicked the key did not much matter to Skinner, though it mattered much to the pigeon. Paradoxically, Skinner's pooh-poohing of movements appears to have struck a chord with psychologists. With few exceptions, the analysis of body movements has received little attention in psychology except as a means of addressing other questions. Thus, facial expressions have been used to study emotion (Ekman & Oster, 1979), eye movements have been used to study reading (Rayner, 1983), eyeblinks have been used to study memory (McCormick & Thompson, 1984), and hand gestures have been used to study language (Goldin-Meadow, 1999). The movements people make to control external devices such as buttons or joysticks have generally been less studied than the participants' disposition to use the devices, as measured by response probabilities or reaction times. Generally, the question of how movements are controlled has been ignored.

The Neuroscientists-Have-It-Covered Hypothesis

The final viable hypothesis about the cause of psychology's neglect of motor control is that motor control has long been a forte of neuroscience. Why study a topic when another group of researchers handles it well? To evaluate the neuroscientists-have-it-covered hypothesis, I used Web of Science to access the Science Citation Index in order to count articles on the same topics as I had checked earlier in the Social Science Citation Index. To limit the journals to ones that were relevant, I restricted the search to journals that had the word *brain* or the letters *neur* in their title. The results appear in Table 2, where it is seen that the topic that yielded the most citations was *motor*. Figure 1 shows the relation between number of citations for the same set of topics in Social Science Citation Index and Science Citation Index. Overall, there was a negative relation between the number of citations in the two sources, with *motor* being the topic with the greatest disparity in citation counts.

Why has motor-control research prospered in neuroscience? Apart from the fact that motor disorders cry out for medical research, motor neurophysiologists can precisely stimulate different parts of the nervous system and record the ensuing motor effects. Thus, motor neurophysiologists can escape the problem Broadbent (1993, p. 863) identified: "[I]t is much harder to control what a person does than what stimulates them."

Does the success of motor-control research in neuroscience account for psychology's neglect of this topic? I doubt it is the only source of the neglect, but I think it has been an important one. Psychologists, like professionals in any field, are less prone to pursue topics that are well covered in other disciplines, particularly when they feel they may have nothing special to offer. Psychologists do in fact have something special to offer the study of motor control: They can analyze macroscopic as well as microscopic aspects of behavior, and they can exploit their knowledge of experimental design to reveal functional principles that might otherwise go unnoticed. Still, if psychologists come from a tradition that is epistemologically rather than action-based (the think-before-you-act hypothesis), if their tradition has made motor behavior a pariah rather than an attractive research target (the baby-with-the-bathwater hypothesis), and if grant money and other sources of recognition are more liberally doled out to scientists in other fields (the neuroscientists-have-it-covered hypothesis), there is not much incentive for psychologists to "get on the move".

Table 2
Citations of Selected Topics in the Science Citation Index for Journals Containing "Brain" or "Neur" in Their Titles From 1986 to 2004

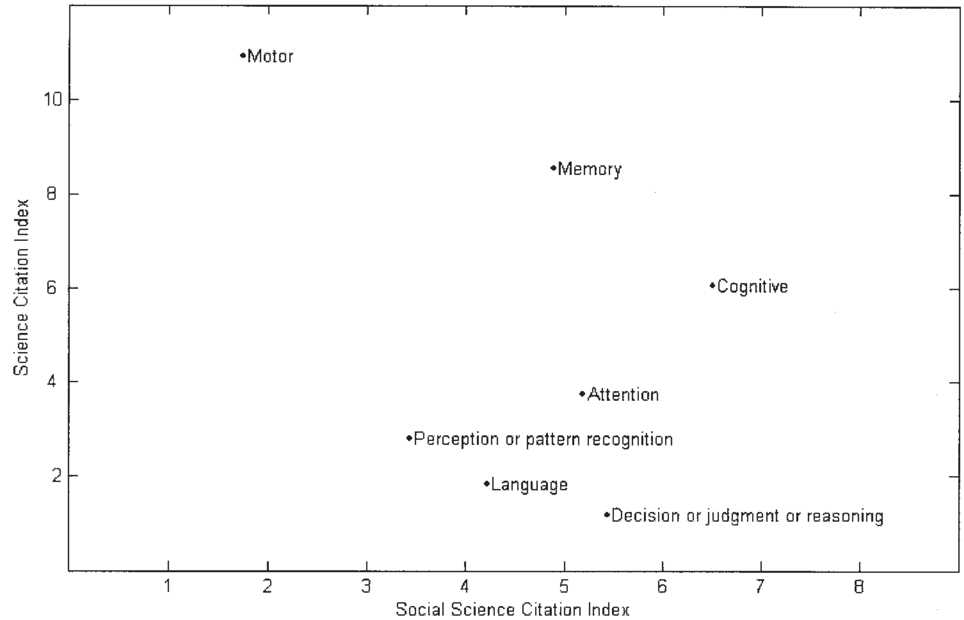
Topic	Occurrence
Attention	3,747
Cognitive	6,049
Decision or judgment or reasoning	1,177
Language	1,833
Memory	8,537
Motor	10,913
Perception or pattern recognition	2,791

Note. All topics except for *Motor* are referred to in Ashcraft's (2002) *Cognitive Psychology* (3rd ed.; see Appendix B).

The Future

In the story of Cinderella, a modest chamber maid, abandoned by her wicked stepmother and stepsisters, is rescued by a handsome prince. My aim in likening motor control to Cinderella has not been to equate research domains to wicked relatives, nor to equate myself with a prince, handsome or otherwise. Instead, my aim has been to point out that motor control, which one may argue lies at the heart of the science of mental life and behavior because it joins the two, has had a surprisingly modest presence in psychology. The reasons, I have suggested, are intellectual and economic. Intellectually, psychology grew out of philosophy, where questions of knowing were taken to be quintessential to epistemology. Only recently have psychologists come to appreciate that acting and knowing are inseparable (Carlson, 1997), and only recently have psychologists come to appreciate that purposeful movement helps initiate or sustain perception–action cycles rather than just being a response to input (for a particularly eloquent, early statement of this position, see Weimer, 1977). Economically, psychologists have been inclined to work on problems for

Figure 1
Number of Articles in the Social Science Citation Index (Abscissa) and Science Citation Index (Ordinate) Pertaining to Each Topic Listed in the Graph



Note. Values on the abscissa are 1/10,000 the number of reported values. Values on the ordinate are 1/1,000 the number of reported values. For the Science Citation Index, the only journals included had the word *brain* or the letters *neur* in their titles.

which they were especially well equipped. Thus, motor control, long a jewel in the crown of neuroscience, became less attractive than other topics for which psychologists felt they could make more distinctive contributions.

Will psychologists pay more attention to motor control in the future? There are reasons to think they will. One is that the division between neuroscience and psychology is blurring. Neuroscientists are becoming more interested in the insights that psychologists can provide and vice versa. As more neuroscientists identify with psychologists and as more psychologists identify with neuroscientists, motor control is becoming an interdisciplinary topic to which psychologists are being invited. One sign that such a change is occurring is the recent appearance of the first American cognitive psychology textbook with an entire chapter devoted to motor control, *Cognition: The Thinking Animal*, by Willingham (2004), a cognitive neuroscientist.

Another reason to expect motor control to become more popular in psychology is the emergence of ecological psychology and dynamical systems analysis. Advocates of ecological psychology argue that the primary function of perception is to guide action (Gibson, 1979) and that the control of action enlists rather than resists physical properties of actor–environment couplings (Bernstein, 1967). Advocates of dynamical systems analysis seek to describe ongoing cycles of perceiving and acting in the form of differential equations (e.g., Sternad, Duarte, Katsumata, & Schaal, 2001). The advent of the ecological and dynamical systems perspectives has fostered the analysis of classes of behavior that were left out of the research portfolio of traditional cognitive psychological research, which focused on internal representations and computations to the exclusion of embodied cognition (Clark, 1997; Glenberg, 1997). Newly studied topics include walking and jumping (Goldfield, Kay, & Warren, 1993; Thelen, 1995), juggling (Beek & Turvey, 1992), skiing (Vereijken, Whiting, & Beek, 1992), pistol shooting (Arutyunyan et al., 1969), wielding objects (Carello & Turvey, 2004), bouncing a ball on a tennis racquet (Sternad et al. 2001), swinging two handheld pendulums of different lengths and weights (Turvey, 1990), and oscillating two index fingers at different frequencies and relative phases (Zanone & Kelso, 1997).

A third reason to expect a growth of interest in motor control is that there is an expanding appreciation of the computational challenges of skilled movement. Although humanoid robots can walk in controlled environments (Sony QRIO Honda Asimo), can vocalize (KRT-v.3; Kagawa University, Takamatsu, Japan), can smile and frown (WE-4R; Waseda University, Tokyo, Japan), can play the trumpet (Toyota's Partner robot), and can hit baseballs (University of Tokyo), they are poor at performing in open-ended situations where novel movements are required (see http://informatiksysteme.pt-it.de/mti-2/cd-rom/index.html). Thus, robots cannot clear tables at restaurants, make beds in hotel rooms, or open and inspect luggage at airports. Engineers interested in building better robots have become interested in biological perception and action to improve robot design. Their interest in this topic may spur more psychological research on motor control and, from there, the connections between mental life and behavior.

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Appendix A
Brief Contents of Neisser's (1967) *Cognitive Psychology*

1. The Cognitive Approach
2. Iconic Storage and Verbal Coding
3. Pattern Recognition
4. Focal Attention and Figural Synthesis
5. Words as Visual Patterns
6. Visual Memory
7. Speech Perception
8. Echoic Memory and Auditory Attention
9. Active Verbal Memory
10. Sentences
11. A Cognitive Approach to Memory and Thought

Appendix B
Brief Contents of Ashcraft's (2002) *Cognitive Psychology* (3rd ed.)

1. Cognitive Psychology: An Introduction
2. The Cognitive Science Approach
3. Perception and Pattern Recognition
4. Attention
5. Short-Term Working Memory
6. Episodic Long-Term Memory
7. Semantic Long-Term Memory
8. Interactions in Long-Term Memory
9. Language
10. Comprehension: Written and Spoken Language
11. Decisions, Judgments, and Reasoning
12. Problem Solving