logical perspective. He constructively finds elements in each chapter that fit with the anthropological viewpoint and that hold promise for the future broadening of developmental theory.

This volume is not a disappointment. The contributors tackled a difficult topic and could have retreated to the safe haven of broad abstractions. In the main, they did not; rather, they faced development in its complexity, admitted to past errors of the discipline, and pointed to directions that ought to be followed in subsequent research. There is unevenness across presentations, but overall constructive thinking was the rule. Graduate students should read this volume because it will tell them what developmental psychology was like 25 years ago, how the discipline has changed since then, and where the concept of development needs to be taken by the next generation. ■

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Old Problems and New Directions in Motor Behavior

Richard A. Schmidt
Motor Control and Learning: A Behavioral Emphasis
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Review by
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"As long as man has existed, he has puzzled over the 'agencies' by which animal action was affected." So said Franklin Fearing (1930, p. 1) in a remarkable little book on the history of reflex action and its relation to the development of physiological psychology. Although some notable psychologists have contributed to an understanding of the processes underlying the organization of movements, it is probably fair to say that in the last thirty years or so, psychology in general has expressed only a dabbling interest. There are signs, and this book is one of them, that the times are changing. Part of the impetus comes from neuroscience, which has told us for a long time that a healthy portion of the brain contributes to the generation and regulation of movements (e.g., Evarts, 1979). If, as the popular press is wont to inform us, the brain constitutes "the last frontier," the study of motor control becomes even more interesting than one might have first thought. Still another push for a more serious consideration of action processes comes from the newly developing area of cognitive science. Donald Norman, for example, in his paper "Twelve Issues for Cognitive Science" (Norman, 1980), identifies "the problem of output, of performance . . . [as] too long neglected, now just starting to receive its due attention" (p. 23), and the issue of skill as not just "a combination of learning and performance. More than that, perhaps a fundamental aspect of cognition" (p. 24).

Of course, none of this is particularly new to a small and persevering group of people in physical education and kinesiology who have been plugging away in the laboratory for some years now, experimenting and speculating on what goes on when people acquire skill and control movements. The fact is that for even the simplest of movements, no one really knows. The author of this book, Dick Schmidt, is a leader in the kinesiology field. He has contributed, among other achievements, two interesting and provocative papers in *Psychological Review* (Schmidt, 1975; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) that combine theory and data about the learning and control of simple movements.

Here Schmidt turns his hand to producing an undergraduate textbook whose cover claims it to be "the most comprehensive book on motor behavior to date." With some reservations, but with no little sense of awe, I have to agree. Previous textbooks, in the opinion of many, have possessed a sort of supermarket quality, with plenty of isolated facts collected from all sorts of diverse settings but with little or no structure to hold them together. In short, as someone said in a rather different context, they turned out not to be worth your green stamps. This book is a welcome change, and as a textbook geared to undergraduates "with little or no background in experimental psychology or the neurosciences" (p. xix), it represents a first-class effort.

The emphasis of the book, as the title indicates, is largely behavioral. Its major aims are "to understand the variables that determine motor performance proficiency, and to understand the variables that are most important for the learning of movement behaviors" (p. 5). Yet the book also promises an integration of the behavioral literature with the fields of biomechanics and neural control. Though this is welcome, it probably overextends the author a little, as indeed it might anyone. Biomechanics and neural control are rapidly expanding fields whose tools and techniques are constantly changing. Each discipline could contribute not one but many books to the area of motor control. It is unlikely that investigators and teachers in either field will get too excited about the integration presented here. Each, I suspect, might feel a bit shortchanged. In Chapter 3, for example, there is a brief though useful discussion of kinematics. But this just about covers Schmidt's treatment of biomechanics and is probably not enough to keep the biomechanics people happy. As for neural control, much of the author's treatment deals with work on locomotion and so-called "spinal generators" (in relation to open-loop, motor programming processes discussed in Chapter 7), although there is also a fairly brief presentation of the role of sensory receptors that might contribute to motor control (in Chapter 6, which emphasizes closed-loop processes). I doubt if this is enough for the student who is interested in integrating motor behavior with associated neural control processes, although it provides a good hint of the possibilities.

Interactions exist at multiple levels

For me, the guts of the book are in Section 2, which contains eight chapters under the heading Motor Behavior and Control. These are bounded by rather conventional but necessary chapters (at least if a semester course is envisaged) dealing with the history of the area and scientific methods (Section 1) and motor learning and memory (Section 3). The latter section is a bit disappointing; there is no recognition of the important biological constraints perspective on learning (see Garcia, 1981, and Johnston, 1981, for a recent review), and ethological approaches are completely ignored. As Saltzman and I have recently pointed out (Saltzman & Kelso, in press), the area of motor memory and learning continues to deal with "items" as relevant stimuli (see Schmidt, Chapter 4 and p. 606), a term that is completely neutral to the kinds of functions that people and animals perform. Treating motor memory as a collection of items linked to traces "in" memory is a vestige of old verbal learning theory and associationism. It tacitly assumes what Seligman (1970) called "equivalence of associability," namely, that it is equally possible to learn any relation between stimulus and response; it fails to recognize important evidence that animals do *not* operate in universal contexts, that they are not general-purpose machines (e.g., Bolles, 1972). In contrast to Schmidt's critique of task-oriented approaches (p. 82ff), maybe it is time to give more thought to the types of tasks that organisms (including humans) perform, in recognition of the fact that those tasks that meet existing constraints are easier to perform than others that do not. Perhaps, as Greene (1971) and others have long argued, we need a theory of tasks that takes as its goal a clarification of the intrinsic relation between a particular environmental structure and the animal rather than focus, as Schmidt does, on the characteristics of animals themselves (e.g., the heavy emphasis on the composition and structure of so-called motor programs, a topic to which I shall return).

Relatedly, the psychologist reading this book may be surprised to find very little on the action system as a coherent perceptual-motor or, for that matter, motor-perceptual unit. In fact, this book hardly deals with perception. To the extent that it does, it does so in a way that many readers might find unsatisfactory. For example, some reference is made to the important role of optical flow fields in the visual control of movement (e.g., p. 96). These are treated, however, as no more than inputs to stimulus identification in a conventional stage model of information processing. Of course, the latter involves the assumption that the system *constructs* its various memory representations on the basis of its inputs, whereas the theoretical import of the optical flow work is that the information for action is readily available to a suitably attuned performer. Thus, in this viewpoint (Gibson, 1966, 1979), skill does not require the construction or accumulation of cognitively based representation; rather, the information being *picked up* becomes more and more precise as skill develops. Putting Gibson's treatment in with information-processing approaches misleads more than informs. This aside, the main point is that a book with a largely behavioral emphasis might have elaborated more fully on the importance of perception for the planning and control of action. Arbib (1980, 1981) made some nice contributions in this regard that are conspicuous by their absence in Schmidt's book.

Also, Schmidt could be criticized (and this may be nit-picking on my part) for perpetuating a distinction between "sensory" and motor" that in the minds of many no longer holds water. Yet it crops up in a number of places throughout the text. In his discussion of motor short-term memory (itself possibly a misnomer), for example, Schmidt harbors the suspicion that the memory was not about motor things at all but "rather was concerned with the retention of sensory information about the feedback associated with the target position" (p. 623). Also, in his earlier mention of Fukuda's observation that many skilled athletes exhibit fundamental movement patterns that resemble reflexes, the author suggests that it is not because the tonic neck reflex is being recruited when the baseball player jumps to catch the fly ball but rather because the player is "merely looking at the ball" (p. 224). But in both of these examples and elsewhere in the book, the author can be faulted for trying to draw too simple a contrast between sensory and motor events. In the days of Bell and Magendie this may have been permissible; in 1982 (and indeed much earlier), the data no longer allow it. Interactions between so-called afferent and efferent pathways occur at all levels of the neuraxis (see Miles & Evarts, 1979; Roland, 1978; Smith, 1978). Central signals modulate and are modulated by the activities at the periphery; consequently, attributing undue importance to afference, as closed-loop theories do, and efference, as in motor-program theorizing (see Schmidt, Chapters 7 and 8), is at best misguided. Students of motor behavior are ill-served when the distinction is overemphasized.

Motor programs and degrees of freedom

In reading through the book, I was both pleased and surprised that the author included some issues that have not previously been central aspects of his work. Among these are a nice discussion of *tuning* (in Chapters 6 and 8) and the so-called degrees of freedom problem identified by Bernstein (who, by the way, was writing as early as the 1920s [e.g., Bernstein, 1926], not, as Schmidt says, the 1940s). For some of us a rationalization of how the many potentially free variables become regulated in the course of coordinated movement remains at the core of a viable theory of action systems. Schmidt quite rightly points out that the degrees of freedom problem is "one difficulty for the closed-loop model, and for any other model that holds that the contractions of the various muscles are handled by direct commands from higher centers" (p. 245). The "other model" in this case, however, happens to be very close to the author's favorite topic, motor programs, which, in spite of some provisos that have been introduced for the involvement of feedback during movement execution, still remains in the modified definition as "a central structure capable of defining a movement pattern" (p. 299) and still retains "the essential feature of the open-loop concept" (p. 299), that is, direct command specification to muscles.

Thus, Schmidt argues that Wadman, Denier van der Gon, Geuze, and Mol's (1979) work on the triphasic electromyographic pattern between agonists and antagonists during rapid elbow flexion can be explained by motor programming: "It is as if the individual said, 'Do the arm movement,' and a motor program was called up that handled all the details, producing the EMG pattern found. In this way the number of degrees of freedom involved in the limb action, from the point of view of the stages of information processing, is reduced to one" (p. 247). Of course, it is precisely this type of account that Bernstein warned us against—that is, when asked the question: "How are the degrees of freedom of the motor apparatus regulated?" one responds that the details are taken care of by a motor program. This is a fait accompli but not an explanation.

Elsewhere my colleagues and I have argued that the strategy of assigning orderly and regular behavior to a construct such as a program or reference level that *embodies* said order and regularity is fraught with problems. Here is not the place to elaborate on these (but see Kelso, 1981; Kelso, Holt, Kugler, & Turvey, 1980; Kugler, Kelso, & Turvey, 1980) except to emphasize that an alternative strategy is available. Such a strategy seeks to explicate the necessary and sufficient conditions for orderly behavior to arise, to understand the dissipation of the body's many degrees of freedom as an *a posteriori* fact of its dynamical organization, not as an *a priori* prescription for the system.

For example, it is very tempting, on the basis of elegant kinematic evidence by Shapiro, Zernicke, Gregor, and Diestal (1981) regarding the proportions of time spent in the various phases of human locomotion, to assume, as Schmidt does, that "a given gait is controlled by a given program" (p. 315, see Schmidt, Figures 8–12). But this account ranks in Rudyard Kipling's "just so" category. Because one observes a different phasic pattern for walking and jogging, there is no reason to conclude that walking and jogging are controlled by different programs.

Indeed, if recent work on horse locomotion is an indicator, a very different account is possible, and one that for me at least is slightly more revealing. Thus, Hoyt and Taylor (1981) found, using metabolic measures of oxygen consumption, that the minimum energy cost per unit distance is almost the same for a horse, whether it walks, trots, or gallops. These three stable locomotory modes, therefore, correspond to regions of minimum energy dissipation. Like many other examples of phase transitions in nature, these modes can be "broken" when the system becomes unstable. Thus, it becomes extremely expensive energetically for a quadruped to maintain a walking mode at increased speeds. A sudden and discontinuous transition occurs at a critical velocity value, and the animal switches into the next stable and less energetically expensive mode. This is not a hard-wired and deterministic phenomenon: Horses can trot at speeds at which they normally gallop, but as anyone who has watched pacers on a race track knows, it takes a lot of training and is metabolically costly. My point is not that we know a lot about gaits and gait transitions (we do not); it is that there is promise here in an account that draws on theories of nonlinear dynamics and nonequilibrium phenomena in general. Common features of such phenomena (and there are some remarkable similarities across many different natural events; see Haken, 1977) are that when a stable system is driven beyond a certain critical value, bifurcations may occur, and qualitatively new forms arise. What is important for Schmidt's interpretation is that no "program" or "central representation" of the upcoming behavior need exist *prior to* the occurrence of the new space–time organization.

In conclusion, many of my remarks have really addressed the second main claim on the cover of this book, namely, that "New hypotheses are advanced . . . resulting in new insights and, in some cases, conclusions that differ from prevailing views." My remarks attest to the highly volatile and stimulating nature of a field that is presently undergoing continuous change. The problems of action as I remarked at the beginning are deep ones that have puzzled scientists and philosophers for a long time. A textbook in this area is not like *Gray's Anatomy*; it reflects only one person's view of the state of the art. To the extent that a textbook is a desirable thing in the motor behavior area (I believe it is, but many—I suspect—might find it premature), this one by Schmidt presents the issues as he sees them in a coherent and well-organized way. I recommend the book highly to those psychologists who want to find out more about motor control. But in the same breath, I would warn them that what they see before them today may be grist for the mill tomorrow. That is as this reviewer, and I suspect the author, would want it to be.

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