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Motor Learning and Control Foundations of Kinesiology: Defining the Academic Core

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This paper outlines the kinesiological foundations of the motor behavior subdisciplines of motor learning and motor control. After defining the components of motor behavior, the paper addresses the undergraduate major and core knowledge by examining several classic textbooks in motor learning and control, as well as a number of contemporary textbooks in these fields, searching for topics that have persisted over time, as well as topics that have emerged more recently. The paper also discusses the changing nature of the undergraduate kinesiology major in terms of their backgrounds and career goals. I address what I perceive to be a "measurement paradox" in assessing our students' knowledge, skills, and abilities, and suggest that the undergraduate kinesiology major, in addition to learning core content in motor learning and control, must also gain an appreciation of research as a way to acquire knowledge about these subdisciplines.

One can marvel at the incredible tennis skills of Roger Federer, or the golf skills of Tiger Woods, currently the world's top-ranked players in their respective sports, and wonder how they acquired the capability to coordinate and control their muscles and joints to produce shots that leave even other professionals awestruck. But in the same vein, we can also marvel at individuals who, perhaps as a result of injury or disease, have learned to control a wheelchair, or prosthesis, in order to perform basic acts of daily living or participate in recreational activities that enhance quality of life. At the core of these extreme examples is, of course, movement—the acquisition and control of which has been the purview of the kinesiological subdisciplines known as *motor learning* and *motor control*.

This paper addresses the contributions of motor learning and motor control to the overarching discipline of kinesiology. What should the undergraduate kinesiology major know and be able to do with respect to these subdisciplines? What in motor learning and control is critical for the study of kinesiology as an academic discipline? My perspective on these questions is the result of having taught the undergraduate motor learning and control course two to three times per year for the past 18 years at Auburn University, and before that, for 7 years at Southern Illinois University. At Auburn, we have three undergraduate programs in kinesiology:

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physical education pedagogy, health promotion, and exercise science. By far our largest program is exercise science, which, at over 280 majors, is twice the size of the other two programs combined. These students are preparing for graduate school in one of the exercise science subdisciplines, which we have identified as biomechanics, exercise physiology, and motor behavior, or to enter professional programs in physical therapy, occupational therapy, or related allied health fields.

The paper approaches the topic by first presenting the components of *motor behavior* and their interrelationships, followed by definitions of the terms *motor learning* and *motor control*. The main focus of the paper is on the undergraduate major and core knowledge, where it is useful to do a content analysis of several classic textbooks in motor learning and control, as well as a number of more recent textbooks in these fields. The paper also addresses the changing nature of the undergraduate student major in terms of their backgrounds and career goals, and what I perceive to be a "measurement paradox" in assessing our students' knowledge and skills. Finally, I suggest that part of the kinesiology core should provide our undergraduate majors with tools for acquiring knowledge about motor learning and motor control. In short, they must appreciate the value of research, and become intelligent consumers of research.

Motor Behavior and Its Components

Motor learning and motor control fall under the broader label of motor behavior, which also includes motor development (see Ulrich, 2007, for discussion of the kinesiological core in motor development). For many, there is no good justification for separating the study of any of these fields from one another, as there is significant overlap in scientific issues, theories, and methods (see e.g., Schmidt & Lee, 2005; Ulrich & Reeve, 2005). The artificial separation can inhibit the understanding of issues that cut across all three areas. And as Newell's (1986) model suggests, in any motor skill performance context there are three interacting sources of constraint: the task, organism, and environment. Surely issues of development, learning, and control involve all three constraints simultaneously. Having said that, however, there may still be some utility in addressing the undergraduate core content of these subdisciplines individually, and in fact, one of the major scientific organizations for the study of motor behavior—the North American Society for the Psychology of Sport and Physical Activity (NASPSPA), still treats these areas separately.

Motor Learning and Control Defined

Motor behavior scientists have defined motor learning and motor control in a variety of ways, with perhaps a distinguishing characteristic being greater emphasis placed on the structure and function of the neuromuscular system (e.g., central and peripheral nervous systems, proprioceptors) in the study of motor control, and less so in motor learning. But, we *learn* to control the system so that motor acts can be performed faster, more automatically, and with greater consistency, and so, as Rosenbaum (2005) pointed out, studies of motor control have also focused on learning. Magill (2007) defines motor control as the study of how the neuromuscular

system functions to activate and coordinate the muscles and limbs involved in the performance of motor skills, both new skills, and those already acquired (also see Shumway-Cook & Woollacott, 2001 for a similar viewpoint). As a field of study, motor control is concerned with how the central nervous system solves the degrees of freedom problem (Bernstein, 1967) so that the many individual muscles and joints become organized into coordinated functional movements. Interestingly, the study of motor control is not limited only to humans, but can include animals (Schmidt & Lee, 2005) and artificial creatures, such as robots (Rosenbaum, 2002).

Motor learning is a science that addresses skill acquisition. Contemporary definitions of motor learning point to the pivotal role played by practice or experience in skill acquisition. For example, Rose and Christina (2006) define motor learning as "a process by which the capability for producing movement performance and the actual movement performance are reliably changed through instruction, practice, and/or experience." (p. 168). This is similar to the definition given by Magill (2007), who states that learning is "a change in the capability of a person to perform a skill that must be inferred from a relatively permanent improvement in performance as a result of practice or experience." (p. 247). For Magill, motor learning also includes the performance enhancement of already learned or highly experienced motor skills, as well as the reacquisition of skills that are difficult to perform or cannot be performed because of injury, disease, etc. The above definitions contain two terms that warrant further comment. First, if we define motor learning as a *process*, or set of processes, the implication is that learning cannot be seen directly, as these processes occur internally. Therefore, we must *infer* that learning is occurring (or not) based on something that can be seen directly, and those are the changes in performance, which are observable behaviors that can be measured. This is important because it sets the stage for what we are willing to call learning variables, which produce relatively lasting changes in the capability for skilled actions, versus those variables that affect performance, but only temporarily. These concepts are among the most important for undergraduates to understand, as they serve as the basis for evaluating motor skill learning.

Core Knowledge in Motor Learning and Control

So what should the undergraduate kinesiology major know and be able to do with respect to motor learning and motor control? My thesis in this section is that the need of undergraduates is principally for basic knowledge that will be useful in preparing them for a variety of fields and contexts, such as graduate school, industry, the military, and physical therapy/occupational therapy programs. Undergraduates need introductory-level work, broad exposure to all of the kinesiology subdisciplines, and integrated knowledge. A similar argument has been made earlier by Barnett (1992) where he questions whether scholar-researchers are best qualified to teach undergraduates, particularly at Carnegie classification RU/VH institutions. At these institutions the demands of prolific publication and grant writing may be incompatible with the skills and time commitment needed for excellent teaching, at least at the undergraduate level. But this issue is beyond the scope of the present paper.

Coverage in Textbooks

As McCullagh and Wilson (2007) have shown for the area of psychology of physical activity, textbook topics tend to reflect the content of undergraduate syllabi. They also reflect the paradigm of a field (Kuhn, 1970). So we can examine textbook content to find out what instructors are covering in their classes. How has the content of undergraduate textbooks changed over time? Is there any consensus regarding "sacred" topics? To help define the core knowledge in motor learning and control, I examined the contents of eight classic textbooks in these subdisciplines (Cratty, 1967, 1973; Lawther, 1968, 1977; Sage, 1971, 1977, 1984; Singer, 1968), as well as a number of more recent textbooks in these fields (Coker, 2004; Rose & Christina, 2006; Schmidt & Wrisberg, 2004; Shea, Shebilske, & Worchel, 1993; Shumway-Cook & Woollacott, 2001). All of the books examined were authored by kinesiologists, broadly speaking. One text, Richard Magill's, *Motor Learning and Control: Concepts and Applications*, receives a bit more detailed scrutiny, since it was first published in 1980 and is now in its eighth edition (Magill, 2007; see references for a listing of all eight editions). Thus, we have a nice picture of what topics have been consistently addressed over the years, and what has been recently added as well as deleted. Rosenbaum (2005) applied a similar analysis in cognitive psychology to document the neglect of motor control in psychological science. I realize the texts I have selected do not include every book ever written on motor learning and control; nevertheless I believe they are a good representation of what has been used, and are currently being used, in typical undergraduate courses.

The older classic textbooks drew heavily from the field of psychology, which is not surprising since motor learning had its historical roots in that discipline. Psychology has always been concerned with learning, as well as the performance of high-level skills, but with very little reference to the neural control mechanisms involved (Schmidt & Lee, 2005). This can be verified by perusing the table of contents and subject indexes from Cratty (1967, 1973), Lawther (1968, 1977), and Singer (1968), where the term "motor control" is absent, although Singer (1968) does have a chapter titled *The Nervous System: Coordination of Movement*, where structures are diagrammed and functions are addressed.

To provide some quantitative "data" to support my thesis that the classic texts were dominated by psychology, I examined the bibliography of Cratty's (1967) book *Movement Behavior and Motor Learning*, which contains 1,000 entries. I counted any journal name, book title, or conference organization containing the root "psych" as part of its title, which included terms such as psychology, psychological, psychiatry, psychometrike, psychologist, psychological, but not psychomotor. My count revealed 502 such entries, or 50.2% of the total citations. I did a similar count from Magill (1980), the first edition of his book, and found that 83 of 200 total references (41.5%) contained any of the above "psych" terms. By contrast, the most current edition of Magill's book (Magill, 2007) contains a total of 753 references, with only 205 (27.2%) containing "psych" in the title.

A few notable exceptions to the domination by psychology in early motor behavior textbooks are volumes by Sage (1971, 1977) *Introduction to Motor Behavior: A Neuropsychological Approach*, and Sage (1984) *Motor Learning and Control: A Neuropsychological Approach*. In the two earlier editions, the term "motor control" is absent from the subject index, but can be found in the table of

contents ("Motor Integration and Control of Movement"). In the 1984 edition, "motor control" is found in both places. In each of these books, nearly half the text is devoted to neural structures and functions. Sage strongly believed that the nervous system played an important role in movement behaviors, and that this role had received relatively little attention in previous texts on the subject. Sage (1984) stated in the preface *". . . when advances are made toward better understanding about skilled human behavior, chances are very strong that they will be made by scholars who possess a thorough knowledge of the neurological basis of reflex and voluntary mechanisms that control human movement."* (p. xiii). Interestingly, the first three editions of Magill's textbook (Magill, 1980, 1985, 1989) contained chapters on the structure and function of the neuromuscular system, but the fourth through seventh editions (Magill, 1993, 1998, 2001, 2004) did not. In the most recent edition (Magill, 2007), this information reappeared. Also, the seventh and eighth editions of Magill (2004, 2007) introduced a new title, changing from *Motor Learning: Concepts and Applications*, to *Motor Learning and Control: Concepts and Applications*, an obvious acknowledgment of the integral tie between these two subdisciplines of motor behavior.

Another interesting analysis reveals how physical therapy, occupational therapy, movement disorders, and rehabilitation citations have increased their presence in motor behavior textbooks over the past 40 years. For example, Cratty (1967) contains one reference to a journal titled *Journal of Physical and Mental Rehabilitation*. This comprises 0.1% of the total citations. Magill's (1980) bibliography contains no citations to physical/occupational therapy, movement disorders, or rehabilitation, but the 2007 edition contains 47 such references (6.2%), including 15 citations from *Physical Therapy*, 9 from the *Archives of Physical Medicine and Rehabilitation*, and 4 from the *American Journal of Occupational Therapy*. In addition to these three journals, there are also 14 others cited that could be broadly classified as physical/occupational therapy, movement disorders, or rehabilitation. The reference list of Rose and Christina (2006) contains 7.7% of its 920 citations that could be similarly classified. Of course, it is possible that early motor behavior textbooks did not include physical/occupational therapy or rehabilitation citations because these journals did not exist at that time. This hypothesis, however, can be rejected as the *Archives of Physical Medicine and Rehabilitation* and *Physical Therapy* published their first volumes in 1920 and 1921, respectively, and the *American Journal of Occupational Therapy* was first published in 1947. Clearly, there was relevant research on motor learning and control being published in physical/occupational therapy and rehabilitation journals; it just was not being cited in our textbooks. It has been fairly recent that the relevance of motor learning and control to these worlds was finally realized (see e.g., Gentile, 2000; Giuliani, 1991; Schmidt, 1991; Shumway-Cook & Woollacott, 2001; Winstein, 1991). This point is further addressed later in this paper.

The "Sacred" Core

A number of topics in motor learning and control have received fairly consistent coverage over time, although the amount of space devoted to a topic may vary, and current thinking replaces older views as more research becomes available. For example, augmented feedback is one of the most important topics in all

contemporary motor learning textbooks, yet Cratty (1967) had only a 2-page section on knowledge of results, and Lawther (1968, 1977) contains even less. Lawther (1968) stated the prevailing view at the time that *"Little or no learning takes place without knowledge of results of performance"* (p. 98). The same statement was also made in his 1977 text. This view has been replaced as we have learned more about the potential negative effects of too-frequent augmented feedback (Salmoni, Schmidt, & Walter, 1984; Swinnen, 1996).

In addition to augmented feedback, other motor learning and control topics that should constitute the undergraduate core for a kinesiology major include attention and information processing, memory, transfer of learning, the structure of practice, neural and sensory contributions to movement, vision and proprioception, dynamic systems theory, and measurement issues.

The statement that practice is the single most important variable controlling the learning and performance of motor skills, would likely receive little argument. Instructors, coaches, physical and occupational therapists must be able to structure appropriate practice experiences to promote optimal skill learning. No doubt the amount of practice is a crucial variable for achieving high-level performance (Ericsson, Krampe, & Tesch-Römer, 1993), but so too is the specific nature of the practice environment, and it is here that an interesting counterintuitive finding emerges with respect to variability of practice. Based on early work in the verbal domain by Battig (1979) and in the motor domain by Shea and Morgan (1979; see Brady, 1998 for a review), when multiple skills have to be learned that require different patterns of coordination (as opposed to a simple parameter modification for an already acquired coordination mode), a random order of practicing the skills produces better long-term retention and transfer than a blocked order of practice. With random practice the learner experiences a different skill on each trial, whereas with blocked practice all the practice trials for one skill are completed before moving on to the next. Clearly, random practice presents a much more difficult environment for the learner, with higher levels of *contextual interference* present compared to blocked practice. Blocked practice, which is akin to rote repetition, or drill, is a much easier context for the learner, and probably for the instructor, coach, or therapist as well. However, the contextual interference effect shows that the more difficult practice environment, while depressing performance during acquisition, ends up producing better long-term learning.

One of the most important theoretical challenges to traditional cognitive psychological approaches to motor learning and control is dynamic pattern theory (e.g., Kelso, 1995; Wallace, 1996). This multidisciplinary perspective draws on concepts from physics, chemistry, biology, and mathematics and views human movement control as a complex system that behaves similarly to other complex biological or physical systems and must be modeled with nonlinear dynamics. To truly understand dynamic pattern theory, one must have a very strong background in nonlinear mathematics and physics, which is probably beyond the scope of the typical undergraduate kinesiology major. However, I do believe that the important concepts from dynamic pattern theory are certainly within the grasp of the undergraduate kinesiology student. Concepts such as stability, attractors, control parameters, order parameters, and self-organization provide rich descriptors of motor behavior and new ways to view changes in motor behavior over time. Dynamic pattern theory should become part of the kinesiology major's knowledge repertoire.

The Changing Nature of the Student Major

Over the last 10 years or so, I have noticed a change in both the backgrounds and the career goals of the undergraduate exercise science majors at my university. Many of my colleagues who grew up in the 1940s, 50s, and 60s came to kinesiology from backgrounds in physical education and sport/athletics. In college, we studied primarily to become physical education teachers. Today, the vast majority of exercise science majors at my university plan to go into physical therapy programs at either the masters or doctoral level; a small number plan to enter more traditional masters programs for advanced study in biomechanics, exercise physiology, or motor behavior. But far fewer of these students are coming from physical activity backgrounds. To illustrate, last year I was lecturing in the undergraduate motor learning class on the structure of practice. Specifically, we were deciding on how to incorporate variability of practice to develop the skills a shortstop in baseball or softball would need. After I introduced concepts of constant and variable practice, a student raised her hand and asked "Dr. Fischman, what's a shortstop?" In his keynote address for this conference, Newell (2007) characterized many current undergraduates as being "physically illiterate" and argued that physical activity needs to be made more central in the study of kinesiology.

If larger numbers of our students are planning to enter physical or occupational therapy programs, then do we, or should we, change what we teach to accommodate their professional goals? Or should our examples and applications of principles and concepts be adjusted to capture the interest of students? A perusal of the current crop of motor learning and control textbooks suggests that there has been a sharp increase in examples that relate to physical therapy and rehabilitation (Coker, 2004; Magill, 2007; Rose & Christina, 2006; Schmidt & Wrisberg, 2004; Shea et al., 1993; Shumway-Cook & Woollacott, 2001). I think it is important that instructors add relevant examples and applications, but without discarding basic theories and principles of learning and control.

The Measurement Paradox: The Value of Research

How are we to assess what our students know and can do with respect to motor learning and motor control? Contemporary views of skill learning argue that motor learning must be assessed on the basis of retention tests and transfer tests, given after practice has been completed for some time. This is so we can separate the temporary effects of variables that operate during an acquisition, or practice phase, from those that exert relatively permanent effects on changing the individual's capability for skilled performance. For example, as we saw earlier, augmented feedback presented at high frequencies, and practice schedules that are blocked (low contextual interference) tend to produce very good acquisition performance, but relatively poor retention and transfer. So if we evaluate our students' content knowledge and laboratory skills at the end of a unit of study, or on a final exam at the end of a semester, are we really measuring what they have learned about motor learning and control? Perhaps we need to track our students into the future

and evaluate how they apply the knowledge, skills, and abilities we supposedly taught in our classes. To some extent we do this with our doctoral students as we follow the development of their careers, but I suspect we do very little at the undergraduate level.

Finally, I want to briefly comment on the importance of knowing how to acquire knowledge about motor learning and motor control, or for that matter, about any subdiscipline of kinesiology. As part of undergraduate training, kinesiology students should be exposed to research, both basic and applied, so they can appreciate its value in knowledge acquisition and in driving professional practice. They need to become intelligent consumers of research; doing so may go a long way toward solving the measurement paradox I raised above.

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