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Invited Commentary

Since Keele’s seminal paper1 in 1968, the term “motor program” has become part of the vocabulary of theorists in motor control and motor learning, and, as Morris et al point out, the term has also become widespread in the clinical literature. Unfortunately, despite considerable theoretical development in the concept of a motor program (reviewed nicely by Morris et al), the term is still frequently used in its original formulation. That is, it is used to imply that when we learn a movement skill, we learn a specific set of muscle contractions. As Morris et al demonstrate, this assumption is simply untenable. Even small changes in the context in which an action takes place will radically affect the magnitudes and timing of muscle contractions necessary to carry out the act, and even...
which muscles will contract. For example, when we reach to pick up a cup to drink from it, the muscle activation patterns associated with this action depend on the location of the cup; its size, shape, and weight; and even the temperature of the liquid inside of it. Thus, if the concept of a motor program is to be useful in describing the process of skill acquisition, it must be more than simply a stored set of muscle commands.

This rejection of a narrow definition of motor programs has important clinical implications. It implies that we should not hope to facilitate skill acquisition in our patients by simply having them repeat the same movement pattern over and over again. Such a strategy may, if anything, make it more difficult for them to adapt their motor patterns to the changes in context that they will inevitably encounter in the real world. Moreover, we cannot simply analyze our patients' movement patterns, determine the missing or disordered component, and have them practice that component isolated from the motor act. Again, such an approach assumes that when we learn a skill, we learn specific muscle activation patterns that can be simply plugged in at the appropriate times.

As these comments make clear, I am in full agreement with the main thrust of the article. And, if this article helps to overcome the all-too-pervasive assumption that skill acquisition is the process of learning muscle activation patterns (the common definition of motor programs), it will have made an important contribution, not only in the theoretical domain, but also in clinical practice. In addition to its convincing demonstration of the inadequacy of a "muscle command" definition of motor programs, the article also provides an excellent review and summary of the theoretical development of the concept of a motor program. Nevertheless, although I generally agree with the main points made by Morris et al, I find myself uncomfortable with the conclusion that, because of its ambiguity, the motor program concept has lost its usefulness. In this commentary, I will attempt to show that the motor program continues to be a useful concept in the study of motor control as well as in forming a basis for clinical practice. Furthermore, I disagree with the statement at the end of the article that "it is useful to delimit the processes associated with motor control from those involved in motor skill learning." I will address this issue at the end of the commentary.

I am concerned that after reading this article, the reader may be left with the impression that, after a strong but flawed initial definition, the concept of the motor program has simply become more and more ambiguous and watered down. Indeed, the original definition generated strong predictions. As these predictions were found not to be tenable, revisions to the concept led to more complex concepts of the motor program. These concepts, in turn, were tested and found to be wanting, and so on. Although one might interpret this history as a failure of the motor program concept, an alternative perspective would be to view it as a strength. In fact, one might read the same history and conclude that the motor program concept has served as a remarkably robust paradigm, a conceptual-experimental framework in which to study motor control.

To illustrate this, I will present a slightly different view of a motor program. A useful place to start is with Bernstein's formulation of skilled motor behavior as the process of solving the problems or tasks that arise when we attempt to achieve a desired goal. Consider, for example, learning to ride a bicycle, something most of us are familiar with. The greatest difficulty is of course learning to balance on the bicycle as we pedal it forward. How do we accomplish this? Specifically, if the bicycle begins to lean to one side, what adjustments are made to prevent falling? The rider does not, as one might first imagine, right the bicycle by leaning to the opposite side (although such adjustments may play a minor role). Instead, the rider makes a small turn of the front wheel in the same direction as the bike is leaning. The resulting curved path of the bicycle generates a centrifugal force that tends to right the bicycle (assuming sufficient friction of the wheels on the road). To verify this, watch a child who has just mastered this task. You will notice that the child will seem to steer in a zig-zag fashion down the road. This is because, although the child has now learned the general rule (ie, steer to the left when falling to the left), he or she has not yet learned the fine-tuning, precisely how much to turn for a given amount of lean. The child is simply over-correcting.

If a motor program is what is learned in skill acquisition, what does this example tell us about its structure? First, the program cannot simply be a set of muscle activations. It is often observed that adults remember how to ride a bicycle after years of not doing it. Clearly, the required muscle activations are different for the adult's body, and will also vary greatly with the size and type of bicycle. Instead, we may view the program as embodying a set of rules about how to solve certain key problems. Second, the program must represent the process of transforming relevant sensory information into the required motor outputs: The program specifies a sensorimotor transform. Third, in addition to specifying general rules, the program must involve, at a lower level, mechanisms for fine-tuning the output, what Grimm and Nashner referred to as the "metrics" of the action.

These fundamental assumptions of the motor program concept have served as a framework for the study of many different motor behaviors. They have led to a task-oriented or "outside-in" approach to understanding how the brain controls movement that has been extremely successful, especially when compared with the "inside-out" approach that dominated motor physiology throughout much of this century. At its core, this approach assumes that in order to understand how the brain controls movement, it is necessary to first understand what...
biomechanical tasks the nervous system faces. A good example of how this approach has been successfully used is the study of reaching movements. Beginning with elegant experiments by Jeannerod and colleagues and corresponding theoretical formulations by Arbib, we now have a detailed task description of reaching and prehension movements. This includes, for example, the understanding that in reaching to pick up an object, there are at least three subtasks: positioning the hand, orienting it, and shaping it. The accomplishment of these tasks depends on distinct channels of sensory information and control of different sets of joints. Moreover, the three tasks are coordinated in time in a precise way. The validity of this model is now well established, and it has led to specific investigations of the neural structures involved, as well as of the nature of certain motor disorders. Furthermore, the general notion of reaching as a process of sensorimotor transformation has led to significant advances in our understanding of how specific structures of the brain participate in this essential human behavior.

In addition to its usefulness in motor control research, I believe that this view of motor programs as task descriptions is also useful for physical therapists. For example, given this framework, we can view disorders of motor control as changes in the way motor programs for specific actions are organized, often to compensate for loss of certain neural capacities. In this way, neurological disorders are viewed from within a task-analytic framework, not simply as the inevitable consequence of loss of neural tissue. In a particularly eloquent article, Grimm and Nasher have elaborated on this aspect of the usefulness of the motor program concept for analyzing motor disorders. Such an overall analytic approach also forms the basis for several contemporary approaches to remediating specific disorders of movement.

To summarize, in agreement with Morris et al, I would reject the notion that motor programs are static and discrete engrams that specify the commands for movement. Instead, motor programs are more usefully viewed as representations of the dynamic and distributed processes through which the nervous system solves motor problems to achieve meaningful goals. I recognize that such a broad definition makes the concept less predictive. We can no longer hope, for example, that we shall discover the discrete part of the brain in which such programs are stored. Nevertheless, I do not believe that greater complexity invalidates the concept or its usefulness.

Where I more clearly disagree with Morris et al is in their assertion at the end of their article that the processes involved in learning motor skills can be viewed independently of the processes involved in motor control. However we may view the motor program controversy, what we are debating here is what the brain learns when a motor skill is acquired. Without such a guiding theoretical perspective, motor learning research becomes, as Kelso put it, a set of “disconnected packets of data that are almost impossible to integrate to produce general scientific principles.” It is impossible to investigate all possible tasks, in all possible contexts, with all possible types of patients, and with all possible treatments. What clinicians need are principles that help them to make decisions about what kinds of practice to implement under defined sets of circumstances. In this regard, it is worth noting that in the 1960s and 1970s most leading motor learning investigators, in recognition of this need, shifted the focus of their research from the factors that influence learning outcomes to the underlying motor control processes (see the two volumes edited by Stelmach and Gentile and Nacson for discussion of this shift).

I am not arguing against the importance of motor learning research. On the contrary, I believe that it can be of enormous value to practicing physical therapists. But there is a danger here that motor learning will be seen as a technique or approach that is applied separately or even in contradiction to other approaches. As Gentile has argued, motor learning is not a therapeutic technique. It is a field of inquiry about human behavior that provides principles that can help clinical decision-making. Moreover, it is misleading to suggest that motor learning studies represent “clinical trials” simply because they involve patients. One might note, for example, that many of these studies involve the learning of discrete movement patterns, with the usually implicit assumption that skill acquisition involves storing sequences of motor commands. Thus, clinicians need to be at least as cautious in applying these results as they should be in applying motor control research.

Finally, I hope my comments convey my respect for the principled way in which the authors have attempted to bring an important theoretical controversy to the attention of physical therapists. As therapists, we need to be aware of the continuing evolution of concepts that too often are presented in textbooks as “written in stone.” As researchers, we need to test our theoretical concepts in the marketplace of clinical practice. This article has stimulated me to rethink my own ideas about motor programs as they relate to physical therapy practice. I hope that it will have the same effect on others.

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References
In reviewing the literature generated by research into rehabilitation of movement, we were struck by the frequency with which the concept of the motor program was cited. In addition, we were aware of the transitions that the concept had undergone in the theoretical literature, transitions that did not appear to be generally noted in the physical therapy literature. The major aim of our article, therefore, was to summarize the current status of the concept, outline its transitions, and derive implications for clinical practice. It is important to note that both our article and the commentary by Dr Gordon concur on the key issue: The concept of a motor program as a set of muscle commands is no longer viable. Both contributions indicate a need for change in the use of this concept by clinicians.

Whether that change should constitute abandonment of the concept or adoption of a modified version is a more difficult question. Gordon argues that the increased complexity and metaphorical nature of more recent conceptualizations warrant retention, exploration, and application. Learning to ride a bicycle is used as an illustration of motor learning to argue (1) that motor programs cannot be muscle-specific commands, (2) that the program must represent a set of rules enabling sensory motor transformations to take place, and (3) that the program must involve fine-tuning at a lower level.

Although we agree with the first deduction, the second and third deductions seem more difficult to accept simply on the basis of the example provided. That motor programs must exist, and in a particular form (ie, that a general rule has been learned), just because a performance skill is acquired is not self-evident. Much more needs to be demonstrated before the idea becomes more than a plausible hypothesis. Moreover, alternative explanations need to be considered. For example, dynamical theorists might argue that change in behavior emerges from new couplings, or coordinative structures, that arise as the person interacts with the task. Similarly, dynamical theorists may argue that the concept of a motor program is not necessary in order to successfully couple perception and action.

We agree that the idea of a motor program has indeed stimulated research into motor behavior, but the more current concepts are also likely

References