

Review

Motor Programs: Do They Exist?

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When an athlete performs certain movements (e.g., kicking, punching, throwing), it seems that the individual plans the movement in advance and then “triggers” it, as a whole, to occur. During the movement the athlete has too little time to make conscious adjustments in the execution of the movement because it lasts such a short duration. So, if the athlete does not consciously control the action, then the question arises: How is the movement controlled? Many scientists and motor control experts have theorized that these movements are controlled through motor programs. The idea of motor programs controlling certain movements is a fundamental field of motor behavior and is the focus of this paper. Thus, the scope of this paper shall be to explain motor programs and discuss the research that provides evidence for their existence such as: reaction time and the complexity of movement; deafferentation and its effect on motor performance; and electromyographical results of blocked muscular movements.

A motor program is defined as a “centrally located structure that defines the essential details of skilled action; analogous to a central pattern generator” (Schmidt, 1991 p. 285). What Schmidt means by this is the motor program is a prestructured set of commands for the movement that controls, shapes, and defines the movement. However, a simpler way to state a motor program is provided by Kerr (1982), when he writes a motor program is “a set of muscle commands that allow movements to be performed without any peripheral feedback” (p. 310). Here, the idea of a lack of feedback is introduced. This absence of feedback is key to the idea of motor programs and is essential to open-loop control systems.

Open-loop control systems have no feedback for error control. These systems “exert their influence” (Stelmach, 1976 p. 89) on the movement by the transformation during input; meaning, the pre-conceived program is initiated and the movement occurs without the aid of feedback to correct for errors. The reason that feedback is not used is that many times the movement (e.g., kicking and throwing)

is performed too fast and the human body simply does not have enough time to receive a signal and react. Thus, some form of a pre-planned motor program must be in effect.

Drowatzky (1981) discusses the concept of motor programming as an attempt to explain the “selection and initiation of responses” (p. 141). He believes a motor program is a “well-coordinated sequence of subroutines that operate together to control movement and are not dependent on feedback” (p. 141). These programs are stored in the brain or, occasionally, in the spinal cord as “internal representations” of movements. Many times, these programs are used to control movements without subsequent kinesthetic feedback to control for errors. What occurs is if a program directly controls a movement, the environment must be predictable and stable for the program to be effective in controlling the movement precisely and having a high degree of success. However, the environment during human skills is often unpredictable and the performance is undesirable if no feedback is involved, time permitting, in the correction of errors. Thus, feedback does play a role in certain movements and is involved in closed-loop control, but is beyond the scope of this paper.

Past research conducted on response selection and control indicates that evidence does exist to support the idea of motor programming. Henry and Rogers (cited in Drowatzky, 1981) suggested a memory drum model that would control movement. This memory drum theory “postulates the storage of neural commands which, upon their elicitation, are transmitted to the appropriate muscles in the correct temporal sequence to produce the movement” (Stelmach, 1976 p. 69). In this viewpoint, reactions are viewed as a whole; meaning the movement reaction “cannot be separated into a series of successive mental and motor acts” (Drowatzky, 1981 p. 143). Thus, a response that is well-learned is governed by a motor program that is stored cognitively. In fact, the researchers believe that an unlearned response “does not have a stored program but is ‘carried out under conscious control in an

awkward, step-by-step, uncoordinated manner” (Drowatzky, 1981 p. 143). Therefore, the reaction time involved with specific movements is dependent on the degree of learning involved with the response. Drowatzky (1981) states, “Reaction time is longer for poorly learned responses than for well-learned ones and longer for responses that require complex movements than for those that are composed of simple movements” (p. 143). Furthermore, Henry and Rogers believed that well-learned programs are selected more frequently than programs that are poorly learned and that a greater amount of time is required to process complex programs over simple ones (Drowatzky, 1981).

The memory drum model was supported by Henry and Rogers when they examined reaction times (Drowatzky, 1981). The researchers examined reaction times for progressively more complex and difficult tasks. What they found was that as a task became more complex, the reaction time began to lengthen. The results of their study supported the idea of the memory drum theory in that “processing time would increase with an increase in the complexity of [a] task” (Drowatzky, 1981 p. 143). Schmidt (1991) discusses the results of this famous study and states that “elevated RT [reaction time] with movement complexity was caused by increased time for movement programming prior to the action” (p. 85). Essentially, what occurs is the individual selects a response according to past experiences. However, if the response is more complex, the reaction time is longer; thus, this is the basis of Hick’s Law. Schmidt (1982) states, “[Reaction time] increase[s] as the number or possible stimulus-response alternatives increase[s]. Hick’s Law states that “choices [reaction time] appear[s] to increase by a nearly constant amount (about 100 msec) every time the number of stimulus-response alternatives double[s].”

One might ask: How does a longer reaction time demonstrate evidence of the existence of motor programming? What must be remembered is that reaction times are lengthened because of several factors. Firstly, reaction times are affected by additional elements being implemented into a task (e.g., a backswing added to a tennis forehand ground stroke instead of just the forehand ground stroke being performed). Further, if more limbs are involved with the activity (e.g., a one-hand piano chord versus a two-handed piano chord) the reaction time will be longer. And, lastly, the reaction time will increase as the movement itself becomes longer in duration (Schmidt, 1991). However, what must be recognized is that as the movement becomes more complex in any way, the reaction time becomes longer due to more time being

required to select and organize the motor program before the action can be initiated. The organization occurs during the response-programming stage of information processing. Thus, by the nature of the lengthening reaction time due to the type of movement being performed, evidence is provided for the existence of a motor programming control theory.

Other areas of research have provided useful data to support the existence of motor programming. Stelmach (1976) states the “strongest platform for the motor program is deafferentation” (p. 92). Deafferentation is a process where afferent nerve bundles that enter the spinal cord are severed so as to end the reception of periphery stimuli to the central nervous system. This process can eliminate sensory information from being carried to the brain from entire limbs. One of the first such studies was performed by Lashley (1917) who experimented on an individual who had been injured with a gunshot to the spinal cord, making him accidentally deafferented. He discovered that the blindfolded patient could make voluntary movements without the aid of sensory feedback. Thus, Lashley concluded that movement was not controlled by the “moving organ” but by some form of a motor program. Furthermore, Taub (cited in Stelmach, 1976) conducted many studies on the effects of deafferentation. In his studies, Taub would surgically deafferentate monkeys and observe their behavior to see if they could perform motor skills without much difficulty. The results of these studies indicated that the deafferentated monkeys were able to perform motor skills such as walking, climbing, winging, etc. with great ease as if nothing was different. In fact, Taub believed it was extremely difficult to differentiate between the deafferentated and non-deafferentated monkeys. The deafferentated monkeys only had real difficulties with fine motor skills (e.g., picking up marbles, manipulating small objects), but their gross motor skills were still intact and virtually unaffected. Taub, therefore, concluded that feedback was not necessary for movements to be carried out.

All deafferentation studies have not been performed exclusively on animals. Researchers (Stelmach, 1976) have used nerve compression block techniques as well as other drug therapies to induce a reversible “deafferent” human. Furthermore, Schmidt (1982) discusses the “cuff technique” of deafferentation where a blood pressure cuff is placed around an arm and is inflated to above systolic blood pressure to cut off blood flow to the limb. The lack of blood flow causes the afferent fibers to become anoxic and they cannot deliver impulses. The results of these studies would seem to provide evidence for the

existence of motor programming in that the subjects were able to perform certain tasks with the deafferented limbs. However, much debate concerning the deafferentation techniques as well as debate about the interpretation of the results clouds the issue if the results of the studies actually demonstrate if motor programming is occurring. Stelmach discusses the results of these studies and believes that the “non-specific” motor behavior occurring during the studies “limits to some degree the interpretation that motor learning occurred as a result of an internal feedback loop capable of monitoring its own neural impulses without peripheral influences” (p. 22). However, other studies have demonstrated that individuals having been blocked of all peripheral feedback using a Xylocaine nerve block of the metacarpophalangeal joint could perform finger tapping tasks within 6 percent of an unanesthetized group (Provins, cited in Stelmach, 1976). Furthermore, another researcher, Laszlo, had subjects deprived of any sensory feedback to include visual, tactile, auditory, and kinesthetic, and she discovered that the subjects could perform at the same level as Provins’s subjects (cited in Stelmach, 1976). These studies provide strong evidence that some form of central control is governing movements without the use of feedback. These studies, combined with the work of Taub and his associates, “seem to force the conclusion that the movement may occur as the result of centrally stored neural commands which are ‘structured before the movement begins and allows the entire movement to be carried out uninfluenced by peripheral feedback’” (Stelmach, 1976 p. 69). However, what must be remembered is the results of these studies demonstrate “that skilled responding is possible without proprioceptive feedback, not that motor program is a valid concept” (Stelmach, 1976 p. 75). The studies do provide strong evidence for motor programming’s existence, but they do not unequivocally prove it.

The above studies may not necessarily prove motor programming, but many of the “defenders of the motor program” often refer to Lashley and his example of pianists who can move their fingers at a rate of 16 times per second as a means of support (Stelmach, 1976). This information is strictly anecdotal, however, and the movement is extremely too fast to be controlled by a closed-loop proprioceptive feedback control of movement. Reason alone would dictate that some movements are too complex and performed too quickly to be controlled by the use of feedback. So, how are these movements controlled? Obviously, through some central motor program, and these above studies would all indicate that some central controlling mechanism is involved in motor control movement.

Another line of evidence that suggests motor programming occurs is experiments that involve mechanically blocking a limb’s movement. What transpires during these investigations is that a subject is informed “to make a quick limb action (moving a lever) and the patterns of muscle activity are examined” through electromyography (Schmidt, 1991 p. 86). However, during the course of the investigation, one of the trials will involve the limb being immobilized without the subject realizing the limb cannot be moved; it is mechanically blocked. What is most interesting about these studies is that the electromyographical tracings of the muscles involved in the movement are very similar when the limb is moved as well as when it is blocked. Schmidt (1982, p. 248) writes, “[B]ecause the usual pattern of electromyographical activity was emitted, the movement pattern appears to be structured in advance and run off as a unit.” Thus, the results of these studies demonstrate that a motor pattern is being initiated and carried out even without limb movement. More importantly, the antagonist muscles involved in the movements even contracted normally when the limb was blocked. These results “contradict theories that feedback from the moving limb (during the action) acts as a signal (a trigger) to activate the antagonist muscle contraction at the proper time” (Schmidt, 1991 p. 87). Therefore, these research results help to support the belief that motor programs organize in advance muscular activities and when initiated, they run unmodified by sensory feedback.

In summary, three main lines of evidence exist to support the idea of the pre-organization of movements through motor programs. Firstly, reaction time and how it increases for more complex movements provides evidence for the existence of motor programming. The increase in reaction time suggests that organization during the response programming before the action is occurring. Secondly, deafferentated subjects have been shown to perform movements without peripheral feedback. Thus, this demonstrates that peripheral feedback is not critical to movement and suggest a central organization of movement control. And, thirdly, the electromyographical tracings in blocked limb experiments is essentially the same for an unblocked limb, suggesting the pattern is not feedback dependent. Therefore, these lines of evidence provide sound reasoning for the existence of motor programming and that movement originates and is initiated from a central controlling mechanism: a motor program.

References

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