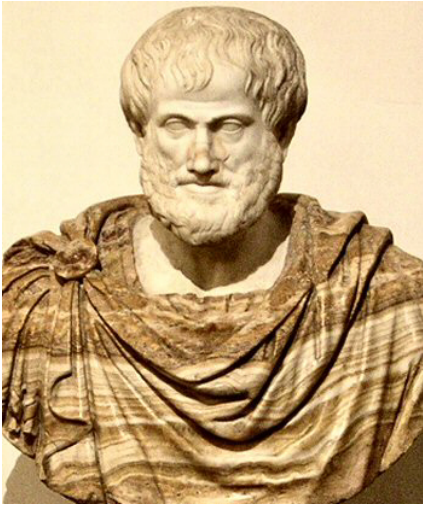


Specificity Part 3: Theoretical Rationales for the Specificity of Movement Control



Researched and Composed by Jacob Wilson, BSc. (Hons), MSc. CSCS. and Gabriel "Venom" Wilson, BSc. (Hons), CSCS.

Abstract

The purpose of this paper was to review the control mechanisms which determine the Specificity between any two tasks. Theoretical rationales covered include Movement Chaining theories, Perceptual Trace theories, and Motor Programming Theories. Finally a discussion of the current state of control theories is introduced.

Introduction

The previous article discussed theoretical rationales for the underlying elements responsible for the Specificity of various tasks. However, Specificity is not only a factor of what elements underlie a task, but also a factor of the constructs which control the task. While there are numerous theories addressing the control of human movement, they can be broadly classified as Movement Chaining theories (James, 1890, Guthrie, 1935, Hull, 1943, 1952; Skinner, 1953), Perceptual Trace theories (Koffka, 1935; Adams, 1971), and Motor Programming Theories (Henry and Rogers, 1960; Keele, 1968; Schmidt, 1975). The purpose of this paper was to provide the basis of each theory and how it pertains to Specificity.

Movement Chaining Theories

James (1890) introduced one of the earliest explanations of learning motor skills, when he proposed the Response-Chaining hypothesis. Chaining is a concept in which a stimulus is said to initiate a response. Following, the response is suggested to serve as the stimulus for a second response. Early examples of chaining include learning the alphabet. In this context, saying the word A is thought to stimulate the response of saying B, and B is thought to serve as a stimulus to trigger the response of saying C and so on. Each previous response automatically triggers the next response (Guthrie, 1935). Clearly this is a Connectionist's theory, in which learning is thought to occur through the formation of bonds between stimuli and responses.

S1-R1 = S2-R2 = S3-R3 = S4 = R4...

James took this chaining concept of learning and applied it to motor control. James (1890) suggested that movement was initiated by an external or internal stimulus leading to a response involving muscular contractions. An example of a stimulus would be the sound of a gun going off before the 100 meter dash. This would lead to contraction of relevant musculature meant to propel the athlete forward. In this context, the muscular contractions would be sensed by various muscle receptors and therefore generate afferent feedback which was carried back to the central nervous system. Not the contraction itself, but the feedback it produced would serve as a second stimulus which would then trigger a second set of muscular contractions. This would continue in an automatic chaining sequence until completion of the movement. Guthrie (1935) who advocated movement chaining summarizes by stating that 'One movement starts another, then a third, the third a fourth and so on. Our movements form series, very often stereotyped in the form of habit. These movements and their movement produced stimuli make possible a far reaching extension of association or conditioning.'

Several important features need to be delineated. First behavior scientists predominantly suggested that stimuli literally automatically triggered responses, and that this process did not require attention (Guthrie, 1935; Skinner, 1953; Thorndike, 1898; Watson and McDougal, 1929). This would explain why well learned tasks appear to be able to be performed automatically and without attention. James (1890) posited that previous contractions ensured that the order of a skill remained stable. In other words because the responses were chained together it ensured an orderly sequence each time the movement was executed. A final concept that is suggested to occur in well learned skills is that the timing between movements appears to also occur at a stable rate. James proposed that the latencies (delays) in processing of information were what ensured the stability of the timing between sequences. To elaborate, the Stretch Reflex can be analyzed. The stretch reflex is a reflex that occurs in response to rapid lengthening of a muscle. Information from the stretch is sent back to the spinal cord, which sends an automatic command back to the muscle to contract. This process is extremely stable and occurs in 40-50 milliseconds (see Wilson, 2004 for a more in depth discussion). In this context, sensorimotor skill acquisition was comprised of forming bonds between contractile generated afferent feedback and subsequent triggered responses. Generally behavior scientists believed that the more a response occurred to a given stimulus, the stronger the bond became (i.e. Aristotle's law of frequency, Thorndike's law of practice). In the context of this Specificity, the movement chaining Hypothesis would propose that modifications of skilled movements were a function of forming specific bonds to specific stimuli.

It is important to clearly realize that this hypothesis is based on feedback mechanisms. Meaning that feedback from muscular contraction is intimately involved in control of movement. Early on, Sherrington (1906) provided great support for this Hypothesis. In an investigation he cut the nerves responsible for carrying feedback from muscular contractions to a forelimb of a monkey (deafferentiation). If movement control was indeed dependent on feedback then the organism would lose the ability to control movement if it could not receive sensory feedback. After deafferentiating the animal it ceased to use its forelimb and kept it tucked against its body for the rest of its life. While this seemed to support James (1890) theory overwhelmingly, evidence discussed further on in the article demonstrates that Sherrington's experiment may not have truly reflected what the Monkey was actually capable of. For example, if an individual falls asleep on their arm, causing it to go numb, they become uncomfortable using it until it has been reoxygenated. While this is true, the individual still could have moved the limb.

The most recent theory, with similarity to the Chaining Hypothesis is the Dynamical Systems Approach to movement control. This approach suggests that it is an interaction between the internal and external environment of an organism which causes movement (Kugler et al., 1982; Kelso, 1995). The approach is also dependent on feedback mechanisms. A further important concept in learning in the Dynamical Systems approach is a concept known as degrees of freedom. Bernstein (1967), defined degrees of freedom as independent states. An independent state of the elbow involves saggital movements (i.e. flexion / extension), while the shoulder joint contains three degrees of freedom in saggital, transverse, and frontal planes (adduction, abduction, flexion, extension, internal and external rotation). Further, when musculature crossing these joints are included an almost infinite number of independent states exist. Bernstein (1967) suggested that learning was not only comprised of associations between various movements, but the freeing of independent states between limbs. For example, when an individual is in the early stages of learning to throw, the limbs appear to freeze up, to limit degrees of freedom. As practice continues these independent states are freed up, allowing more precision as well as flexibility.

Perceptual Trace Theories of Human Movement

Perceptual Trace theories of human movement have risen out of Cognitive Learning Psychology. The group of scientists who first popularized the concept are known as the Gestalt Theorists (Koffka, 1935; Hergenhahn and Olson, 2005;). They suggested that a current experience gives rise to a memory process, when it is terminated it gives rise to a memory trace which remains in the brain. The trace was suggested to influence all similar processes that occurred in the future. Thereafter similar experiences result from the interaction between the current experience and the memory trace. Each time a similar experience occurred it modified the organism which again influenced future experiences. In this context the trace becomes more and more influential until it could dominate how an individual both views and reacts in a given situation. This was an intricate way to explain how past experiences influenced future situations. As an Illustration Brewer & Tryens (1981) gave participants a picture of an office. After removing the picture they asked them to write down what they saw. The office picture contained items normally associated with an office such as pencils and paper. However it also contained items not associated with an office such as a wine bottle. The participants tended to remember items normally associated with the office, while not recalling

items not associated. Further, they actually wrote down items which were not in the office picture such as books. According to Gestalt Theory, this would suggest that the past memory trace of similar situations in offices dominated what participants actually saw in the picture, whether it was actually there or not!

Building off of the work of the Gestalt Theorists, Adams (1971) proposed the Closed Loop Theory of motor control. The Closed Loop theory suggests that feedback from movement generates a perceptual trace which is stored in the learner. With continued practice several perceptual trace elements are stored forming a Reference of Correctness, which is a representation of feedback associated with correct movement. In this context, movement was controlled by continually comparing feedback to the Reference of Correctness. An illustration can be found in driving. The Reference of Correctness would represent visual information associated with staying within a proper lane, as well as the feedback associated with the interaction between the car and outside terrain. Visual feedback could be how the car looks when it is within the lines which designate a proper lane, while mechanical feedback could be the smoothness of the road. If feedback matched the reference of correctness than the learner would continue driving in the same pattern, however if feedback did not match, then an error signal would be produced causing the learner to make a correction. For example, if the individual began to dose off and moved outside of the lane boundaries, an error signal would be produced causing the individual to straighten the car up. Or the individual may have veered off slightly causing them to move onto an unpaved part of the road. The feedback generated from driving over the bumpy terrain would be carried back to the reference of correctness, which specified a smooth feeling of driving on a paved road. This would again trigger an error signal causing the individual to make an adjustment.

The evidence supporting Adams model is fascinating. For example when we initiate a movement, impulses are carried from our brain in an area called the motor cortex out toward the relevant musculature. However, Evarts (1973) found evidence that this same information which was sent via efferent pathways (out toward the musculature) was also sent to areas in the brain associated with afferent or sensory information. Schmidt and Lee (1999) suggest that this was evidence that the sensory system was prepared with a Reference of Correctness for movement at the same time that the impulses were sent to the musculature. Other evidence comes from computer tracking and mechanical models, in which a Reference of Correctness is programmed to keep the computer simulated or real mechanical model within a type of tracking task similar to driving (Wickens 1992). In this context, the model behaves nearly identically to humans! Evidence highly supports Adams model for slow tracking tasks. There are several References of Correctness type mechanisms in the human body. These mechanisms keep temperature, ph, and hormone levels in line. However, these models have some limitations, notably in that they rely on feedback, which takes in many cases too much time to process in order to control fast, or ballistic movements in nature (Sherwood and Lee, 2003). This is further discussed in Motor Programming Theory.

The application of Adams (1971) model to Specificity are clearly outlined in article four of this series.

Motor Programming Theories of Motor Control

Motor programming theories require a clear understanding of the concept of Reaction Time (RT). Sawyer (2005) defines RT as the interval between the onset of an unanticipated stimulus and the initiation of a response. RT can be used to infer that information processing is occurring between the onset of the stimulus and the time it takes for the person to respond. Posner (1978) denotes this as the chronometric method of inference. The chronometric approach was used early on by Donders (1868) who proposed that RT was comprised of a number of substages. Current research suggests that three stages exist (Schmidt and Lee, 1999, Sawyer, 2005). The first is known as the stimulus identification stage, in which the participant identifies the stimulus. The second stage is denoted Response Selection stage, in which the individual compares the stimulus to past experiences, and from those experiences selects out a response (Sawyer, 2005, Hicks, 1952, Hyman, 1953). Finally, the third stage is denoted Response Programming, in which most of the work has been done by Henry and Rogers (1960).

Using the chronometric method, researchers often investigate the effect of adding stimuli to the environment on RT. In this context stimulus examinations can be grossly divided into Simple RT and Choice RT. Henry and Rogers (1960) suggested that 'if the situation for a particular response involves no discrimination as between two or more stimuli, and no choice (at the time of reaction) between which of two or more movements is to be made, the RT is simple, regardless of the complexity of the movement itself.' As an illustration, participants may be instructed to press one button when a light turns green. Choice RT can be defined as the possibility of two or more stimuli being presented to the participant within an RT paradigm. An example would include a red and a blue button each corresponding to the flashing of a red or blue light respectively. Once one of the lights flashes the participant must press the corresponding button. It has been found that as the number of choices increases, RT increases (Klapp, 2003). This is known as the Hick's (1952) and Hyman's (1953) Law (the law is actually mathematical, and quantitatively describes increases in RT) and is suggested to reflect the extra time needed to process information in the Response Selection Stage.

Henry (1960) summarizes research on RT by suggesting that "the simplest voluntary response to a stimulus (simple RT) requires 0.15 sec. under the most favorable circumstances; 0.20 to 0.25 sec. may be considered more typical."

The above information is critical in the context that both the Chaining Hypothesis and Closed Loop models of movement control are dependent on feedback. However most ballistic sports movements are far too fast to be controlled by feedback mechanisms (Schmidt, 2003, Sherwood and Lee, 2003, Shea and Wulf, 2005). For example a boxing jab can be thrown in 40 ms! However what occurs when a movement is too rapid to be controlled by higher order correction mechanisms? Enter the Father of Motor Learning, Franklin Henry. With his mind so akin to breaking old traditions, as well as introducing completely new concepts to the world of science he proposed the Memory Drum Theory of Motor Control.

The theory is currently known as the Motor Programming Theory, and is defined by Henry and Rogers (1960) as 'a rich unconscious store of motor memory available for the performance of acts of neuromotor skill.' More recently Sawyer (2005) posits that the motor program 'contains the spatial and temporal elements within an individual, that when initiated allows for the expression of complex movement

behavior or skill.' This construct is suggested to be utilized in a feed forward fashion, and is therefore not reliant on higher order feedback mechanisms.

In this context Henry (1960) proposed that a complicated movement necessarily involves more extensive use of learned and stored neuromotor patterns to initiate the overt motor action. He therefore hypothesized that with richer and more complicated patterns involved, a longer latent period would be required to channel existing nervous impulses from brain waves and general afferent stimuli into the appropriate neuromotor coordination centers, subcenters, and efferent nerves to cause the desired movement. In short, the more complex the Motor Program, the longer it will take to retrieve and initiate it. Henry and Rogers (1960) investigated this phenomenon in a three condition experiment. Participants in each condition all began by lifting their finger from a key when a light flashed from a button in front of them. Condition one consisted solely of the finger lift. In condition two, the participants lifted their finger from the key and grasped a tennis ball in front of them, while condition three involved the finger lift, ball grasp, and an additional striking of a ball to the right of the participant. Though each condition began with the same key lift, the reaction time increased as task complexity increased.

What is important to understand is that the prediction of increased reaction time to increased movement complexity ran against the prevailing view at the time. For example, Paul Fitts (1950), one of the most dominant leaders in the field, and indeed of all time in exercise science suggested that ' the latent time is independent of the rate, extent or direction of the specific movement required by the stimulus.' However, it was indeed found that as movement complexity increased, RT increased, supporting Henry's theory!

There are numerous other lines of evidence. Schmidt (2003) suggests that the most dominant evidence can be found in limb blocking studies. First however, it needs to be understood that the Motor Programming theory predicts exactly the opposite of the Dynamical Systems approach to learning. Programming theory posits that ballistic tasks are controlled in a feed forward fashion, where as Dynamical systems approach posits that it is the interaction between limb dynamics that cause complex movement patterns.

In this context Wadman et al. (1979) investigated rapid elbow extension movements, while monitoring electrical activity (Electromyography or EMG) in the extensor and flexor musculature. During rapid extension it was found that EMG increased in the triceps, followed by extension of the elbow. Presumably to prevent hyperextension, EMG in the biceps increased after extension. Schmidt (2003) summarizes by stating: 'people in a cognitive camp would argue that the motor program was responsible, with these things being a part of the "script" that runs off when the program is activated. The "other camp," however, would argue that the dynamics of the limb's movement and the sensory effects generated by the contracting muscles are received centrally by the spinal cord and initiate the next contractions (Feldman, 1986; Kelso, 1995); these patterns aren't programmed at all but rather emerge from the dynamics.' An example of an interaction between limbs can be found in the stretch reflex phenomenon discussed previously. In this context, rapid elbow extension could initiate rapid lengthening of the biceps, and therefore increase their EMG activity.

To examine which prediction was supported, Wadman et al. (1979) blocked the limbs of participants on unanticipated trials. In short, the participants thought they were going to perform the normal action, but instead could not move as their limbs were blocked. The findings supported the Motor Programming theory as the EMG tracing remained almost identical! First the triceps EMG rose, followed by a biceps burst. Schmidt (2003) summarizes the results by stating that 'From the dynamical perspective, this would radically alter the dynamics of the moving limb and, hence, would be expected to alter the EMG patterning. In fact, if the system depended on the joint reaching some angular position before the muscles were switched from agonist to antagonist action, then the muscles would never be switched if the movement never left the starting position... This clearly contradicts a dynamical viewpoint in which these patterns emerged from the limb dynamics. And, these results clearly support a preprogrammed view in which the script is stored in advance and run off open-loop, without being affected by the momentary changes in the limb's dynamics.'

Schmidt further concludes that 'my questions to people in the dynamical systems camp (both in personal conversations and in public presentations) referring to my interpretations of Wadman et al. (1979) has never yielded a satisfactory answer about where this patterning arises or why it is not disrupted when the limb is blocked. To say that it "emerged from the brain dynamics," as one researcher claimed in response, is just nonsense to me and seems to be just another vague attempt to prevent any "retreat" toward admitting that something was stored in advance as program theory would have it. And, how can a general theory of motor control be developed without having some way to account for phenomena in fast movements? If I am wrong, and the dynamical perspective does have away to account for this, I would certainly love to hear it, but at this writing I view this evidence as devastating to their view.'

While the limb blocking evidence is certainly devastating, Sawyer (2005) suggests that perhaps the most convincing evidence can be found in deafferented studies. As a clear example, Taub and Berman (1968) found that deafferentation of monkeys' forelimbs did not hinder them from performing complex movement patterns such as climbing and swinging, which runs contrary to Sherrington's (1906) findings. This suggests that Sherrington's (1906) results were caused by discomfort rather than ability. Further Deafferented studies in both animals and humans have been replicated with continually similar results (Schmidt and Lee, 1999).

In the context of specificity Sherwood and Lee (2003) summarize by stating that 'The core concept of Henry's view of motor programming was specificity--that motor learning was specific to a particular skill. As such, individuals with well developed motor programs might perform that skill well but would not necessarily perform another skill well, even if it was closely related. In this context, the idea that motor programs were the underlying representations of motor skill was specific to the task that had been practiced.'

Schema Theory of Motor Learning

Building off the work of Henry (1961) Schmidt (1975) proposed the Schema theory of motor learning to primarily explain the acquisition of discrete motor skills. Over the past 30 years the theory has generated much research, being referenced in over 700 journal articles, and achieving the 'citation classic' award by the Institute for

Scientific Information (Sherwood and Lee, 2003, Shea and Wulf, 2005). There are two important concepts involved in the theory. The first concerns the acquisition of a Generalized Motor Program. Like Henry's Motor Program the GPM contains the spatial and temporal elements of a task. The difference is that the program is adaptable to the environment. In this context it contains invariant features and variant features or parameters. The invariant features include the order of action, relative force, and relative timing or phasing. The parameters include absolute force and absolute duration.

An example would include an individual's signature. The signature can be written in large letters or small letters (see Merton, 1972; and Raibert, 1977). Schmidt's (1975) theory predicts that the same GPM would be utilized to write both. To simplify assume that two muscle groups are involved in writing the signature. When the signature is written in small letters muscle A elicits 1 unit of force, while muscle B elicits 2 units of force. However, when the signature is written in large letters muscle A may utilize 2 units of force, while muscle B elicits 4 units of force. In this context the parameter known as absolute force has increased. Note however that the ratio of force remained the same or relative between both signatures. The same concept occurs to phasing. If muscle A speeds up, then muscle B speeds up in such a way to keep the ratio between muscle groups constant. The order of action would concern the sequence of letters written.

The 'Schema' is the second critical concept of the theory. The term Schema has its roots in learning psychology, and was first used by Piaget (1926) and later developed and in large part credited to Bartlett (1932, 1958). The Schema can be thought of as a rule, framework or structure of knowledge about how the world works. Piaget (1926) suggested that learning occurred through the development and modification of Schemas. An example is a grasping Schema. Individuals are thought to have a Schema for 'things they can grasp with one hand.' The Schema is based on past experiences of what the individual has grasped with one hand, and when they come across an object which fits this Schema they attempt to grasp the object with one hand. If however, they reach to grasp the object and have miscalculated and cannot grasp it with one hand, then their Schema is updated with the new information and the Rule is refined. Therefore the more variations in experience an individual has the more predictive and useful their schema will be. Bartlett (1932) developed the theory after he noticed that individuals remembered events which did not actually occur. In this context the Schema Theory serves as an alternative explanation to the office example used above that was previously explained by the Gestalt theorists perceptual trace theory. In this context, individuals are said to have a rule about things which belong in an office. When participants were asked about what they saw in the office, their office Schema was aroused causing them to recall objects which in actuality were not there. Again, the more experiences the participant has had with offices the more refined their schema would become.

The idea of a schema did not have a significant impact on Motor learning research until Schmidt (1975). He suggested that along with a GMP, individuals learned two forms of Schemata. The first is known as Recall Schema and is responsible for 'scaling' the program to the environment, while the second known as Recognition Schema is responsible for error recognition following completion of a movement. Recall Schema learning is suggested to be comprised of forming relationships between the initial conditions, and parameters selected to movement outcomes.

This is analogous to forming a regression line. Parameters would be represented on the Y axis, while movement outcomes would be presented on the X axis. Each time a participant performs a skill a data point is added. Therefore the regression line is continually refined with experience. In this context, striking a baseball, such that it travels 30 or 60 feet would require the same General Motor Program. However the Recall Schema would be utilized to select out differing force parameters.

The Recognition Schema would act similarly to Adams (1971) reference of correctness; however, afferent feedback would only be compared to Recognition Schema after completion of the task. An advanced error detection mechanism is suggested to inform the participant of his or her errors without knowledge of results. Examples include the basketball player who realizes that he or she has made a three point shot after taking it, but before it has actually reached the basket, and the baseball player who is informed of a homerun prior to its exit from the park. The Recognition Schema is formed in a similar manner. The difference is that the relationship is formed between feedback produced by a movement and the movement outcome.

Schmidt (1975) felt that the theory addressed two problems associated with Henry's (1960) view of the Motor Program. The first arguable problem is that Henry proposed a very strict viewpoint, which suggested that each movement and variation of movement was controlled by a separate Motor Program. However, Schmidt (1975, 1999, and 2003) suggests that there are literally an endless combination of variations possible for any program, causing the need for an equally endless store of motor programs. The second issue Schmidt (1975) had was the novelty problem, summed by Bartlett (1932) who suggested that 'When I make the stroke (tennis) I do not, as a matter of fact, produce something absolutely new, and I never repeat something old.' Schmidt also uses the example of a tennis stroke, stating that if an individual makes 50 shots in tennis, examining the fine detail of the movement it would most likely be found that no two movements were exactly the same. Further, he suggests that the ball never has the same velocity, or location. In this context each stroke could be considered new or novel and that unless the program for the stroke was innate it should be not be possible to produce it in such a coordinated fashion.

The Schema Theory attempts to solve the problem by allowing for variation. By scaling the program to the environment, both the Storage and Novelty issues are handled. Schmidt's approach also has several predictions. For the purposes of Specificity however, the main predictions this article are concerned with are those concerning variation. According to the theory, variation will strengthen the predictive value of the recall Schema. Shea and Kohl (1991) investigated the effect of variation within a force requiring task on learning. Three experimental conditions were used. Condition one squeezed a force transducer with 150 Newtons (N), condition 2 had the same number of trials with 150 N with additional practice with +/- 25 N and +/- 5- N. Condition three practiced additional trials on the criterion task of 150 N to match the number of trials for condition two, to control for practice effects. Results indicated that the criterion + variable practice condition performed better on the 150 Newton retention test than both other conditions that only practiced the 150 Newton test! This suggests that participants learned a rule, which was strengthened by the acquisition of more data points.

Phasing also appears to have great support (Heuer, 1988, 1991, Heuer & Schmidt, 1988). In one study Shapiro (1977) had participants practice a pattern of nine wrist twisting movements. After considerable practice participants were asked to speed the movement to various degrees. It was found that, though the overall duration of movement decreased, that the proportion of relative segments of twists remained almost identical. In terms of relative force a classic study was conducted by Hollerback (1978). Participants were to write the word 'Hell' twice, with one condition being twice the letter size as the other. It was found that the size of the letters remained proportional to each other even though the absolute size had increased. Because, the amplitude of the letters is a function of the underlying musculature controlling those letters it is assumed that the relevant muscular contractions controlling the amplitude also remained proportional.

In terms of Specificity, the Schema theory suggests that variation is important quantitatively. For example, in a review on periodized training versus linear training Wilson and Wilson (2005) found an incredibly large number of studies which attested to greater gains by varying the weight and repetition scheme, as opposed to performing the same criterion lift each workout. This certainly supports the Schema Theory well. Schema theory still predicts low transfer between two differing tasks however.

A central tenet to Schema theory is the existence of separate memory states. One which represents the invariant features of the GPM, and one representing the Schema which scales the program. This has been studied by looking at statistical evidence which measures either relative force, timing, or error associated with the GPM or measures of absolute error in terms of force, timing, or error associated with parameter learning

(Shea, Wulf 2005). Consistently studies have demonstrated that practice variables differentially effect the GPM and the ability to scale the GPM, supporting the two memory state construct.

Current Motor Programming State

While the Schema Theory has much experimental evidence, it also contains problems. One such is that the concept of relative force does not hold in all conditions. Schmidt summarizes by suggesting that relative force 'cannot account for actions involving gravity. One example is walking normally versus walking with a load, such as a backpack. Here, the extensor muscles and those involved in the stance phase must operate differently as a function of the load; however, the flexor muscles and those involved with the swing phase can operate essentially independently of the load. Simply scaling all the muscles proportionately will not accomplish this.'

Another problem concerns the fact that it appears that while rule learning has substantial support, that specific practice at criterion parameters also produces specific learning at those parameters. Young and Schmidt (1990) investigated the specificity of parameter learning by having basketball players shoot from numerous distances. The mid distance was 15 feet, which is the free throw line, and is assumed to have been practiced the greatest number of trials. They then plotted a regression line, with the point of predicting the proportion of shots made against the distance the shot was taken at. It was found that while the regression line could

predict the outcome of the other distances, it did not predict the number of correct trials in the free throw shot, which had a higher proportion of shots made. This suggests that both rule learning, and specificity to well practiced parameters are also learned.

In this context, Sawyer (2005) suggests that the true explanation for how the Motor Program functions and is structured lies between Henry's (1960) and Schmidt's (1975) theories.

Creation and Modification of Motor Programs

Another issue which needs further research concerns how a Motor Program is created and modified. Originally Henry and Rogers (1960) suggested that originally without a stored program that an unlearned complex task is carried out under conscious control in an awkward, step by step, poorly coordinated manner. However, with continual practice the elements of the program are stored and eventually take over control. One of the long term notions in learning Psychology proposed by Bartlett (1932) was that memory was reconstructive in nature. This means that the elements forming long term memory had to be recombined before the memory was represented. Each time it was reconstructed it could be modified by present experiences. This notion has been supported by several lines of evidence in Motor learning, leading Wulf and Lee (1993) to propose that modification of the Motor Program is dependent upon its reconstruction. Therefore practice should optimize Motor Program reconstruction. This is covered in the 'Conditions of Practice' aspect of this series.

Cognitive Effort Theory of Motor Program Learning

Recently, Sherwood and Lee (2003) made a critical review of the Schema Theory. They suggested that while it explains learning to a great extent in motor tasks, it is still rooted in a behavioral framework, and does little to address the cognitive processes which underlie skill acquisition.

It is important to understand that behavioral scientists were wholly against mentalistic processes of learning. They suggested that learning occurred automatically through experience. For example Thorndike (1898) suggested that learning was incremental and not 'insightful.' He further stated that we should 'clear our way of one popular explanation, that learning was due to 'reasoning (Thorndike, 1911).' The father of Behaviorism, John Watson suggested that consciousness could not be objectively studied, and therefore should not be studied at all. This reasoning is found in a quote by Watson and McDougal (1929) which suggests that ' the behaviorist cannot find consciousness in the test tube of his science. He finds no evidence anywhere for a stream of consciousness...' Sherwood and Lee (2003) summarize by stating that 'The mechanistic approach to motor learning--as increments in response strength due to movement repetitions--is a remnant of the behaviorist tradition inconsistent with research that has been conducted in the past quarter century.'

There are numerous lines of evidence for cognitive processes in motor learning. For example, several studies have shown that observational learning can occur, and that learning can be improved from imagery in motor tasks (Badets & Blandin, 2004;

Black & Wright, 2000; Blandin et al., 1999; Lai, Shea, & Little, 2000; Shea, Wulf, Park, & Gaunt, 2001). In this context, Lee, Swinnen, & Serrien (1994) propose the Cognitive Effort theory of motor learning. Cognitive effort is defined as "the mental work involved in making decisions" (Lee, Swinnen, & Serrien, 1994, p. 329). More recently Sherwood and Lee (2003) define it as 'those decisions that result in perceptual and motor processes involved in movement control. For example, an ice hockey goalie needs to learn how to anticipate where a shot will go to by using perceptual and decision-making processes.' Because Motor learning requires both Cognitive and Motor processes (Sawyer, 2005), Sherwood and Lee (2003) suggest that practice must encourage both the execution of skill described extensively by Schmidt, as well as the underlying cognitive processes which also underlie the task. An illustration of this can be found in the development of error detection mechanisms. Guadagnoli and Kohl (2001), had participants perform a force replication task in which they were given 100 % knowledge of results. Knowledge of Results refers to a practice variable in which participants are told the outcome of a movement upon its completion. There were two 100 % conditions. The first were given 100 % KR for each trial, while the second condition was first asked to estimate their error and then given 100 % KR. It was found that the 100 % KR condition with a hypothesized difference had greater performance in retention than the other 100 % KR condition. The theoretical rationale is the guidance hypothesis, which suggests that 100 % KR causes participants to become reliant on KR to make adjustments in their errors, instead of the underlying cognitive processes, therefore negating learning effects.

This theory can easily be incorporated into the reconstructive theory. For example, as stated Henry proposed that originally tasks were performed consciously. The current authors posit that perhaps a portion of modifications to motor programs begin cognitively, before being integrated into unconscious motor memory. This suggestion is explored further in the Conditions of practice article.

The Stringing Theory of Motor Program Construction

Keele suggests that Motor programs may be generated by stringing together smaller programmed units of behavior so that eventually this string of behavior is controllable as a single unit. For example assume there are 9 elements in an entire sequence and these are controlled at first one at a time each by a separate motor program. With practice the first two may be linked together, the next three act as another element and the last four a third. Finally with a greater amount of experience the entire sequence may be controlled as one program.

Complexity Effect on Response Programming Stage

One of the more fascinating postulations is that the programming stage itself can be fractionated into various subcomponents. Klapp (1995, 1996, 2003) of California Hayward State University suggests that response programming can be fractionated into an INT and SEQ stages. In the INT 'the internal structure of each chunk is programmed, whereas the other process, SEQ, relates to the overall sequence of chunks.' Therefore stored information is first constructed, recalled, or programmed, then the information is properly sequenced. Based on Pews (1966) suggestion, Klapp posits that the structure itself can change with practice. Briefly, his theory explains the linking theory of motor programming. It suggests that a number of chunks can be linked together, therefore lowering RT.

Klapp (1995, 1996, 2003) has examined this through the use of Choice Reaction Time studies and Simple Reaction Time studies. Briefly, in RT paradigms the participant is first readied with a precue stimulus (denoted initial stimulus). Once the precue stimulus occurs a timer is turned, and once the time ends the second stimulus, such as a light occurs, this leads to the response (known as the implicit stimulus). Task complexity can be increased one of two ways. First, if the individual is only asked to load one chunk or sequence of information, RT will be effected by the complexity of the chunk. For example, it is suggested that motor programs run our speech. In this context, the greater the number of syllables in a word the greater the complexity of a chunk (i.e. saying 'lift' is less complex than saying 'Barbell'). The second way to increase complexity is to add sequences or chunks. An example of this was found in the Henry and Rogers (1960) study, in which they added sequences.

It is posited that INT (the programming stage) can be separated from the SEQ (sequencing stage). In simple RT, the individual already knows what response to initiate, in this context if there is only onc chunk of information, then the complexity of that chunk should not effect RT, because the response is thought to be preloaded. Evidence supports this, as increasing complexity of a chunk does not increase simple RT! However in choice RT, the individual does not know what chunk to load until the implicit stimulus. Evidence supports this as for example increasing the number of syllables in a word increases choice RT. One of the phenomenal aspects in regards to sequencing is that the elements are suggested to be able to be linked together. In experimentation Klapp had participants perform morris code pressing sequences. It was found that as the numer of sequences increased from 1 to 4 that simple RT increased. However, by session 9 the differences had disappeared. Klapp summarizes by stating 'The interpretation of that result was that, whereas the presses were each coded as single chunks initially, an entire sequence of four presses was recoded into one chunk after extensive practice According to the analysis of process SEQ, simple RT depends on the number of chunks. Thus, after extensive practice, simple RT did not depend on number of presses because both one-press and four-press responses were composed of one chunk..'

The implications of this on specificity are huge and will be discussed in conditions of practice. However, briefly one of the major benefits of specific practice is the linking together of chunks, deviations from this are suggested by the current authors to hinder chunking.

Slow Verses Fast Movement Control Mechanisms

Finally, it should be noted that it is currently thought that slow and fast movements are controlled by differing mechanisms. Adams (1971) theory for example does an excellent job explaining the control of slow tracking movements, while Henrys open loop mechanism explains the control of fast tracking movements.

Conclusion

Chaining, perceptual trace, and programming theories were discussed. Chaining theories view motor learning as a series of acquired associations between muscular contraction produced stimuli and automatic responses leading to a stable movement pattern. The perceptual trace theories explain slow tracking movements well. In this context it is thought that practicing a criterion skill generates feedback specific

to that movement, which leads to the formation of a reference of correctness. Movement is said to be controlled by a chaining of comparisons between movement generated feedback and the reference of correctness, leading to no change when movements are correct, and a correction when incorrect feedback is detected. Programming theories primarily explain tasks which are ballistic in nature. It is postulated that such movements are controlled by a rich unconscious store of motor memory. In this context, practicing a different task requires a different program to control the task, resulting in little transfer.

References and Sources Cited

- Guthrie, E.R. (1935). *The Psychology of Learning*. New York: Harper.
- Hull, C.L. (1943). *Principles of Behavior: An Introduction to Behavior Theory*. New York: D. Appleton-Century Company.
- Hull, C. L. (1952). *A behavior system: An introduction to behavior theory concerning the individual organism*. New Haven, CT: Yale Univ. Press.
- Koffka, K. (1935). *Principles of Gestalt Psychology*. New York: Harcourt, Brace & Company.
- Skinner, B.F. (1953). *Science and Human Behavior*. New York: The Free Press.
- Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior*, 3, 111-150.
- Keele, S. W. (1968). Movement control in skilled motor performance. *Psychological Bulletin*, 70, 387-403.
- Specificity of practice: the case of powerlifting. *Research Quarterly for Exercise and Sport*; 9/1/1998; Proteau, Luc
- Wadman, W.J., Denier van der Gon, J. J., Geuze, R. H., & Mol, C. R. (1979). Control of fast goal directed arm movements. *Journal of Human Movement Studies*, 5, 3-17.
- Sherwood, D. E., & Lee, T. D. (2003). Schema theory: Critical review and implications for the role of cognition in a new theory of motor learning. *Research Quarterly for Exercise and Sport*, 74, 376-382.
- Feldman, A. G. (1986). Once more on the equilibrium-point hypothesis ([lambda] model) for motor control. *Journal of Motor Behavior* 18, 17-54.
- Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Cambridge, MA: MIT Press
- Young, D. E., & Schmidt, R. A. (1999). Specific v. generalized learning in discrete actions. In

Heuer, H. (1988). Testing the invariance of relative timing: Comments on Gentner, 1987. *Psychological Review*, 97, 402-497.

Heuer, H. (1991). Invariant relative timing in motor program theory. In F. Fagard & R H. Wolff (Eds.), *The development of timing control and temporal organization in coordinated action* (pp. 37-68). Amsterdam: Elsevier.

Heuer, H., & Schmidt, R. A. (1988). Transfer of learning among motor patterns with different relative timing. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 241-252.

Merton, P. A. (1972). How we control the contraction of our muscles. *Scientific American*, 226, 30-37

Raibert, M. H. (1977). *Motor control and learning in a state space model* (Tech. Rep. AI-M-351), Cambridge, MA: Massachusetts Institute of Technology (NTIS No. AD-A026-960).

Donders, E C. (1969). Over de snelheid van psychische processen [On the speed of mental processes]. In W. G. Koster (Ed. and Trans.), *Attention and performance H*. *Acta Psychologica*, 30, 412-431. Original work published 1868.

Wilson, J. (2004) A Psycho Somatic Approach to the Initiation of Hypertrophic Stimuli. *The Journal of HYPERplasia Research*.

Sherrington, C. S. (1906) *The integrative action of the nervous system*. New York: C. Scribner's Sons.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of bmin and behavior* Cambridge, MA: MIT Press

Kugler, P. N., Kelso, J. A. S., & Turvey, M. T. (1982). On the control and coordination of naturally developing systems. In J. A. S. Kelso & J. E. Clark (Eds.), *The development of movement control and coordination* (pp. 5-78). New York: Wiley.

Evarts EV. (1973) Motor cortex reflexes associated with learned movement. *Science*. 1973 Feb 2; 179(72):501-3.

Posner, M. I. (1978). *Chronometric explorations of mind*. Hillsdale, NJ: Erlbaum.

Shea, C. H., Wulf, G. Schema theory: a critical appraisal and reevaluation. *Journal of Motor Behavior*

Piaget, J. (1926) *The language and thought of the child* (M. Gabain, Trans.). New York: Harcourt, Brace.

Bartlett, F.C. (1932). *Remembering: An Experimental and Social Study*. Cambridge: Cambridge University Press.

Bartlett, F.C. (1958). *Thinking*. New York: Basic Books.

Shapiro, D. (March, 1977). Bilateral transfer of a motor program. Paper presented at the annual meeting of the American Alliance for Health, Physical Education, and Recreation, Seattle, WA.

Wulf, G., & Lee, T. D. (1993). Contextual interference in movements of the same class: Differential effects on program and parameter learning. *Journal of Motor Behavior*, 25, 254-263.

Badets, A., & Blandin, Y. (2004). The role of knowledge of results frequency in learning through observation. *Journal of Motor Behavior*, 36, 62-70.

Black, C. B., & Wright D. L. (2000). Can observational practice facilitate error recognition and movement production? *Research Quarterly for Exercise and Sport*, 7(4), 331-339.

Blandin, Y., Lhuisset, L., & Proteau, L. (1999). Cognitive processes underlying observational learning of motor skills. *The Quarterly Journal of Experimental Psychology*, 52A, 957-979.

Lai, Q., Shea, C. H., & Little, M. (2000). Effects of modeled auditory information on a sequential timing task. *Research Quarterly for Exercise and Sport*, 71, 349-356.

Shea, C. H., Wulf, G., Park, J., & Gaunt, B. (2001). Effects of modeled auditory model on the learning of relative and absolute timing. *Journal of Motor Behavior*, 33, 127-138.

Lee, T. D., Swinnen, S. P., & Serrien, D.J. (1994). Cognitive effort and motor learning. *Quest*, 46, 328-344.