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Predicting Actual Physical Performance with Mental Image Accuracy

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1984

PREDICTING ACTUAL PHYSICAL PERFORMANCE WITH MENTAL IMAGE ACCURACY

A Thesis
Presented to the Faculty
Department of Psychology
Western Kentucky University
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In Partial Fulfillment
of the Requirement for the
Master of Arts Degree

Rodney Earl Young
May, 1984

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PREDICTING ACTUAL PHYSICAL PERFORMANCE WITH MENTAL IMAGE ACCURACY

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Rodney Earl Young May, 1984 59 Pages

Directed by: Daniel L. Roenker, Leroy Metze, and Richard Miller

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The purpose of this study was to tap into and index the motor program that is believed to control human movement, and to use that index in the prediction of future performance on the same task. A total of 75 right-handed undergraduates were tested on the rotor pursuit operating at 45 revolutions-per-minute, subjects were asked to imagine themselves tracking the target with the stylus in their left hand. During the imagery trial or trials, depending on group assignment, the subjects verbalized the word "top" each time their image made one complete revolution. Each subject received an initial 20 sec of mental imagery which included the "top" procedure. Following the initial mental imagery, each subject in each group received 12 practice trials. For Group 1 a trial consisted of 20 sec of left handed physical practice, 20 sec of mental imagery, and 40 sec of occupied rest. A trial for Group 2 was 20 sec of left hand physical practice followed by 60 sec of occupied rest, and for group 3 a trial was up of 40 sec of left hand physical practice,

followed by 40 sec of occupied rest. Accuracy of the motor program was measured by the number of "tops" the subject verbalized (the accuracy of their mental image) during each 20 sec imagery trial. Physical performance was measured by the total amount of time the subject kept the stylus over the rotating target during each performance trial.

An analysis of variance showed that the three groups did not differ in their level of performance over trials ($\underline{F}=.43$, $\underline{P}>.05$). This result was unexpected, but could be attributed to the effects of work decrement (Kohl and Roenker, 1980). This analysis of variance also showed that as expected the three groups all improved their level of performance over practice trials ($\underline{F}=60.57$, $\underline{P}<.01$). A second analysis of variance showed that the three groups did not differ in the accuracy of their initial mental images of the task ($\underline{F}=1.09$, $\underline{P}>.05$). A third analysis of variance showed that group 1's image accuracy changed over trials, that is they improved their accuracy over trials ($\underline{F}=5.86$, $\underline{P}<.01$). The most important analysis was on the data for group 1. A regression analysis was conducted by use of the Times Series Analysis Parks Method. This regression showed that the number of previous trials and the accuracy of the mental image was a significant model to use to predict future physical performance (Beta values for the two variables were 1.57 for the number of previous trials, and .24 for the accuracy of the mental image, $\underline{P}<.05$ for both variables).

Chapter I

Literature Review

Most people have experienced or observed that physical practice increases subsequent performance on a task. A few measures of skill improvement include the change in speed, strength, or efficincny of responding. Examples of the research investigating the benefits of practice in the acquisition of motor skills and cognitive abilities are examined below.

Actual Practice

In one of the earliest reports, Myers (1911) studied the influence of practice on a calculation test that subjects repeated over twenty-six days. In this test, subjects had to practice adding simple combinations of numbers over the course of the experiment. Myers found that the influence of practice was most noticeable at early stages of skill acquisition. More specifically the gain was 12.2 percent over the first ten days due to practice, the daily increase declined to 2.6 percent over the second ten days, and fell further to 1.9 percent for the last six days of the experiment. Myers concluded that the improvement which occurs with practice is not continuous. Periods of improvement are followed by periods of arrested progress, regardless of the amount of attention devoted to the task. He felt that practice may involve some unconscious process, and improvement can not occur until this process has had time to develop (Myers, 1911).

Myers (1911) also wrote that optical illusions tend to disappear with practice. He reported that the magnitude of both the Muller-Lyer and filled and empty space illusion disappear after prolonged periods of practice. During practice on the Muller-Lyer, the subject has the opportunity to learn to disregard the whole of the figure and to limit attention to the length of the horizontal line being estimated. Practice on the filled and empty spaces illusion allows the subjects to apprehend the whole image and synthesize all of the parts, thus allowing them to overcome the impulsive reponses that occur with unpracticed exposures to these illusions (Myers, 1911).

Woodrow (1939) investigated the idea that everyone improves with physical practice, but that some people improve more than others. He carried out several studies in the late 1930's to investigate his hypothesis, but concluded that there existed no common factor to explain differential score improvements for individuals (Woodrow, 1939).

Physical practice has also been shown to improve subsequent performance in skills found in laboratory experiments. In a study using a rotor pursuit apparatus to examine motor skill learning, Ammons (1947b) had subjects follow a target with a pointer while the target rotated in a circular pattern at 60 revolutions per minute (rpms). Ammons (1947b) found that after eight trials of six minutes duration each, subject's percent time-on-target increased significantly.

Levels of performance, efficiency, speed, and acquisition of new skills are areas that have been studied in relation to practice or training in sports and motor activities. Karpovich (1959) reported that the only way to develop strength in muscles is to exercise (practice) them against gradually increasing resistance. He used as an example the ancient story of Milo of Crotona, who was able to carry a four-year-old bull only because he had practiced lifting it since it was a calf (Karpovich, 1959). He reported a replication attempt of this example by a seventeen-year-old, 149 pound boy. The calf initially weighed 75 pounds, and over the 201 days he lifted it the calf grew to weigh 365 pounds and thus forced him to abandon the effort. Karpovich (1959) concluded that the principle of developing strength remains the same after hundreds of years: training or practice.

In a later report, Karpovich (1965) studied bicycle riding and found that training considerably increased work output. This study involved the endurance of jail inmates and college students on stationary bicycles. He found that subjects who practiced five times a week for at least seventeen weeks improved their endurance. These subjects increased their amount of time riding on a stationary bicycle by from 75 to 4420 percent of their original time on the bicycle (Karpovich, 1965). He concluded that training produced more improvement in skills that require endurance, rather than speed. Karpovich (1965) also studied efficiency in swimmers. He found that efficiency can be improved in activities where mastery of skills is an important factor, such as technique in swimming. Karpovich (1965) found that some swimmers, defined as poor swimmers, used five times more energy than swimmers with good technique. Practice reduced the amount of energy spent on subsequent trials when the atheletes had learned to improve their technique during training (Karpovich, 1965).

The effects of conditioning (practice) in exercise were studied by Lersten (1971). He felt that the an athelete's progression through a conditioning system follows the typical learning curve. Lersten identified the first phase of the conditioning process as a period of rapid gain characterized by physiological and psychological adjustments. During the second phase physiological gains are decreasing in quantity, but increasing in quality. In Lersten's third phase, individuals approach the limit of their physiological functioning. With practice, all atheletes should be able to approach their peak performance state and perform physical tasks at that high rate for extended periods of time according to Lersten (1971).

Astrand and Rodahl (1977) define physical training as exposure to a training or work load of sufficient intensity, duration and frequency to achieve a measurable training effect, i.e., an improvement of the trained act.

In a later study of physical practice in a laboratory setting Noble, Salazar, Skelley, and Wilkerson (1979) used college students on a rotor pursuit apparatus. In this experiment the apparatus rotated at 60 rpms with groups having different work/rest ratios. They found significant physical practice effects in all work/rest ratio groups. All subjects received 30 minutes of total practice time, and their percent time-on-target increased as seconds of total practice time increased. The effect of increased time-on-target with increased practice time was true for both male and female subjects.

In summary, the studies outlined above showed that improvement occurs after physically practicing a task. These are only a few reported studies that show these effects. One of the central elements in theories which have attempted to explain these practice effects (improved performance) is the role of feedback in performance. Feedback may be broadly defined as all the response produced information that the organism receives during and after a movement has been made (Schmidt, 1982). This information (feedback) allows the organism to select, initiate, and correct movements that have been made, so such actions can become more accurate on later trials. With the importance of feedback in mind, we now turn our attention to open-loop systems, closed-loop systems, and motor programs to attempt to outline possible differences in the use of feedback in skill acquisition theories.

Theories of Skill Acquisition

Adams (1976) outlined the difference between open-loop and closed-loop systems of feedback. He defined an open-loop system as having no way of using feedback and no mechanisms for error regulation. In this system, the input events exert their influence, and the input is transformed or processed, and then the system responds by action. There is no compensatory capability in an open-loop system. Error in an open-loop system is seen as a result of poor input, poor processing of the input, or inadequate internal conditions in the responder.

An alternative way of conceptualizing the use of feedback is the closed-loop system. Adams (1976) defined this system as having error detection and correction built in as key elements. An internal reference specifies the desired value of the output. The system's output is then fed back through the closed-loop and compared to the reference for the detection of an error. If an error in the output is detected it is then corrected. Adams views the closed-loop model as having three essential components: feedback, a reference mechanism, and error detection and correction. In Adams' (1976) theory of the closed-loop system, the reference mechanism is called the "perceptual trace." This perceptual trace is not a single entity, but rather a collection of traces formed by various movements that have occured on previous trials during practice. Adams sees the mode of this collection of traces as what governs the subject's responding. Error correction is seen as the comparison of the perceptual trace to knowledge of results.

A rival theory of the open-loop theory is that of the motor program (Adams, 1976). Like the open-loop theory, the theory of the motor program downplays the importance of feedback as a primary element necessary for movement. The motor program according to Adams (1971) is a central sequencing mechanism which runs off segments of a motor behavior without feedback playing a role. Keele (1973) wrote that if feedback is not needed for the execution of a movement, then that movements pattern must be stored centrally in the brain, or spinal cord in special cases. This stored pattern is the motor program. According to Keele,as this motor program is run off "neural impulses are sent to the appropriate muscles in the proper sequence, timing, and force, as predetermined by the program, and the neural impulses are largely uninfluenced by resultant feedback" (p. 124). Schmidt (1982) defines the motor program as a structure or structural code that, when executed, runs off a segment of motor activity that is carried out in the absence of feedback about correctness of that action.

Schmidt (1982) wrote that there are three major reasons why scientists believe that the motor program exists. The first is that the transformation or processing stage for input is too slow to maintain control over all the details involved in very rapid movements. An example he uses is Muhammad Ali's left jab. The movement time for Ali's left jab has been measured at 40 msec. According to Schmidt, feedback does not have a chance to be processed or make modifications in the action, because the movement has already been completed before the feedback arrives to be processed. This sort of rapid movement is called a "ballistic movement." A more concise definition has been given by Basmajian (1962), who wrote that ballistic movements are spurts of action followed by a period of relaxation where the action continues through its course via the momentum imparted in the initial spurt of action. The initial spurt is one of the two broad classification categories proposed by Whiting and Cockerill (1972) for ballistic movements. The second category is that it is a movement where it is important to reach the target, in order to hit it, but where the result of an overshoot, "too much" effort, does not hurt the level of performance.

In an attempt to gain a measure of the role that feedback plays in movement, Schmidt (1972) proposed the "index of preprogramming" (IP). He felt that the IP was a measure that was sensitive to "algebraic error" (AE-which is the difference between the actual time of the subject's arrival at a location and the time the subject should have arrived); movement time (MT); and starting time (ST). The IP is defined by Schmidt as being the within-subjects correlation between AE and ST over all trials. Schmidt (1972) found that an analysis of a study by Poulton (1952)showed that all subjects had high IP's, which he felt reflected the fact that MT's were short, a condition which would not have allowed for the use of feedback.

In another study testing the IP as a measure of the role of feedback in movement, Schmidt and Russell (1972) trained twelve subjects to make a 22.8 or a 49.5 cm. movement in either 150 or 750 msec. These subjects then performed a striking movement task under timed conditions to estimate the degree of feedback control in rapid and slow movements. Schmidt and Russell (1972) found that reducing the MT from 750 to 150 msec. nearly doubled the IP. This supported the idea that the lack of feedback involvement in movement of the short duration type (150 msec.) was due to the limitations in temporal feedback processing. They concluded that even "very slow" responses in the 150 msec. MT range are probably mostly preprogrammed

(Schmidt and Russell, 1972).

Glencross (1977) also proposed that ballistic movements take place free of sensory feedback control because the feedback produced by a movement is always "out of phase" with the movement to which it is relevant. This "being out of phase" is a result of the sluggishness of feedback processing. Once the feedback has been received and processed, the ballistic movement has been completed. Thus the feedback is irrelevant to the person's movements once it finally becomes available for use.

Schmidt also cites evidence that movements can not be inhibited once they are triggered as a reason for believing in motor programs. Movements also run for a brief period before they are even modifiable. Henry and Harrison (1961) used twenty subjects in an experiment that measured the speed of modification for rapid movements. They had subjects make a forward right arm swing, starting at the hip, when signaled to "go." Subjects moved their arm upward toward the shoulder as rapidly as they could, and an average simple reaction time of 214 msec. was obtained for this action. The average movement time for this action (time that the arm was actually in motion) was 199 msec. On some trials, subjects were exposed to a second signal telling them to "stop" their movement. The "stop" signal came at one of four times: 110, 190, 270, and 350 msec. after the subject had received the "go" signal. The 110 and

190 msec. signals occured during the subject's reaction time, while the 270 and 350 msec. signals occurred during the subject's movement time. Henry and Harrison (1961) found that only when the signal to stop occured at 110 msec. was there a tendency to slow down the arm movement before it was completed. For the "stop" signal at 190 msec., which also occurs during the time to react, the subjects carried out their arm movement without attempting to slow or reverse the motion. Schmidt (1982) reviewed this same study and concluded that the motion was preprogrammed, or structured in advance and run off as a whole unit with very little chance of modification by the changing conditions of the environment.

The second reason for believing in motor programs according to Schmidt is that research from various deafferentation studies have shown that all feedback may not be crucial to all performance, but may very well aid it. Deafferention means eliminating the sensory input to the spinal cord while leaving intact efferent output structures. Numerous studies report that people are able to make movements to a desired extent despite the fact that they receive no feedback from the muscles or joints involved. Insects and cats have been used to study electrically stimulated sections of the spinal cord, and results have been production of movement without the involvement of feedback to higher brain centers. Such movements are feedback free, but occur anyway. These movements are characterized as crude and rough, and it is thought that feedback, although not manditory, can aid movement in allowing for complex smooth actions once the movement has begun to occur.

Schmidt's third reason to believe in the motor program is that reaction time increases as motor task complexity increases, thus supporting the notion that rapid movements are structured in advance. Henry and Rodgers (1960) showed that reaction time, time between the presentation of a stimulus and the initiation of actual movement, increases as the movement's required complexity increases. Thus the reaction time for a simple task like raising your arm will be shorter than the reaction time for a task like catching a ball. The explanation for this increased reaction time for more complicated tasks is that the complicated task has a more complex motor program which requires more time for the muscles to get ready for action (Henry and Rodgers, 1960). The preparation of the system occurs before the actual movement begins, thus causing a longer reaction time for the complex tasks.

The subject of motor control is a complicated area, with different theories as to the nature of that control existing in contradiction of each other. The two polar camps in this debate are the centralists, who believe that movement is controlled by centrally stored motor programs, and the peripheralists, who believe that feedback-based mechanisms control movement (Schmidt, 1982).

Centralists cite studies of rapid movements, like Ali's left jab, to support their view on movement control. This approach holds that such movements do not require feedback, and may even exclude feedback from the system until after the action is completed. Feedback is seen as playing a role only in the initiation of a movement, and alterations of the motor program if the movement made does not occur correctly (Schmidt, 1982). A few problems exist in arguments supporting the centralist view of motor control. One is that as the movement time increases, the potential for using feedback also increases, thus the motor system has the potential to process such information during a long movement. A second problem is that of storage for such programs (Schmidt, 1982). Schmidt holds that a separate motor program must exist for each movement. Considering the diversity of human movement, a huge number of programs must be stored in the brain. MacNeilage (1970) studied speech as controlled by motor programs. After identifying numerous "phonemes" (sounds), movements of vocal musculature, accents, and inflections of sounds, MacNeilage estimated that there exists over 100,000 separate programs for speech. The ability of the brain to accomodate these and other mental programs appears to be a major drawback for the centralist theory. The third problem for the centeralist view is how the system responds to new and novel situations (Schmidt, 1982). The basic concern here is that if movement is produced by mental programs, how do people make new or novel movements: where do these programs come from. Schmidt reports that a careful study of 50 tennis strokes reveals that each is unique, and thus 50 different motor programs need to exist if the centralist view is correct in explaining movement. Although each stroke is a unique event, they are similar to each other as a result of practice and experience (Schmidt, 1982).

The peripheralist view of motor control, that feedback-based mechanisms control movement, also falls short of explaining all motor activity. This approach fails to explain rapid movements, but is very good at explaining movements that are slow, or require high response accuracy. Schmidt (1982) felt that this view is true because the "processes involved in the analysis of the error information takes considerable...time and mental energy." A large body of knowledge exists that supports the closed-loop control of movements that are regulated at a constant value. Schmidt gives the example of keeping a car on a highway as support for the feedback-based control of tracking behavior. The reference, or goal, in this example is staying in the road while moving at a particular speed and a certain distance behind the traffic ahead of the car. Each condition above has feedback associated with it. If at anytime the feedback from one of these sources does not match the goal, an error is detected, and the executive level is fed this information and a correction is computed (Schmidt, 1982). He concludes that the control of the car is a series of such corrections that keep the vehicle on the road. The basis for such corrections is the reference of correctness, which is a mental image or program of the goal.

Most individuals are capable of executing both rapid movements and extremely slow movements. None of the above feedback systems, as we have seen, can totally explain both slow and fast movements. Another problem for trying to explain motor behavior from one or the other camp in the centralist-peripheralist debate is that some systems can operate as both open and closed-loop systems. Schmidt (1982) discusses this point by use of the example of a car engine to explain this duel system operation. He writes that a speed-control device (cruise conrol) is a closed-loop, because it senses errors in speed and makes continuous corrections. At the same time, some of the engine parts (e.g., distributor) are operating as an open-loop system. The open-loop system is embedded within the closed-loop system in this example, while other examples could show that closed-loop systems can be, and are indeed, embedded within open-loop systems.

In light of the above issues, Schmidt (1982, p.192) reviewed the centralist and peripheralist arguments in the control of motor responses and concluded that "it will often make more sense to regard ourselves as complex combinations of open-loop and closed-loop systems." In his consideration of the narrowness of the open-loop and closed-loop debate , Schmidt felt that both systems must be considered as operating as a part of a larger more complex motor system and that one would probably be wrong to believe that only one system of control really explains the human motor system. Thus, Schmidt is arguing for a combined systems theory. He called this combination the "hybrid system." A feature of the hybrid system is that it combines distinct features from both the centralist and peripheralist theories of control in trying to explain the complexity of human movement (Schmidt, 1982). This theory allows a system to act as an open-loop or closed-loop, depending on the level of inspection.

The idea that some sort of combination of the theories of human movement control is needed is not an original idea of Schmidt's. After reviewing relevant research for the centralist-peripheralist debate, Kelso and Stelmach (1976) concluded that " the major challenge facing researchers ... lies in elucidating the manner in which central and peripheral processes interact in coordinating movements.... Both peripheral and central approaches, if accepted in isolation of each other, leave the question unanswered " (p.34).

In another review of the literature, Glencross (1977) found that the "evidence suggests an integrated control mechanism incorporating a closed-loop executive system and an open-loop motor program component." He found that most of the evidence he reviewed did not provide much support for either the centralist or peripheralist theory. He concluded that a more useful theory would be an integrated control mechanism. This central mechanism would incorporate a central control system and a sensory feedback system that sends data to the system's executive component. Glencross (1977) felt that this proposed "two-level control system" seems to provide an adequate description for the control of rapid movements, skilled actions and error correction. He further felt that responses are composed of small units of actions. Initially such small units are under sensory control, and performance is slow enough to allow feedback loops to operate. The system progressively changes to an open-loop system as the original responses become predictable, with practice, and adjacent units are combined to make larger units that can be run-off with little need for feedback (Glencross, 1977).

Reed (1982) also reviewed the literature supporting the centralist-peripheralist systems and concluded that the distinction between sensory and motor systems derived from the central-peripheralist dichotomy is incompatable with what is known about the processes underlying sensory as well as motor processes. He sees this dichotomy as resulting from the misinterpretation of the anatomical and physiological processes involved in movement. Reed (1982) argues that the idea that some movements are preprogrammed, while other movements are controlled by feedback monitoring is the psychologists misinterpretation of human anatomy. This combined theory is seen by Reed (1982) as a typical solution to the inadequacy of the central and peripheral theories of movement control. Although a number of theorist have proposed combined theories, Reed sees such combinations as being unacceptable. He writes that if movements are controlled by both central and peripheral processes, then output must sometimes have a sensory function and also a motor function (Reed, 1982). In response to what he sees as the incompatability of the proposed combined theories, Reed feels that movement is always under mixed control, not sometimes controlled by a central process and sometimes controlled by a peripheral process. Reed (1982) thus proposes a new theory of movement called the "action system."

The action system holds that movements are a result of the organisms constantly seeking to maintain an equalibrium with the environment. Reed (1982) differs from other action theorists in that he feels that the organism is not an isolated machine, because all movements intrinsically involve the environment and the organism's perceptions of that environment. All movements are seen by Reed (1982) as being an attempt to maintain the orgamism's equalibrium, but the organism had to preceive a deviation from equalibrium for it to initiate motion. It is this constant interchange of sensory and motor activity that led Reed (1982) to conclude that the centralist-peripheralist dichotomy, and proposed combination theories, are no longer acceptable as a means to explain the complexity of human movements.

The above discussions have been comprehensive reviews of the literature that have led the observers (Glencross, 1977 & Reed, 1982) to reject the dichotomous position of central or peripheral control of movement, and instead argue for a combined system to adequately explain the complexity of movement. A look at several of the specific studies that are cited as support of the combined systems theory will now be undertaken.

Roy and Marteniuk (1974) conducted a study in which subjects were required to move a free sliding cursor along a 27.5 inch long, near-frictionless track in 1 second. The thirty subjects responded in either a "fast" balistic movement or a "slow" self paced movement. The fast movement required the subject to release the cursor at a specific point and have it moving freely along the track for 1 second. The slow response required the subjects to move the cursor along the track for 1 second. Based on the results of this manipulation of feedback, Roy and Marteniuk concluded that the open-loop control system explained performance in the fast response, while the closed-loop theory explained performance in the slow response. They also felt that their findings strongly suggested that the theory used to explain motor control depends on the nature of the actions being studied (Roy and Marteniuk, 1974).

Bizzi (1980) applied sudden, unexpected torque to monkeys heads while they engaged in goal directed acts. Bizzi found that if intact monkeys are trained to make a visual discrimination which involves shifting of gaze in a purposeful manner, and then subjected to torque on their heads while looking around, they will easily compensate for the torque. Deafferented animals that observe a target flash on and off move their gaze accordingly. However, the resisting torque on these animals heads caused a disturbed movement trajectory. When the torque was removed from these animals heads, they again achieved the goal, despite lack of feedback (Bizzi, 1980). Bizzi pointed out that these results do not support a purely central process underlying movement control.

In summary, feedback is believed to play a part in the acquisition of motor skills. Various theories of feedback use in movement control were discussed, and it was shown that the centralist or peripheralist positions are inadequate in explaining the complexity of human movement. A combination of the centralist-peripheralist theories was shown to be most suited to explain the control of both ballistic and slow movements.

Mental Practice

Physical practice is not the only way to improve one's subsequent performance on a task. A large body of evidence exists to show that subjects improve their physical performance by imagining or thinking about performing that task (Richardson, 1967b). This imagining or thinking about one's performance is called "mental practice." Richardson (1969) defines mental practice as "the symbolic rehearsal of a physical activity in the absence of any gross muscular movements." Richardson (1967a) reviewed the mental practice research and concluded that 11 studies showed significant positive results that mental practice procedures are associated with improved physical performance on the tasks. In addition, seven studies showed a "positive trend" that mental practice is associated with improved performance. Richardson (1967a) reported that only three studies report negative results and that one showed "equivocal" results.

In a more recent review of the mental practice literature, Corbin (1972) says that certain classic studies (Vandell, Davis, and Clugston, 1943 and Twing, 1949) have shown that mental practice is an effective "ergogenic aid," and that there are 24 studies that have supported the view that mental practice "evokes beneficial effects" in skill acquisition. Two studies are reported to have made positive conclusions based on questionable data, and three studies are reported to have found no skill facilitation based on the use of mental practice (Corbin, 1972). The literature cited shows overall positive support for the use of mental imagery in improving motor skill. Specific studies investigating the effects of mental practice will now be reviewed.

In one of the original mental practice studies, Vandell et.al. (1943) had high school students practice basketball freethrow shooting on day one for 35 practice shots. A control group (C group) had no further practice until the final day of the experiment. A physical practice group (PP group) continued the 35 practice shots each day for 19 days. Vandell's mental practice group (MP group) engaged in 15 minutes of mental practice a day from day two through day 19. On day 20, all three groups took 35 freethrows to conclude the experiment. The daily physical practice (PP group) showed a definite improvement in performance, and a lack of physical practice (Control group) resulted in no gain in performance. Results for the MP group showed that daily mental practice resulted in later improved performance on that particular practiced skill to such a degree that mental practice was as effective as physical practice (Vandell et.al., 1943). In another skill acquisition experiment conducted along the same lines, Vandell (1943), using dart throwing skills of college freshmen, found that mental practice was again as effective as physical practice in the acquisition of this skill. Both mental practice and physical practice groups showed gain, while a control group showed no gain in performance. The effects of type of practice were measured by the percentage of gain from the inital to final day of the experiment.

Ulich (1967) examined whether motor abilities can be learned by observational learning and mental training (MP) as well as active learning (PP). Mental training was defined as mental practice through repeated imagination of the skill one is trying to learn. Subjects were tested on the following tasks: the O'Conner finger dexterity test, dart throwing, mirror drawings, folding paperboards, typewriting and riveting loops in cards. Ulich (1967) conducted sixteen experiments, but reported on only six in detail; however he also included a summary of the remaining ten studies in this article. He concluded that motor skills can be learned by observational and mental training, as well as physical training (Ulich, 1967). He also concluded that in 15 of his 16 experiments, the M.P. groups were superior to those who were trained by observation and that in a number of the experiments M.P. was as , or more, sucessful than P.P. in aiding skill acquisition.

In a study specifically testing the affects of mental practice (MP) on rotary pursuit performance, Rawlings (1972) compared MP, physical practice (PP), and a control group's time on target after 10 days of practice. The groups all practiced tracking on a rotor at 60 rpm for 25 trials, with a 30 second rest period between each trial where each subject read aloud from a color name list. The PP group continued this procedure for the next eight days. The MP group mentally practiced for 30 seconds followed by 30 seconds of color naming from day 2 through day 9. The control group was given 30 seconds of color naming followed by 30 seconds of rest from day 2 through day 9. On day 10, all subjects were retested on the rotor pursuit apparatus for 25 trials. Time on target for each subject was calculated as the average of the 25 trials only on days 1 and 10. The results were that MP was as effective as PP in acquiring proficiency on the rotor pursuit task (Rawlings, 1972).

In a recent study, that attempted to control for the methodological problems found in earlier studies involving mental practice, McKay (1981) studied speech production. His subjects practiced producing a sentence at their maximal rates by either mental practice or physical practice. Subjects then produced a transfer sentence that was similar or dissimilar to the sentence that they had practiced. Results indicated that the maximal rate of speech was faster for related than for the unrelated transfer sentences. This experiment also revealed that the degree of transfer for M.P. and P.P. groups was equivalent. McKay (1981) concluded that "the mental pratice data indicated that neither muscle movement nor concommitant sensory feedback nor knowledge of results are necessary for increases in skill as a function of practice."

In conclusion, the learning of motor tasks was shown to occur by the use of both PP and MP. When used, each showed improved performance on subsequent performance of that task. A distinction was made between open-loop (no error detection or correction), motor program, and closed-loop (has error detection and correction) theories. The reference mechanism was discussed as being a central part of the closed-loop theory of motor control. A discussion of the feedback systems we have available to us showed that a combination of the three types of motor control systems is the model needed to explain the complexity of human perceptual movement. The limitations of having a narrow scope or theory in attempting to explain feedback and output was shown to be unable to account for both rapid and slow movements and error correction. Combinations of the open-loop and closed-loop theories were proposed to be a more realistic approach to understanding how feedback is used and how the learning of motor skills can be explained.

In an attempt to study how physical skills are acquired, this experiment was designed to examine the perceptual trace subjects develop during skill acqusition via the use of mental imagery. The perceptual trace will be measured and used to predict the subject's next trial's physical performance. The measurement of this perceptual trace will be accomplished by having the subjects mentally practice the rotor pursuit task and verbally communicate the speed of their image by saying "top" as it makes each revolution. It is felt that a perceptual trace (as measured by the number of "tops" during a mental practice trial) is a stable mental program, which remains unchanged in the absence of feedback. This stability was documented by Turner (1982), who had subjects image a rotor pursuit task for nine trials of 30 sec duration each, and verbalize the word top as their image made one complete revolution. Subjects then rested for 5 minutes before engaging in nine 30 sec physical performance trials. During the imagery trials, the number of tops was counted and used to predict the later physical performance. He found that image accuracy did not change over trials of imagery practice. He concluded that accuracy of the mental image remained unchanged during the course of the experiment. Further, he found that imagery accuracy was a significant predictor of subsequent performance. Since the grouping of imagery trials with no feedback for correction of errors has been shown to be a significant predictor of subsequent grouped physical performance trials, it is felt that accuracy of single imagery trials will result in a more sensitive predictor of single physical performance trials.

Chapter II

Method

Subjects

The 90 subjects were all right-handed students drawn from psychology classes at Western Kentucky University. Self-reports from the subjects were the criterion used to establish right-hand dominance and naivete to the rotor pursuit task. Subjects were tested separatly or in pairs.

Apparatus

The principle apparati were two Lafayette Photoelectric Pursuit Rotors (Model Number 30014). The rotor pursuits were connected to Lafayette Universal Timers (Model Number 6010-BF), which programmed the rotors for the PP trials (20 or 40 sec) followed by MI then rest periods of 40 sec for groups 1, and 3, or a rest period of 60 sec for group 2. Lafayette Timers (Model Number 58007) recorded the subject's time-on-target for each trial. A cassette tape recorder was used to record the subjects verbalization of "top" each time their image made one revolution, and another cassette recorder with dual headphones was used to play white noise to cut down on distractions from extraneous noise. The rotor pursuits were checked for accuracy periodically (45 rpms) between subjects.

Procedure

The rotor pursuit device was demonstrated to all subjects prior to any practice trials. During the demonstration the subjects were told to notice that the rotor passed some particular spot as it made a complete revolution. While holding the stylus in their left hand, they were then instructed to close their eyes and imagine the rotating rotor in their mind. They were instructed to imagine themselves following the rotor with their left hand, but not to engage in any overt movement. Every time the rotor in their image made a full revolution (passed one particular spot) they were instructed to say "top" out loud to indicate the speed at which their image was rotating. These instructions can be found in Appendix A. All groups engaged in an initial 20 sec of mental imagery (MI) of the rotor pursuit task, inculding the "top" procedure.

Following the initial 20 sec of MI, each subject in each group received 12 practice trials. For group 1 a trial consisted of 20 sec of left hand physical practice (LHPP), 20 sec of MI and 40 sec of occupied rest. During this rest period subjects worked independently crossing out even numbers on a page of random numbers (digits 1-9 randomly printed in columns). After the initial MI, the second group began with 20 sec of LHPP followed by 60 sec of occupied rest. Finally, after the initial MI trial the third group also engaged in LHPP of the rotor pursuit task for 40 sec and received 40 sec of occupied rest. Subjects in all three groups wore headphones for the duration of the experiment, and listened to soft white noise to reduce the potential of extraneous variables affecting their physical performance and imagery.

Chapter III

Results

Data Analysis

Data were collected for all subjects on the accuracy of their PP, as measured by their time-on-target during practice trials. Actual time-on-target was converted to percent time-on-target for all subjects. It was expected that subjects receiving 40 sec of PP (group 3) would have a higher level of performance than subjects in the other two groups. The subjects who received 20 sec of PP and 20 sec of MI (group 1) were expected to perform at a higher level than subjects who only had 20 sec. of PP (group 2), but group 1 was expected to be closer to group 2 than to group 3. To test for these results an ANOVA procedure was conducted for the PP groups in a simple group by trials design (3x12 design). Two ANOVAS were conducted on the MI results. The first ANOVA compared the imagery accuracy prior to any PP for all three groups. The second ANOVA evaluated imagery accuracy across trials for group 1 (20 sec PP and 20 sec MI).

The most critical analysis was a regression analysis of the MI trial and the next PP trial for group 1. It was expected that the accuracy of the image (MI), as measured by the "top" procedure, could be used to estimate the accuracy of the subject's next physical performance trial on the rotor pursuit task. It was felt that this measure (accuracy of the motor program) would be a valid tool to use in the prediction of future physical performance.

The first reported analysis was a 3 (groups) x 12 (trials) ANOVA performed on the physical performance scores for the 3 groups (see Appendix B). These data are presented in Figure 1. The expected differences among groups did not occur, $\underline{F}(2,72)=1.79$, $\underline{P}>.05$. In other words there were no differences among the three groups in performance accuracy as measured by percent time-on-target. The main effect of trials was significant, $\underline{F}(11,792)=60.57$, $\underline{P}<.05$, and the groups by trials interaction, was not significant $\underline{F}(22,792)=.43$, $\underline{P}>.05$. These last two effects (significant main effect of trials, and non significant groups by trials interaction) show that performance improved across trials equally for all three groups.

The ANOVA performed on the MI results to compare the three groups imagery accuracy prior to any PP trial (see Appendix C) showed that the three groups did not differ in their accuracy, $\underline{F}(2,72)=1.09$, $\underline{P}>.05$. As was expected subjects in all groups were roughly equivalent in their imagery ability prior to any feedback being received regarding their image accuracy.

The ANOVA on the image accuracy across trials of group 1 (see Appendix D) showed that the accuracy of the image

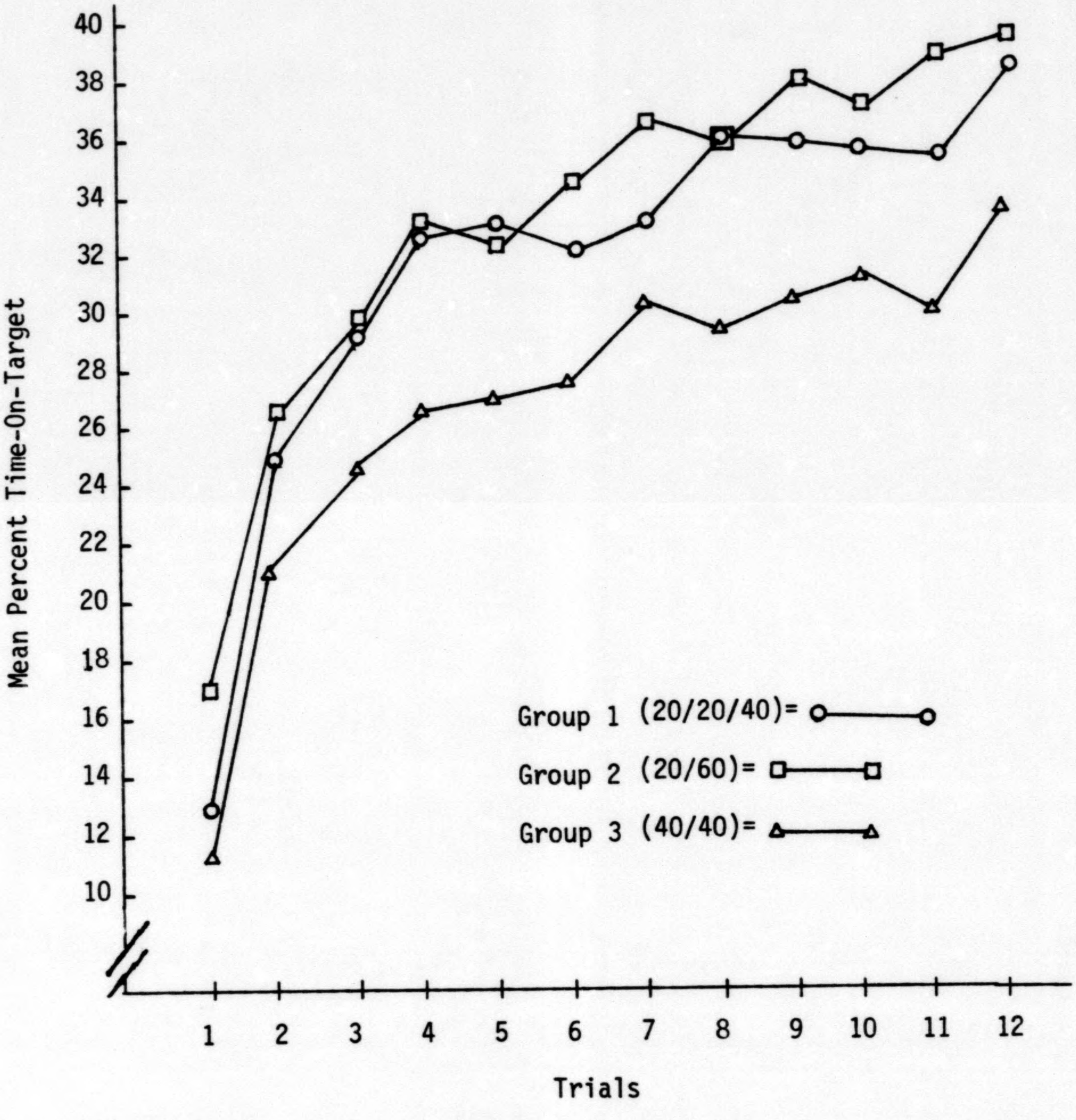

FIGURE 1. Group By Trials Interaction

improved across trials, *F*(11,264)=5.86, *P*<.05. Thus showing that the measure of the accuracy of the image used in this experiment (the "top" proceedure) was sensitive to modifications made in the subject's motor program following feedback on the accuracy of their previous image.

The most critical analysis was a regression analysis of group 1 MI trials and succeeding PP trials. This regression analysis used the accuracy of a subject's MI on trial N and the number of previous trials, to predict the time-on-target on trial N+1. This analysis was conducted with the Time Series Analysis Parks Method (Kmenta, 1971). This statistical method corrects for auto correlation, which is the error associated with using the same subjects scores at time one (trial 1) and time two (trial 2) etc. Such error results from doing correlations on a single subject's scores because such scores are not independent of one another. The regression equation formula obtained by this statistical procedure for this model was (predicted time-on-target) $\widetilde{\text{TOT}}$=.24 Acc + 1.57 PRETRS (number of previous trials) + 18.73. The Beta (B) value for both variables was significant at the .05 level (see Appendix E). The analysis of the slopes (.24 Acc and 1.57 PRETRS) indicates that as the accuracy of MI and the number of previous trials increased, PP accuracy increased as well. The positive slopes were results that were expected and indicate that the knowledge of the number of previous trials (PRETRS) and the accuracy of one's mental image (ACC) can be used to successfully predict future physical performance.

Chapter IV

Discussion

There were a number of findings revealed by this study. The first finding was that the three experimental groups did not differ significantly on level of performance as measured by group mean percent times-on-target over the twelve trials. The three groups were statistically equal in their level of performance and gain in percent time-on-target over practice trials. The second finding, was that all three groups improved their performance over the practice trials. In other words, subjects increased their percent time-on-target with practice. The third finding was that the three groups did not differ in their initial mental image accuracy, measured by their number of "tops." The fourth finding was that for the group that had twelve MI practice trials (group 1) MI accuracy changed over trials--that is, their accuracy improved over practice trials. The fifth and final finding of this study was that the knowledge of the number of previous practice trials and the accuracy of the subject's mental imagery could be used to predict that subject's future physical performance on the task. Each of the above findings will now be discussed in detail.

The first finding, that the three treatment groups did not differ significantly in level of performance was unexpected and puzzling. One possible explanation is the effects of work decrement. Work decrement is an inhibitory factor that builds up during practice and then dissipates during rest (Ammons, 1947). Thus work decrement could account for the lack of statistical differences between the three groups. Group 2 (20 sec PP/ 60 sec rest) may have been provided with enough rest time for the work decrement to totally dissipate, and thus their level of performance may represent skill learning and not the combination of learning and work decrement. Group 1 (20 sec PP/ 20 sec MI/ 40 sec rest) might have maintained some of the work decrement obtained during practice because they had a 20 sec shorter rest period per trial than did group 2. After PP trials group 1 engaged in a 20 sec MI trial, and this MI might have helped maintain some of the work decrement that had built up and thus adversely affected each subject's performance (Kohl and Roenker, 1980). Similarly, group 3 (40 sec PP/ 40 sec rest) might also not have had a long enough rest period for the work decrement to totally dissipate. Thus group 2's performance, like that of group 1, could have been lowered because of the inhibition due to work decrement. Work decrement could account for the lower level of performance of groups 1 and 3 and explain why group 3 with twice as much physical practice as the other two groups showed the poorest level of performance of all. Remember however that the difference between groups was not significant.

The second finding, that subjects in the study improved their performance with practice, was expected. Practicing the rotor pursuit task resulted in increased mean percent times-on-target for all three groups, a finding that was consistant with the literature reviewed in Chapter One.

The third finding, that the three groups did not differ in their initial mental imagery accuracy, was also expected. Thus showing that the three groups were not different in their ability to form and maintain mental images of themselves performing the rotor pursuit task.

The fourth finding, that group 1's MI accuracy (Acc) changed over trials lends support to the idea that the motor program used to initiate and carry out movements can be modified if feedback is available. The change in MI accuracy over trials measured in this experiment lends support for the combination theory (central and peripheral aspects both being involved) of human movement control. The support of the combination theory comes from the belief that the change in MI accuracy measured here reflects a change in the subject's motor program following repeated trials where feedback was readily available to allow for error correction of inaccurate motor programs.

The final finding of this study was that with knowledge of the number of previous practice trials (PRETRS), and the accuracy of one's mental imagery (Acc), future physical performance could be predicted. The predictive use of Acc and PRETRS was anticipated. It was felt that the "top" procedure was a way to tap and measure the subject's motor program, as well as a new way to index the processes that occur in the mind during the learning of motor tasks. It was further felt that the number of previous practice trials would influence the motor program by allowing the subject to make feedback-based modifications of the original motor program for the task. Together these two factors (Acc and PRETRS) were believed to be key elements for the prediction of future physical performance. It was felt that a motor program (which is executed in the subject's mind) controlled physical performance. This motor program was modifiable when feedback was available, and it was also measurable by use of the"top" procedure. Thus changes in the accuracy of the motor program (Acc) resulting from feedback (PRETRS) could be measured and indexed for predicting the subject's next physical performance trial. The results indicated that using both the number of previous trials (PRETRS) and the accuracy of the MI (Acc) to predict future physical performance resulted in a predictive model that was significant at the .05 level.

In summary, subjects in the three groups of this experiment did not differ in their level of performance across trials, or their initial mental imagery accuracy. All three groups improved their level of performance with practice, and group 1's accuracy of mental imagery changed over trials. The model of using accuracy of imagery and number of previous trials to predict future physical performance was significant and in a positive direction.

The need to replicate this study is obvious. This study is one of the first experiments to actually measure the motor program and index the changes it undergoes during practice. Further, this experiment uses the results of the MI indexing and the number of previous trials to predict future performance on the task. The success of this model in such predictions warrants further investigation on its own to determine if the results are accurate and constant. Given that the accuracy of mental imagery changes, and can be used to successfully predict future performance, the next task is to accurately identify those factors which contribute to the altering of the accuracy of the motor program.

APPENDIX A

Introduction to experiment

First of all, let me explain how this apparatus works. Please pay close attention; it is essential that you have a clear understanding of what is about to be said, and what is expected of you during the experiment. In order to insure accurate and valid testing of all subjects, it is important that you not discuss the proceedings with other students.

This is a rotory pursuit apparatus. It is used to measure hand-eye coordination. (Experimenter picks up the stylus with left hand.) One needs to grasp the stylus with the left hand, then assume a comfortable standing position with shoulders facing the apparatus. (Experimenter demonstrates described position.) Place the tip of the stylus over the target. (Experimenter places the stylus tip over the target and demonstrates.) To be successful at this task, one must always keep the tip of the stylus on the rotating target. Make one distinct and continuous movement while following the rotating target with the stylus. Do not make a discrete or jerky movement. (Experimenter demonstrates.) If I were to hand you the stylus right now, would you know what to do with it?

Instructions to practice trials

You will be wearing headphones, that will be playing white noise to cut down on the distraction from outside noise during the experiment. Now let me explain what we are going to do today. To begin with, you will have a 20 sec. practice trial. Grasp the stylus with your left hand. I will tell you when to begin, by saying the word "image." You will then mentally practice the rotory pursuit task. When I say mentally practice, I mean that I want you to imagine yourself following the target with the stylus in your left hand. Conceptualize and create a mental image of yourself performing this task. During the imagery trial (for group 2 and group 3) or trials (for group 1) I would like you to close your eyes. During the mental practice, imagine yourself making a distinct and fluid movement with the stylus. Try to get the feel of executing this task by imagining yourself performing this task as percisely as possible. Please remember that you are conceptualizing this task without any overt movement. In other words, do not actually move the stylus during the mental imagery trial(s).

Each time your image goes around once, I would like you to say the word "top" out loud. Look, pretend that this (Experimenter points to the rotor pursuit rotating at 45 rpms) is your image. You would pick a point, say here

(Experimenter places finger at nine o'clock position on the rotor pursuit while it is rotating). Now each time your image passes this point say the word top like this (Experimenter demonstrates by verbalizing the word top each time the light passes under his finger). Notice the speed at which the light rotates. (Experimenter allows subject(s) to observe the speed at which the light rotates.) Do you have any questions about the imagery practice?

Instructions for performance trials

After the imagery trial(s), you will have a performance trial (20 or 40 sec. depending on group assignment). This trial will begin when I say "practice." Upon hearing practice, open your eyes and begin tracking the target just as I demonstrated, and as you have imagined. When the time is over for the practice trial group 1 will be told to image again. During this 20 sec. of imagery again say top as your image makes a complete revolution. At the end of this 20 sec. trial for group 1, and the end of the physical practice trial for groups 2 and 3, there will be a rest period (40 sec. for groups 1 and 3, or 60 sec. for group 2) which will begin when I say the word "numbers." During this rest period you are to cross out all even numbers on the pages to your right.Please put the stylus down carefully at the start of the rest period. At the end of this rest period I will say practice, again pick up the stylus and track the target. There will be twelve such trials of practice-image-numbers. Remember again that: image means to mentally practice the task with your eyes closed while holding the stylus in your left hand, practice means to actually track the target, and numbers means to carefully put the stylus down and cross out even numbers on the pages on your right. Do you have any questions? Do you understand what to do during the experiment?

APPENDIX B

Analysis of Variance:
Groups by Trials Factorial Design

Source	DF	SS	MS	F	P
Total	899	220,894			
Between Subjects	74	146,197			
Groups	2	6839.60	3420.29	1.77	>.05
Error (b)	72	139,357.4	1935.52		
Within Subjects	825	74,697			
Trials	11	33,909	3082.64	60.57	<.01
Group x Trials	22	480.40	21.84	.429	>.05
Error (W)	792	40,307.60	50.89		

APPENDIX C

Analysis of Variance:
Pre "top" Accuracy

Source	DF	SS	MS	F	P
Total	74	666.32			
Between Groups	2	19.52	9.76	1.09	>.05
Within Groups	72	646.80	8.98		

APPENDIX D

Analysis of Variance:
Tops by Trials

Source	DF	SS	MS	F	P
Total	299	2144.92			
Between Subjects	24	1629.83			
Within Subjects	275	515.09			
Trials	11	101.08	9.19	5.86	<.01
Error (w)	264	414.01	1.57		

APPENDIX E

Parks Method Estimates

Source	B Values	T for H:H=0	Prob>(T)	STD ERR B
$ INT	18.73	24.65	0.0	0.76
Acc	.24	4.81	0.0	0.05
PRETRS	1.57	12.32	0.0	0.13

REFERENCES

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior*, *3*, 111-149.

Adams, J. A. (1976). *Learning and Memory*. Homewood, IL: Dorsey.

Ammons, R.B. (1947). Acquisition of motor skill: II. Rotor pursuit performance with continuing practice before and after a single rest. *Journal of Experimental Psychology*,*37*, 393-411.

Astrand, P. O., & Rodahl, K. (1977). *Textbook of work physiology: Physiological basis of exercise*. New York: McGraw-Hill.

Basmajean, J. V. (1962). Control and training of individual motor units. *Science*, *141*, 440-444.

Bizzi, E. (1980). Central and peripheral mechanisms in motor control. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 131-144). Amsterdam, The Netherlands: North-Holland.

Corbin, C. B. (1972). Mental practice. In W. P. Morgan (Ed.), *Erogenic aids and muscular performance* (pp. 93-118). New York: Academic Press.

Glencross, D. J. (1977). Control of skilled movements. *Psychological Bulletin*,*84*(1), 14-29.

Henry, F. M. & Harrison, J. S. (1961). Refractoriness of a fast movement. *Perceptual and Motor Skills*, *13*, 351-354.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for comlicated movements and a "memory drum" theory of neuromotor reaction. *Research Quarterly*, *31*, 448-458.

Karpovich, P. V. (1959). *Physiology of Muscular Activity*. Philadelphia: W. B. Saunders.

Karpovich, P. V. (1965). *Physiology of Muscular Activity*. Philadelphia: W. B. Saunders.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades, CA: Goodyear.

Kelso, J. A. S., & Stelmach, G. E. (1976). Central and peripheral mechanisms in motor control. In Stelmach, G. E. (Ed.), Motor Control: Issues and trends. (pp.1-40). New York: Academic Press.

Kmenta, J. (1971). Elements of Econometrics. New York: Macmillian.

Kohl, R. M. & Roenker, D. L. (1980). Bilateral transfer as a function of mental imagery. Journal of Motor Behavior, 12, 197-206.

Lersten, K. C. (1971). Physiology and physical conditioning theory to practice. Palo Alto, CA: Peek.

MacKey, D. G. (1981). The problem of rehearsal of mental practice. Journal of Motor Behavior, 13, 274-285.

MacNeilage, P. F. (1970). Motor control of serial ordering of speech. Psychological Review, 77(3), 182-196.

Myers, C. S. (1911). A text-book of experimental psychology (3rd.). New York: Longmans, Green & Co.

Noble, C. E., Salazar, O. G., Skelley, C. S., & Wilkerson, H. R. (1979). Work and rest variables in the acquisition of psychomotor tracking skill. Journal of Motor Behavior, 11(4), 233-246.

Rawlings, E. I., Rawlings, I. L., Chen, S. S., & Yilk, M. D. (1972). The facilitory effects of mental rehearsal in the acquisition of rotary pursuit tracking. Psychonomic Science, 26(2), 71-73.

Reed, E. S. (1982). An outline of a theory of action systems. Journal of Motor Behavior, 14(2), 98-134.

Richardson, A. (1967a). Mental practice: A review and discussion part I. The Research Quarterly, 38, 95-107.

Richardson, A. (1967b). Mental practice: A review and discussion part II. The Research Quarterly, 38, 263-273.

Richardson, A. (1969). Mental imagery. New York: Springer.

Roy, E. A., & Marteniuk, R. G. (1974). Mechanisms of control in motor performance: Closed-loop versus motor programming control. Journal of Experimental

Psychology, *103*(5), 985-991.

Schmidt, R. A. (1972). The index of preprogramming (IP): A statistical method for evaluating the role of feedback in simple movement. *Psychonomic Science*, *27*(2), 83-85.

Schmidt, R. A. (1982). *Motor control and learning*. Champaign, IL: Human Kinetics.

Schmidt, R. A., & Russell, D. G. (1972). Movement velocity and movement time as determiners of degree of preprogramming in simple movements. *Journal of Experimental Psychology*, *96*(2), 315-320.

Turner, M. K. (1982). *Work decrement and facilitation of the accuracy of mental imagery*. Unpublished master's thesis, Western Kentucky University, Bowling Green.

Ulich, E. (1967). Some experiments on the function of mental training of motor skills. *Ergonomics*, *10*(4), 411-419.

Vandell, R. A., Davis, R. A., & Clugston, H. A. (1943). The function of mental practice in the acquisition of motor skills. *Journal of General Psychology*, *29*, 243-250.

Whiting, H. T. A., & Cockerill, I. M. (1972). The development of a simple ballistic movement with and without visual control. *Journal of Motor Behavior*, *4*(3), 155-162.

Woodrow, H. (1939). Factors in improvement with practice. *Journal of Psychology*, *7*, 55-70.

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