THE EFFECT OF TASK STRUCTURE, PRACTICE SCHEDULE, AND MODEL

TYPE ON THE LEARNING OF RELATIVE AND ABSOLUTE TIMING BY

PHYSICAL AND OBSERVATIONAL PRACTICE

A Dissertation

by

CHARLES BEYER BLACK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2004

Major Subject: Kinesiology

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Approved as to style and content by:

David Wright (Chair of Committee)	Charles Shea (Member)
John Buchanan (Member)	Jack Nation (Member)
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ABSTRACT

The Effect of Task Structure, Practice Schedule, and Model Type on the Learning of

Relative and Absolute Timing by Physical and Observational Practice. (August 2004)

Charles Beyer Black, B.S., University of Utah; M.A., University of California, Davis

Chair of Advisory Committee: Dr. David Wright

Three experiments compared learning of relative and absolute timing of a

sequential key-pressing task by physical and observational practice. Experiment 1

compared a task with a complex internal structure (goal proportions of 22.2, 44.4, 33.4

on the three movement segments) to one with a simpler structure (goal proportions of

33.3, 33.3, 33.4). Observers only learned the relative timing as well as physical

practicers when the internal structure was simple, but learned the absolute timing in both

conditions.

Experiment 2 compared variable (700, 900, and 1100 ms overall time) with

constant practice (900 ms overall time). Observers of constant practice models learned

the relative timing better than no-practice control participants, but not as well as the

models, while observers of variable practice models learned the relative timing no better

than the control group. Observers in both practice conditions were able to produce the

absolute timing as well as those who physically practiced.

In Experiment 3 observers of an expert model were able to produce the relative

timing as well as those who physically practiced the skill, while those who observed

learning models were not. All observers and the physical practice participants were able to produce the overall duration as well as the expert model.

The results of these three experiments support earlier findings that increasing stability during practice promotes better learning of relative timing, but that absolute timing can be learned under less-stable conditions (Lai, Shea, Wulf, & Wright, 2000b). These findings also have important implications on the limitations of Scully and Newells' (1985) prediction that relative timing, but not absolute timing, could be learned by observation. Experiments 1-3 along with earlier findings (Black & Wright, 2000) have consistently found that absolute timing could be learned by observers even as the nature of the task, practice schedule, and model are manipulated. Furthermore, the results suggest a limitation to the effectiveness of learning models (Adams, 1986; McCullagh & Caird, 1990).

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CHAPTER I

INTRODUCTION

Much human behavior is learned through the observation of others from the time of infancy throughout childhood and into adult life (Piaget, 1951). Observation provides the ability to learn the consequences of different behaviors vicariously and provides information important for successful future performance. Observation is a powerful means of learning correct social behaviors and for developing values and attitudes about society (Bandura, 1987). Training through observation has the additional benefit of allowing many observers to learn simultaneously.

In addition to its function in learning appropriate social behaviors, observation is instrumental for the learning of movement skills (Martens, 1990). Considerable effort and cost is incurred in teaching movement skills in physical education, sport, and rehabilitative settings. Despite this prevalent role of observation in motor skill learning, it has received considerably less research attention than has knowledge of results (KR), though several researchers (e.g. Adams, 1987) have emphasized the need for more research into observational learning. Little is understood about what information is conveyed through observation or how this information is used by learners (McCullagh & Weiss, 2001). Efforts to improve the understanding of the mechanisms involved in observational learning have an important application to the improvement of instruction in physical education, sport, industry, and rehabilitative settings.

This dissertation follows the style of *Journal of Motor Behavior.*

Observational learning is the process of learning behaviors by observing another person (Williams, Davids, & Williams, 1999). Occasionally observational learning has been used to refer to learning from computer-generated task-relevant information (Lee, Wishart, Cunningham, & Carnahan 1997), but generally live or videotaped human models are used. There are numerous other terms that are used interchangeably with observational learning, sometimes with slightly different meanings (McCullagh & Weiss, 2001). *Modeling* is to act as a model for learners to observe. *Imitation* is the act of copying another's performance, in contrast to observational learning, which is the act of acquiring information about how to perform a task (Darden, 1997).

Observational learning is likely the most common avenue for the learning of behavior in general (Bandura, 1986; Piaget, 1951). The desire to model seems to be instinctual and is evident from a very young age (Piaget, 1951; Williams et al., 1999). New behaviors are often learned by observing the behavior of others. Observing the results and consequences of the model's actions can provide information about the effectiveness and consequences of these behaviors (Bandura, 1977). Though vision is the most common channel for observational learning audition is also important, particularly for the learning of movement timing (McCullagh & Weiss, 2001; Schmidt & Lee, 1999). Since so much behavior is learned by observation, increasing the understanding of the process of learning through observation is important in the development of a general understanding of movement control and learning in general.

Though there is a fairly extensive body of experimental work in the area of observational learning (see McCullagh & Weiss, 2001; McCullagh, Weiss, & Ross,

1989; Williams, 1993; Williams, Davids, & Williams, 1999 for reviews) these experiments have addressed many diverse issues and produced little evidence in support of any particular theoretical position (Williams et al., 1999). The most fundamental questions seem to be *what* aspects of movement can be learned through observation, and *how* is this information acquired, retained, and reproduced (Bandura, 1986; Scully & Newell, 1985). Scully and Newell said that the 'what' question needs to be answered before the 'how' questions can be addressed.

Theories of Observational Learning

Early theories of imitation tended to stress the stimulus-response relationship, with little attention paid to the problem of how observers acquired behavioral patterns necessary to imitate the actions of others (Scully & Newell, 1985). Piaget (1951) was perhaps the first to suggest that imitation was dependent on cognitive processes, though he was not specific as to the specific nature of the processes might be. Sheffield (1961) provided a more specific cognitive explanation for the ability to imitate assembly tasks. Sheffield's position was further elaborated by Bandura (1969, 1977, 1986) who provided a much more detailed cognitive explanation for learning by observation. Scully and Newell (1985) presented an explanation for observational learning effects based on Gibson's (1979) direct perception theory that specifically refuted earlier cognitive theories (see Gibson, 1979).

Piaget (1951)

Child psychologist Jean Piaget (1951) presented a six-stage developmental description of imitation, from early infancy (within days of birth) to older childhood. He

believed that imitation was a learned process dependent on internal representations of objects and actions. Beyond this Piaget presented few specific ideas as to what information is extracted from the demonstration or how this information is used to reproduce actions.

Sheffield (1961)

Like Piaget (1951), Sheffield (1961) proposed an indirect, representational basis for observational learning. Sheffield said that perceptual information is used to create a mental representation or *cognitive blueprint* that can be used to guide subsequent action. Sheffield proposed that the blueprint is a perceptual code that is used as a reference of correctness. The learner manipulates the motor output until the perception of the output fits the perceptual blueprint that is held in memory. This idea was primarily developed from research on assembly tasks in which a product created by the learner could be matched to a mental image to see if had been assembled correctly (Williams, 1993). The cognitive blueprint is particularly useful in explaining these tasks (such as machine assembly) whose timing is under the control of the performer, allowing periodic pausing in the assembly to match the product with the cognitive blueprint to check for accuracy. Other types of skill, such as open-loop movements, are more difficult to explain with the cognitive blueprint (Williams et al., 1999) since it assumes visual matching during performance of the skill.

Bandura, (1969, 1977, 1986)

Bandura's (1969, 1977) social learning theory was first presented in the late 1960s and was later expanded and renamed social cognitive theory (Bandura, 1986).

Social cognitive theory is the most popular psychological theory in the area of observational learning and it has been extensively applied in the motor learning literature (McCullagh & Weiss, 2001). Social cognitive theory includes an extensive treatment of observational learning. According to Bandura, most human behavior is learned by observation. Social cognitive theory strives to explain much about human motivation, thought, and action, with observational learning only forming a part, albeit a central part, of the theory. Bandura's views of observational learning principally address social learning (of behaviors such as aggression and nurturing) and motivational issues (such as how the gender and social status of the model affect behavior acquisition). As is the case with Sheffield's theory, the efficacy of social cognitive theory to be generalized may be limited by the peculiarities of the tasks that Bandura chose to study. Much of the work of Carroll & Bandura (1982, 1987, 1990) used tasks in which the goal was the correct ordering of a series of arm and hand positions, with recognition and recall being tested as a function of the number of ordering errors. In the Carroll and Bandura studies the quality of movements was generally not evaluated, only the presence or absence of the different parts of the movements. Though it is frequently important to produce a series of movements in the correct order, it is also important to produce those movements with correct precision and timing, which are also common measures of learning of motor skills (Adams, 1987).

Bandura proposed four processing stages in observational learning: attention, retention, production, and motivation. Though motivation is presumably necessary in order for skills to be learned, typically motor learning research assumes that subjects are

motivated enough to attend to and learn the task at hand at some level. Attention refers to the ability to perceive and extract information from the environment to create a cognitive reference, which allows later reproduction of the movement. Bandura suggested that it may be necessary to channel the attention of the learner by narration or by accentuating the essential features of the modeled performance, since the perceptual display contains an overwhelming abundance information, much of it presumably irrelevant to task performance.

Cueing is the pointing out of important features of a modeled performance to subjects (Rothstein and Arnold, 1976). Rothstein and Arnold analyzed studies of video tape replay (VTR) and found that cueing was important for lower-skilled performers to make use of VTR, but that more-skilled performers were able to perform equally well whether cues were available or not. This interaction with skill level may be due to the development of knowledge of what cues to attend to or due to improved perceptual efficiency, or both. This interaction may also indicate that irrelevant environmental information gets filtered out by more experienced learners. This idea is supported by comparisons of full visual displays to those that present only essential kinematic information (Williams, 1989).

Kinematic models highlight kinematic features (such as joint angles, limb displacement, limb acceleration, relative motion of different limbs) of a modeled performance in an effort to reduce distracting stimuli. Point-light displays, in which the joints are represented as points of light (Runeson and Frykholm, 1981; Williams, 1988, 1989), and stick-figure displays, which display body segments as line segments

(Williams, 1988), are two kinematic modeling techniques that have been used. Runeson and Frykholm found that it was possible for subjects to perceive kinetic as well as kinematic properties of movement from point-light displays. Participants in William's studies were able to perceive and reproduce throwing tasks with point-light and stick-figure information as well as they could with information from a full visual display.

The results of these experiments emphasize the importance of kinematic or topological information in observational learning. If the kinematic information is readily available through one would expect learners to be able to reproduce kinematic features of movement quickly relative to changes in outcome such as speed or accuracy. Williams (1988, 1989) indeed showed that subjects were able to accurately reproduce the kinematic sequence of a throwing accurately after four to six trials. Most observational learning studies have measured only outcome scores and not changes in form kinematics (McCullagh, 1993; Wiese-Bjornstal & Weiss, 1992). Presumably changes in form will take place before significant changes are evident in outcome. In short-term experimental situations, looking at changes in form as well as improvements in outcome scores may better assess modeling effects. Rothstein and Arnold (1976) indicated that the effects of self-modeling took several weeks to take effect, supporting this viewpoint.

Retention is the process of retaining information from the demonstration so that it can be used to aid in later reproduction of the movement. In contrast to Sheffield (1961), Bandura proposed that information is not stored as a perceptual code, but is translated into imaginal or verbal code. Studies in which subjects were encouraged to

use verbal mnemonic procedures support that some information is more effectively retained in verbal form than in imaginal form. Other studies indicate that information about larger or more spatially separated objects take longer to mentally manipulate indicate that some information is stored in an imaginal or spatial form (Bandura, 1986). Bandura suggested that learners must store observations symbolically, because modeled activities are too rich with irrelevant details to be efficiently retained in perceptual code. Recent work on context-dependent memory somewhat argues against this notion, as the absence of irrelevant or redundant cues may lead to poorer retention of skills (Wright & Shea, 1994), implying that these irrelevant cues may also be coded in memory. An alternative explanation is that the removal of some stimuli changes the nature of the stimulus environment, causing perceptual decrements.

Bandura was not specific as to how observed information is abstracted, suggesting that representations may be rule-based, or may be reduced forms of the original perceived information, or even elaborated forms (such as through dual modality representations) of that information (Williams, Davids, Williams, 1999). He also said that verbal representations are useful for retaining certain types of movement information, such as when serial ordering of elements is important (e.g. Carroll & Bandura, 1982, Weiss & Klint, 1987). Both verbal and imaginal representations can be rehearsed, and Bandura proposed that mental rehearsal is a mechanism for learning, with rehearsals providing vicarious movement experiences. Though there is research evidence that mental rehearsal can produce movement learning, particularly in the case of movements with a large cognitive element, the effects are generally considerably smaller

than those found in observational learning studies (Ryan & Simons, 1983). Therefore this mechanism isn't likely to explain more than a small percentage of motor learning from observation. In any case, mental rehearsal takes place in working memory and cannot directly account for the long-term retention of skill. Mental and verbal rehearsal can at best be said to be a mechanism to enhance the strength of long-term representations.

Bandura (1986) proposed that subjects who could recall correct sequences could also reproduce them. He therefore proposed that there is a single representation for recognition and recall memory. This idea may well be an artifact of the methods used in many of Bandura's studies, in which subjects were only asked to pick out elements of the serial positioning task as correct or incorrect, and no assessment was made of the quality of the movement. In one study (Carroll & Bandura, 1987), correlations between recognition and reproduction were statistically significant, but far from perfect (r =.34-.64). However, it is not uncommon for learners to be able to successfully recognize errors in their own or others performances and yet be unable to correct the errors without considerable additional practice (McCullagh, 1993). This implies that recognition and recall are separate memory states, an important feature of Schema Theory (Schmidt, 1975), a theory that will be discussed later.

Bandura's description of production processes are the most general of his ideas on observational learning. He proposed that production is primarily a conception-matching process in which sensory feedback is matched to cognitive conceptions. Movement information is hierarchically organized, with the simpler elements learned

first. If these elements are not sufficiently learned, the observer must improve them before the movement conception can be effectively implemented. Feedback is used to correct these movement errors and to augment the information that was initially gained by observation. As skill improves, movements can be performed without much attention to feedback.

Scully and Newell, 1985

Scully and Newell (1985) proposed an alternative view of observational learning based on Gibson's (1979) direct perception ideas. Scully and Newell suggested that there is no need for a cognitive representation of movement, since cues in the environment contain all the information necessary to initiate and guide movement. This idea suggests that observational learning has its effect by increasing the learners' familiarity with the information that is available in the environment so that this information is used more efficiently and effectively in future performances, rather than in the development of a motor program that can be invoked later.

The major contribution to the observational learning literature made by Scully and Newell is the idea, based on the research of Johansson and associates (Gunnar Jansson, personal communication, September, 1995), that aspects of coordination (analogous to the generalized motor program in Schema Theory), such as the relative motion of the body and limbs, are what is most effectively acquired through observation. Scully and Newell pointed out that many observational learning studies use tasks that involve scaling of an already existing coordination pattern, thus limiting the effectiveness of observation. Magill's (1993) review of the observational learning

literature concluded that studies which used tasks that involved learning new coordination patterns were more likely to demonstrate observational learning effects than those which used tasks that involved scaling already learned movements.

Magill and Schoenfelder-Zohdi (1996) also provided some experimental support for Scully and Newells' (1985) hypothesis. In an experiment using a rhythmic gymnastics rope manipulation skill, participants either observed a model or not and either received knowledge of performance (KP) or not. Participants who observed the model made fewer errors pertaining to the coordination patterns of their body and limbs than did those participants that had not observed the model. Whiting (1988) also found that those who observed a model performed a ski-simulator task with more "fluency" of the platform movement and less variability than those who had not observed the model.

Several recent papers have questioned the assumption that relative motion is necessarily readily discernable. Scully and Newell (1985) based their predictions on a body of literature that relied largely on recognition of running and walking, movements that are very familiar (Johansson, 1973, 1976). Bingham, Schmidt, and Zaal (1999) and Zaal, Bingham, and Schmidt (2000) found that observers found unfamiliar relative motion patterns difficult to perceive without additional information. Hodges, Chua, and Franks (2003) found that demonstrations alone were insufficient for participants to either learn to recognize or learn to produce unfamiliar coordination patterns unless augmented feedback was also provided. These studies argue against Scully and Newells' prediction that relative features of motion can be learned by observation alone, at least if the task is an unfamiliar one.

Vogt (1995, 1996), Willingham (1998)

The most recent contributions to ideas about observational learning involves the relationship between mental imagery and observation. Vogt (1995) proposed that mental imagery formed a bridge between perceptual processes (observing a demonstration) and motor processes (performing the skill). He therefore predicted that observational practice (in which a distracter task was used after the demonstration to prevent mental rehearsal) would be inferior to physical or mental practice. Using a cyclical arm flexion-extension task, he found that physical practice, mental imagery, and observational practice produced similar improvements in relative timing. He concluded that observation involves motor production processes as well as perceptual processes. He extended this finding (Vogt, 1996) by comparing immediate to delayed retention after a single demonstration. Performance either stayed the same or deteriorated between the retention sessions, leading Vogt to conclude that the effects of observation or imagery were evident after only one demonstration, strengthening his conclusion that motor generative processes are involved during observation. Blandin, Lhuisset, and Proteau (1999) found that observers could match physical practice participants after the first few trials of practice, supporting the view of Vogt.

Willingham (1998) suggested that proprioception was critical for implicit learning, but that learning on an explicit level could take place in the absence of proprioception by either observation or mental practice. Though Willingham said that observation and mental practice can only produce conscious, explicit knowledge, there is certainly evidence from the implicit learning literature that at least the perceptual events

that precede movement production can be learned subconsciously (Green & Flowers, 1991; Shea, Wulf, Whitacre, & Park, 2001; Wulf & Schmidt, 1997).

Learning Models versus Skilled Models

Traditionally, it was assumed that models should be highly skilled at the target activity so that observers would receive information about how to perform the task correctly. This assumption questioned by Adams (1986) who used "learning models" that practiced a task on which they had no prior exposure. Adams found that observers of learning models who also received the models' KR were superior on a retention test to those who had viewed the model without receiving the KR and those who had physically practiced the task and received their own KR. This view was extended by McCullagh and Caird (1990) with the finding that participants who viewed an learning model and received the model's KR were superior to participants who viewed an expert model or who viewed a learning model but did not receive the model's KR. These results were interpreted by Adams as well as McCullagh and Caird as showing that by receiving KR about performances of varying accuracy, observers were able to go through the same cognitive processes as physical practice participants, and were able to develop a reference of correctness that could be used when they performed the task themselves (see also Schmidt & Lee, 1999). Pollock and Lee (1992), Herbert and Landin (1994) and McCullagh and Meyer (1997) provide additional support to the effectiveness of learning models with model KR.

Relative Timing and Absolute Timing

Schmidt (1975) proposed that relative timing and absolute timing of movement were housed in separate memory structures (the generalized motor program and recall schema). Though schema theory as proposed by Schmidt has been the topic of much debate, there is considerable evidence that relative timing and absolute timing of movement are learned independently. Wulf, Schmidt, & Deubel (1993) found that reducing the frequency of knowledge of results enhanced the learning of the relative features of a spatio-temporal task, but that this degraded the learning of the absolute force and timing of the task. Similar results were found by Wulf, Lee, & Schmidt (1994).

The more recent dynamic systems approach to movement (Kelso, 1995) also emphasizes a distinction between relative phase or timing and speed or frequency of movements. In this view, relative phase (i.e. the spatial and timing relationship between different limbs or joints) is a "collective variable" that defines the coordination characteristics of s skill. This idea is similar to the role of relative force and timing, which define a "class" of skills in the generalized motor program idea.

Another contribution of the dynamic systems approach is to view learning as a re-mapping of intrinsic dynamic patterns (Hodges & Franks, 2000; Hodges, Chua, & Franks, 2003; Zanone & Kelso, 1995). According to this view, certain coordination patterns are intrinsic and stable (such as in-phase bimanual coordination) and the learning of new coordination patterns requires a de-stabilization and re-structuring of the intrinsic patterns to develop stabile performance with a new pattern. Hodges et al. (2003) found that observation of the goal pattern was insufficient to learn a new coordination

pattern (90 degree relative phase) unless video feedback of the learner's performance was also available.

Several experiments have also compared the learning of relative and absolute timing by observers. Lai, Shea, and Little (2000a) and Shea, Wulf, Park, and Gaunt (2001) found that after being presented with a perfect model and watching learning models, observers were able to learn the relative timing of a key-pressing task as well as the models, but that they were not able to produce the absolute timing as accurately. In contrast, Black and Wright (2000) and Blandin, Lhuisset, and Proteau (1999) found that observers learned the absolute timing of a sequential movements, but not the relative timing. Blandin et al. did find that observers of an advanced model were able to learn the relative timing, but only after engaging in physical practice with feedback.

Purpose of the Study

The present experiments measured three aspects of performance on a timing task; relative time of the three movement segments, production of the goal overall time, and ability to estimate correct overall time production. The nature of the task (complex or simple segment ratios), practice schedule (varied or constant), and the type of model (learning or expert) were manipulated. Numerous studies have shown independence in learning of the relative timing and overall timing structures of movements (Lai & Shea, 1998; Wulf, Lee, & Schmidt, 1994; Wulf, Schmidt, & Deubel, 1993). Scully and Newell (1985) predicted that observational learning would also result in differential learning of relative and absolute features of movement.

Black and Wright (2000) tested the prediction of Scully and Newell and found that relative and absolute timing were not learned equally well, but in the opposite direction of Scully and Newells' prediction (i.e. absolute timing was acquired by observers but relative timing was not). More recent experiments by Shea and colleagues supported the predictions of Scully and Newell. The three experiments of the present study were conducted to further explore the effects of observation on the learning of relative and absolute timing and to examine the apparent contradiction between the findings of Black and Wright (2000) on the one hand and Shea and colleagues on the other. Another purpose of the present study was to further explore the role of error detection ability (as assessed by subjective estimation of overall movement duration) in observational learning.

CHAPTER II

EXPERIMENT 1- THE INFLUENCE OF TASK STRUCTURE ON LEARNING BY PHYSICAL AND OBSERVATIONAL PRACTICE

Introduction

Demonstrations are one of the most common techniques for the teaching of motor skills (Darden, 1997). An implicit assumption of demonstrations is that information about movement production can be acquired through observation of another performing a skill. A fundamental question for researchers of this observational learning process is what can be learned from observation (Scully & Newell, 1985). Scully and Newell predicted that relative features of movement can be learned by observers, but that absolute features of the movement can not. This is of theoretical importance in light of motor program theory that relies on the independence of relative and absolute timing (Schmidt, 1975). Furthermore, recent research has supported independent learning of relative and absolute timing (Lai & Shea, 1998).

A previous experiment (Black & Wright, 2000) found that observers of were able to produce the absolute timing of a key-pressing task as effectively as did the models who had engaged in physical practice and received knowledge of results (KR) about their performance. Observers were unable however to produce the relative timing structure of the movement as well as those who had physically practiced, and in fact produced the relative timing no better than had participants who had no exposure to the task prior to the retention test. This result was contrary to the predictions of Scully and Newell (1985). One possible reason for this result was that the physical practice

participants that served as models in Black and Wright produced the relative timing quite poorly as compared to data from previous experiments using the same task (Lai & Shea, 1998; Lai, Shea, Wulf, & Wright, 2000b). Thus the models may not have provided sufficient information for the observers to learn the relative timing of the task from observation alone. The goal of Experiment 1 was to provide models for the observers that produced lower relative timing error than did the models in Black and Wright. It was hypothesized that lower relative timing error by the models would enable observational learners to acquire the correct relative timing since observers would be able to get a better sense of what correct reproduction, especially the relative characteristics, of the task entailed.

In the Black and Wright experiment, the goal was to produce the three segments of the movement with proportions of 22.2, 44.4, and 33.4 for segments one, two, and three, respectively. This timing pattern is challenging to acquire and typically takes a reasonable amount of practice (Lai & Shea, 1998; Lai et al., 2000b). Wright and Shea, (2001) used a variation of the task that required the three segments to be performed at a constant speed (i.e. goal proportions of 33.3, 33.3, and 33.4 for the three task segments) and found that relative timing error was considerably reduced compared to the 22-44-33 version of the task. Performing at a constant speed seems to be a 'natural' or 'intrinsic' pattern (Blandin, Lhuisset, & Proteau, 1999; Kelso, 1995) that is already within the repertoire of the participants (i.e. participants are able to perform this timing from the start of practice with little error).

Experiment 1 compared acquisition of the 22-44-33 (complex) task with the 33-33-33 (simple) task. It was predicted that the simple task would lead to considerably reduced relative timing error (RTE) by physical practice participants during acquisition of the task. This reduced error during acquisition was in turn hypothesized to lead to reduced RTE on the retention test by the individuals that observed the models.

Methods

Participants

Sixty participants (32 males and 28 females) were recruited from undergraduate kinesiology classes and received course credit for their participation. Informed consent was obtained from all participants prior to participation in the experiment.

Apparatus

The numeric keypad portion of a standard computer keyboard was used. Task stimuli and knowledge of results were provided on a 17" VGA computer monitor.

Task

Each task involved typing a particular sequence of keys on the computer keyboard, specifically the "2", "4", "8", and "6" keys in sequence with the right index finger. Not only was the participant required to reproduce the correct sequence of keys but also a pre-determined set of goal times for each component of the sequence. The task required that the sequence of key presses maintain particular goal proportions for the three segments of the task (Segment 1 = "2" to "4", Segment 2 = "4" to "8", and Segment 3 = "8" to "6"). The goal proportions for the simple task were 33.3 for Segment 1, 33.3 for Segment 2, and 33.4 for Segment 3. The goal proportions for the complex

task were 22.2 for Segment 1, 44.4 for Segment 2, and 33.4 for Segment 3. Moreover, the task required that a particular overall time be achieved. For both task conditions, overall times of 700 ms, 900 ms, and 1100 ms were practiced.

Procedure

All participants were presented with written instructions prior to practice. Individuals assigned to the physical and observational conditions worked in pairs during acquisition, with the physical practice participants serving as models for the observational practice participants. During the practice session, the physical practice participant sat at the computer and practiced for 108 trials, presented as six blocks of 18 trials with 15-second rest intervals between blocks. Each block of 18 trials consisted of 6 trials each of the 700, 900, and 1100 ms versions of the task. These three task versions were presented in random order. The observational practice participant sat to the right of the physical practice participant so that a clear view of both the numeric keypad and the monitor was available.

Knowledge of results (KR) was provided after the production of the key sequence. The KR included both the required goal proportions and overall time for that particular trial as well as the proportions and overall time as performed by the participant immediately below (proportion results were rounded to the nearest whole number). The

KR was displayed in the following fashion:

33-33-33 900

28-34-37 808

Approximately 24 hours after the practice session, each participant returned for the retention session. All participants performed alone during the retention session. Participants in the no practice condition participated in the retention session but without prior exposure to the task. The retention session consisted of 18 trials of the 900 ms version of the simple task for those assigned to the simple task during acquisition or the complex task for those assigned the complex task during acquisition. Participants assigned to the complex task were presented the complex task goals (22-44-33) prior to each trial and participants assigned to the simple task were presented the simple task goals (33-33-33) prior to each trial. Participants received no KR during the retention session. In order to assess recognition ability, after each trial of the retention session, participants were asked to provide an estimate, in milliseconds, of their movement time on the previous trial.

Results

Error Measures

Relative timing error (RTE) was calculated for each trial as the sum of the absolute difference between the goal proportion for each segment and the proportion for the segment as performed by the participant:

Relative Timing Error (complex) $= |s1\text{-}22.2| + |s2\text{-}44.4| + |s3\text{-}33.4|$

Relative Timing Error (simple) $= |s1\text{-}33.3| + |s2\text{-}33.3| + |s3\text{-}33.4|$

in which s1,s2, and s3 were the proportions as performed by the participant for segment 1, segment 2, and segment 3, respectively.

Overall Duration Error (ODE) was determined as follows:

$$Overall\ Duration\ Error = \sqrt{CE^2 + VE^2}$$

Where constant error (CE) was the average of the signed errors over a block of six trials and variable error (VE) was the standard deviation of the CE for a block of six trials. ODE in this case is considered a measure of overall accuracy that considers both response bias and response variability in specifying the overall duration of the movement. ODE and RTE have been used as indexes of absolute and relative timing errors in previous studies (Lai & Shea, 1998) and have been shown to assess independent dimensions of movement production (see Lai et al., 2000b).

To assess recognition accuracy in the retention test, absolute difference error (ADE) was calculated as the absolute value of the difference between the overall movement time and the participant's estimate of the movement time for each trial. Mean ADE for the retention trials for each participant were calculated. Level of significance was set at .05 for all variables for all experiments. Simple main effects analysis was used to analyze interactions and Duncan's Multiple Range Test was used for post-hoc analyses of main effects when appropriate.

Acquisition Session

Since only physical practice participants performed during the practice session, only data for these individuals could be analyzed. Separate 2 (Task Complexity: simple or complex) X 6 (Practice Block: 1-6) ANOVAs were calculated for RTE and ODE. No
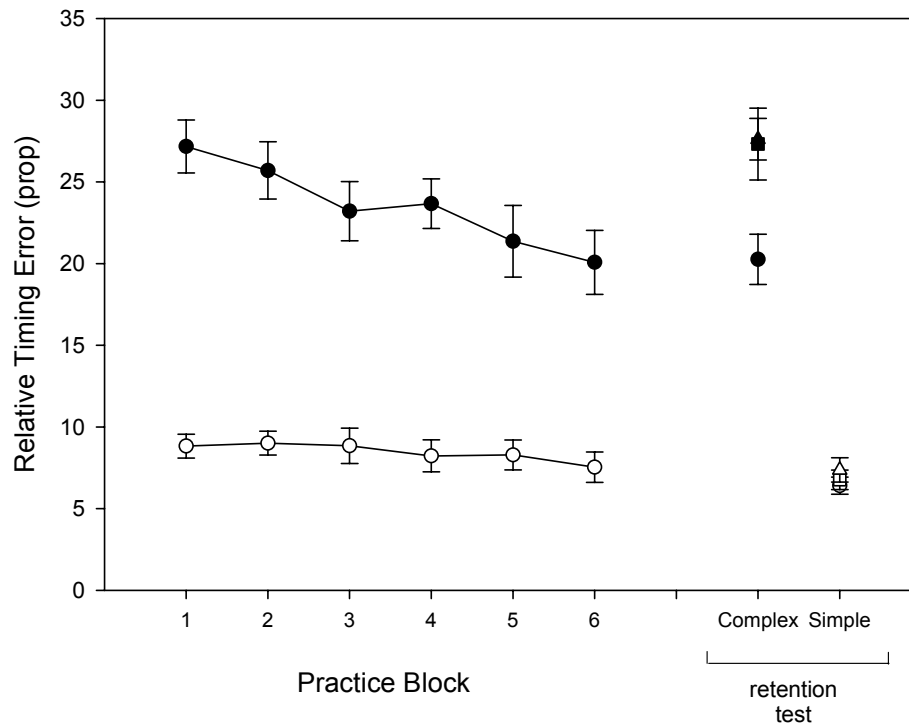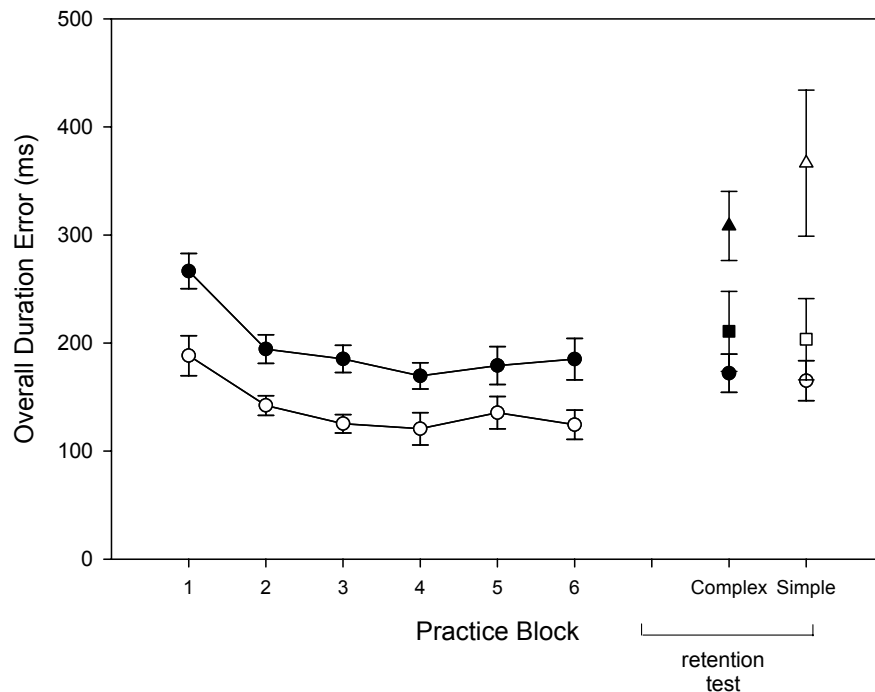
FIGURE 1. Mean relative time error for acquisition and retention phases of Experiment 1 Symbols represent physical practice (circle), observational practice (square) or no practice (triangle). Open symbols indicate simple relative timing and filled symbols indicate complex relative timing. Error bars represent standard error.

subjective estimates were made during the acquisition session, so ADE was not assessed. The analysis of RTE revealed a significant effect of task complexity $F(1, 108) = 269.5$, $p < .05$. Participants in the simple task condition ($M = 8.5$, $SD = 3.1$) had lower RTE than participants in the complex task condition ($M = 23.5$, $SD = 6.6$). The analysis of RTE also revealed a significant effect of Block $F(5, 108) = 1.9$, $p < .05$. Post-hoc analysis of the main effect of RTE for Block revealed that Block 6 ($M = 13.8$, $SD = 8.3$) had lower RTE than Blocks 1 ($M = 18.0$, $SD = 10.3$) and 2 ($M = 17.4$, $SD = 9.7$). Blocks

3, 4, and 5 (M = 16.0, 15.9, & 14.8, SD = 8.9, 9.0, & 8.8 for Blocks 3, 4, and 5,

respectively) were not different from any of the other practice blocks. The interaction of

task complexity and Block failed to reach significance $F (5, 108) = 1.0$, $p > .05$. Figure 1

presents RTE data for the retention and acquisition sessions of Experiment 1.

The analysis of ODE revealed a significant effect of practice condition $F (1, 108)$

$= 37.9$, $p < .05$. Participants in the simple task condition (M = 139 ms, SD = 51 ms) had

FIGURE 2. Mean overall duration error for acquisition and retention
phases of Experiment 1. for participants who experienced physical
practice (circle), observational practice (square) or no practice (triangle).
Open symbols indicate simple relative timing and filled symbols indicate
complex relative timing. Error bars represent standard error.

lower ODE than participants in the complex task condition (M = 197 ms, SD = 61 ms).

The analysis of ODE also revealed a significant effect of practice block F (5, 108) = 7.0,

p < .05. Post-hoc analysis of the main effect of Block revealed that Block 1 (M = 227

ms, SD = 72 ms). had higher ODE than Blocks 2 through 6 (M = 168, 155, 145, 157, 155

ms for Blocks 2-6, respectively, SD = 47, 48, 53, 60, & 64 ms for Blocks 2-6,

respectively) which did not differ from each other. The interaction of task complexity

and Block failed to reach significance F (5, 108) = .3, p > .05. Figure 2 presents ODE

data for the retention and acquisition sessions of Experiment 1.

Retention Session

Separate 2 (Task Complexity: simple or complex) X 3 (Practice Condition:

physical, observational, or no practice) ANOVAs were calculated for, RTE, ODE, and

ADE. The analysis of RTE revealed a significant main effect of task structure, F (1, 54)

= 243.8, p < .05 and of practice condition, F (2, 54) = 5.1, p < .05 as well as a significant

task structure X practice condition interaction, F (2, 54) = 3.5, p < .05. Simple main

effects analysis of the latter interaction revealed that physical practice participants

practicing the complex task variation (M = 20.3, SD = 5.4) produced lower RTE than

those in the observation condition (M = 27.3, SD = 7.7) and the no practice condition (M

= 27.6, SD = 4.4). The latter two conditions did not reliably differ from each other. For

those participants practicing the simple task variation, physical practice (M = 6.4, SD =

1.8), observational practice (M = 6.8, SD = 2.1), and no practice (M = 7.4, SD = 2.6) did

not reliably differ from each other. Physical, observational, and no practice participants

in the simple condition all had lower RTE than those in the same conditions in the

simple condition. There was no difference between complex and simple conditions for

physical, observational, and no practice for ODE or ADE.

The analysis of ODE revealed a main effect of practice condition, $F(2, 54) =$

10.4, $p < .05$. The main effect of task structure, $F(1, 54) = 0.2$, $p > .05$ and the
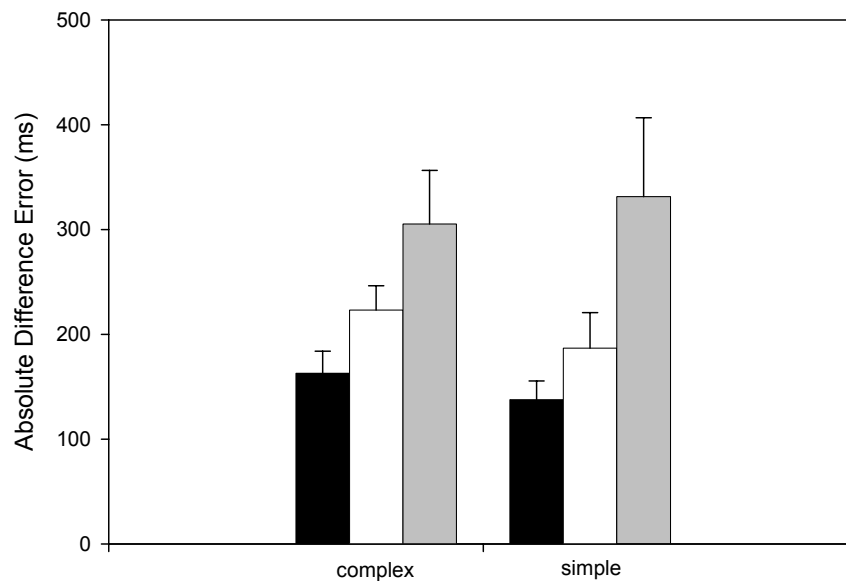
FIGURE 3. Mean absolute difference error for the retention phase of
Experiment 1. Fill colors represent physical practice (black),
observational practice (white), or no practice (gray). Error bars
represent standard error.

interaction of task structure X practice condition, $F(2, 54) = 0.5$, $p > .05$ failed to reach

significance. Post-hoc analysis of the main effect of practice condition revealed that

ODE for physical practice ($M = 169$ ms, $SD = 56$ ms) and observational practice ($M =$

207 ms, *SD* = 115 ms) were not different and were lower than the ODE for the no

practice condition (*M* = 337 ms, *SD* = 166 ms).

The analysis of ADE revealed a main effect of practice condition, F (2, 54) = 8.2,

p < .05. The main effect of task structure, F (1, 54) = .1, p > .05 and the interaction of

task structure and practice condition, F (2, 54) = 0.3, p > .05 failed to reach significance.

Post-hoc analysis of the main effect of observation condition revealed that ADE for

physical practice (*M* = 150 ms, *SD* = 62 ms) and observational practice (*M* = 205 ms, S

SD = 91 ms) were not different and were lower than the ADE for the control condition

(*M* = 318 ms, *SD* = 199 ms). Figure 3 presents ADE data for the retention session of

Experiment 1.

Discussion

It was predicted that the simple task variation would lead to lower acquisition

RTE for the models based on the results of Wright and Shea (2001). The results of the

acquisition session supported this prediction. Mean error for the simple task was less

than 40% that of the complex task (8.5 versus 23.5). Physical practice participants in the

simple condition also produced lower ODE during the acquisition session. Participants

in the simple condition were able to perform the relative timing essentially correctly

from the beginning of practice, so they likely had more attentional resources that could

be devoted to performing the overall duration correctly. This ability to perform with

lower ODE during practice did not lead to better learning as assessed by the delayed

retention test. The retention result is compatible with previous findings of independence

of relative and absolute timing learning (Lai & Shea, 1998).

Participants in the complex condition replicated the results of Black and Wright (2000). That is, observers were unable to produce the relative timing as well as those who physically practiced and were no better than the no practice participants. Again, it was found that the overall timing characteristics of the movement could be learned without overt practice. Observers were also able to estimate their overall duration performance as well as the physical practice participants regardless of the complexity of the task. The dichotomy between the relative timing and overall duration results reinforced previous findings that the learning of relative and absolute timing are independent (Wulf, Schmidt, & Deubel, 1993).

The inclusion of the simple task had the desired effect of allowing the models to perform with considerably reduced RTE during the acquisition session when they were being observed. Unlike the case with the complex timing task, observers were able to produce the relative timing of the simple task as well as were the participants who had physically practiced the task. Complicating the interpretation of the results is the fact that the no practice participants were able to produce the relative timing of the simple task as well as the physical and observational practice participants, though they were inferior at producing the correct overall duration and at estimating their own overall duration performance. Since the no practice participants had no exposure to the task prior to the no-KR retention test, it would be inaccurate to conclude that the ability of observers to match the relative timing performance of the models is a learning effect. Indeed the purpose of the no practice control group was to be able to assess whether learning was occurring. On the basis of these results, it must be concluded that neither

the models nor the observers demonstrated learning of the relative timing, but rather that they possessed the ability to perform the relative timing with relatively low error at the start of practice, as did the no practice control group.

Thus, on the basis of these data it is difficult to conclude that observing superior performance of the relative timing component of this task was sufficient to engender better performance of this aspect of movement when the observer first physically produces of the movement. It does appear however that producing a sequential movement that requires maintenance of equivalent velocity across the segments of the movement is somewhat easier to achieve than a movement that involves changes in velocity across the segments. This is most clearly apparent from the performance of individuals in the no practice condition who exhibited low levels of RTE with the simple task despite having no exposure to the task and having no KR on their own performance.

An alternative method to assess the influence of the models' acquisition performance with observers' retention performance needs to lower RTE for the models without simplifying the relative timing structure of the task itself. This was accomplished in Experiment 2 by manipulating the practice schedule.

CHAPTER III

EXPERIMENT 2- THE INFLUENCE OF PRACTICE SCHEDULE ON

LEARNING BY PHYSICAL AND OBSERVATIONAL PRACTICE

Introduction

Scully and Newell (1985) predicted that observation is not conducive to the learning of absolute timing. In addition, Schmidt (1975) proposed that variable practice leads to better learning of absolute timing requirements as a result of the development of schema that define the relationship between the task variations. Presenting task variations in random fashion generally leads to better learning of absolute timing than presenting the variations in blocks of only one variation (Lai, Shea, Wulf, & Wright, 2000b). For these reasons, random variable practice was used to enhance learning of absolute timing in Black and Wright (2000) and in Experiment 1 of the present work.

Surprisingly, considering Scully and Newells' (1985) prediction, Black and Wright (2000) found that the absolute timing was learned by the observers but that the relative timing was not. This result was replicated in Experiment 1. In Experiment 2, the emphasis is therefore on a practice condition that has been shown to enhance relative timing rather than absolute timing.

Though relative timing by the observers was enhanced in Experiment 1 by using the simple task variation, the interpretation of this result is confounded by the fact that the simple task itself produces much lower RTE even in those who had no exposure to either practice or modeled performance (the no practice condition). This implies that the reduction in RTE is due to the nature of the task itself rather than due to the more

accurate performance of the models. It therefore remains questionable whether the failure of observers to learn relative timing in Black and Wright (2000) was due to the poor performance of the models at producing the correct relative time.

A task manipulation that does not produce a general lowering of error (i.e. not in the no practice condition) would be a better test of the hypothesis that models who produce relatively low RTE are necessary for observers to learn to perform the task with low RTE. To further investigate this issue, Experiment 2 used a manipulation that has previously been shown to produce a reduction in RTE in physical practice participants. Lai, Shea, Wulf, and Wright (2000b) proposed that practice manipulations that promote trial-to-trial stability in the participants' performance enhance the learning of the relative timing structure of a movement. Constant practice is one of these practice manipulations. Lai and Shea (1998) found that constant practice (practice of a single movement variation throughout the acquisition session) produced lower RTE in both the acquisition and retention sessions relative to variable practice. Adams (1986) proposed that observers of learning models who are also exposed to the models' KR engage in the same cognitive processes as the models and therefore show similar learning. If this is the case, then increasing practice stability for the models should also enhance the ability of observers to learn the relative timing requirements of the movement. It was predicted that constant practice would result in lower RTE during acquisition and lower RTE during retention by both physical and observational practice groups.

Methods

Participants and Design

Sixty (36 males and 24 females) participants were recruited from undergraduate kinesiology classes and received course credit for their participation. Participants were randomly assigned to one of six practice conditions: constant physical practice, constant observational practice, constant practice control (no practice), variable physical practice, variable observational practice, or variable practice control (no practice). Informed consent was obtained from all participants prior to participation in the experiment.

Apparatus and Task

The apparatus was identical to that used in Experiment 1. The task was identical to the complex task version used in Experiment 1.

Procedure

Physical practice participants practiced for six blocks of 18 trials each of the 22-44-33 task. Constant physical practice participants performed all 108 practice trials with an overall time target of 900 ms. For the variable practice participants, each practice block of 18 trials consisted of 6 trials each with overall target times of 700, 900, and 1100 ms versions of the task. These three task versions were presented in random order. Participants assigned to the observation conditions were each paired with a physical practice participant and observed that participant throughout the practice session. Approximately 24 hours after the practice session, physical practice and observational practice participants returned individually and performed the retention test, which consisted of 18 trials of the 900 ms task with no knowledge of results. Individuals
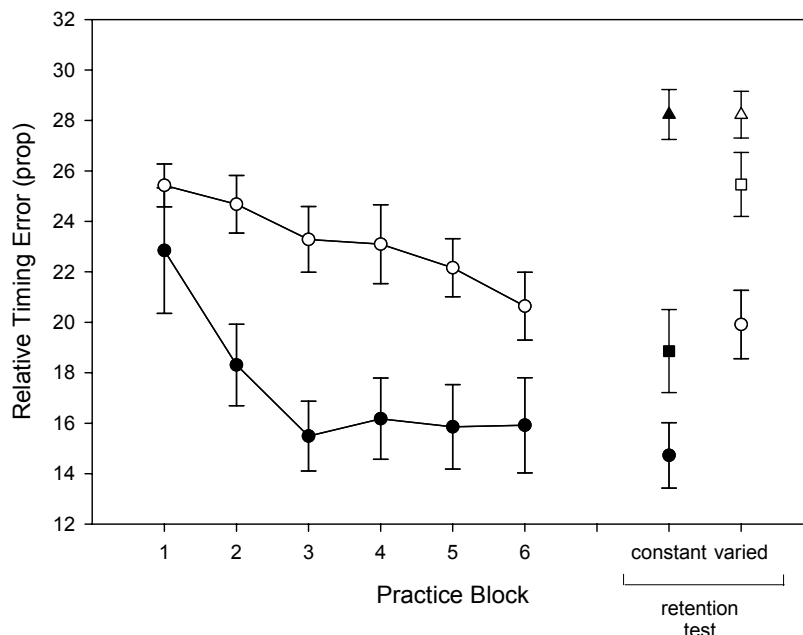
FIGURE 4. Mean relative time error for acquisition and retention phases of Experiment 2. physical practice (circle), observational practice (square), or no practice (triangle) of either constant practice (filled symbols) or varied practice (open symbols). N = 10 for all groups. Error bars represent standard error.

assigned to the no practice condition performed the retention test with no previous

exposure to the task.

**Results**

Acquisition Session

Since only physical practice participants performed during the practice session,

only these groups could be analyzed. Separate 2 (Practice Schedule: varied or constant)

X 6 (Block: 1-6) ANOVAs were calculated for RTE and ODE. The analysis of RTE

revealed a significant effect of Practice Condition $F(1, 108) = 41.5$, $p < .05$. Constant

practice ($M = 17.5$, $SD = 6.1$) had lower RTE than varied practice ($M = 23.2$, $SD = 4.1$). The analysis of RTE also revealed a significant effect of Block F (5, 108) = 3.8, $p < .05$. Post-hoc analysis revealed that Block 1 ($M = 24.1$, $SD = 5.9$) had greater RTE than blocks 3-6 ($M = 19.4$, 19.6, 19.0, 18.3 for blocks 3-6, respectively, $SD = 5.8$, 6.0, 5.5, 5.6 for blocks 3-6, respectively). Practice block 2 ($M = 21.5$, $SD = 5.4$) did not differ from any of the other practice blocks. The interaction of practice schedule X practice block failed to reach significance F (5, 108) = .7, $p > .05$. Figure 4 presents RTE data for the acquisition and retention sessions of Experiment 2.

The analysis of ODE revealed a significant effect of Practice Schedule F (1, 108)
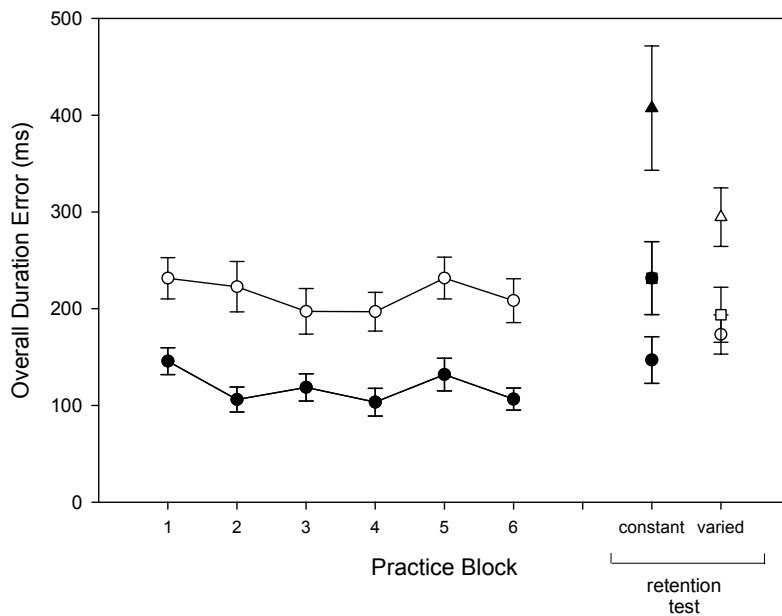
**FIGURE 5.** Mean overall duration error for acquisition and retention phases of Experiment 2. Conditions represented are constant physical practice (filled circle), varied physical practice (open circle), constant observational practice (filled square), varied observational practice (open square), constant no practice (filled triangle), varied no practice (open triangle). N = 10 for all groups. Error bars represent standard error.

= 78.2, $p < .05$. Constant practice ($M = 119$, $SD = 45$) had lower ODE than varied

practice ($M = 215$, $SD = 70$). The main effect of Block, $F (5, 108) = 1.2$, $p > .05$ and the

interaction of practice schedule X block, $F (5, 108) = 1.3$, $p > .05$, failed to reach

significance. Figure 5 presents ODE data for the acquisition and retention sessions of

Experiment 2.

Retention Session

Separate 2 (Practice Schedule: varied or constant) X 3 (Condition: physical,

observational, or no practice) ANOVAs were calculated for, RTE, ODE, and ADE. The

analysis of RTE revealed significant main effects of Practice Schedule, $F (1, 54) = 14.4$,

$p < .05$ and of condition, $F (2, 54) = 37.2$, $p < .05$. The analysis of RTE revealed a

significant Practice Schedule X Condition interaction, $F (2, 54) = 3.8$, $p < .05$. Post-hoc

analysis of the interaction revealed that for varied practice, physical practice ($M = 19.9$,

$SD = 5.3$) had lower RTE than observational practice ($M = 25.5$, SEM $= 4.0$) and no

practice ($M = 28.2$, $SD = 2.9$). The latter two conditions did not differ. For participants in

the constant practice condition, physical practice participants ($M = 14.7$, $SD = 4.1$)

performed with lower RTE than did the observational practice participants ($M = 18.9$,

$SD = 5.2$) who in turn produced lower RTE than did the no practice participants ($M =$

28.2, $SD = 3.1$). RTE was significantly lower, $t (18) = 2.8$, $p < .05$ for physical practice

participants who engaged in constant practice ($M = 14.4$, $SD = 4.2$) than for those who

engaged in varied practice ($M = 19.9$, $SD = 4.3$). There was no difference between varied

and constant practice for ODE, $t (18) = .87$, p $> .05$ or ADE, $t (18) = .32$, p $> .05$. RTE

was significantly lower, $t (18) = 3.2$, $p < .05$ for observational practice participants who

engaged in constant practice ($M = 18.9$, $SD = 5.2$) than for those who engaged in varied

practice ($M = 25.5$, $SD = 4.0$). There was no difference between varied and constant

practice for ODE, t (178) = .80, p > .05 or ADE, t (18) = .34, p > .05.
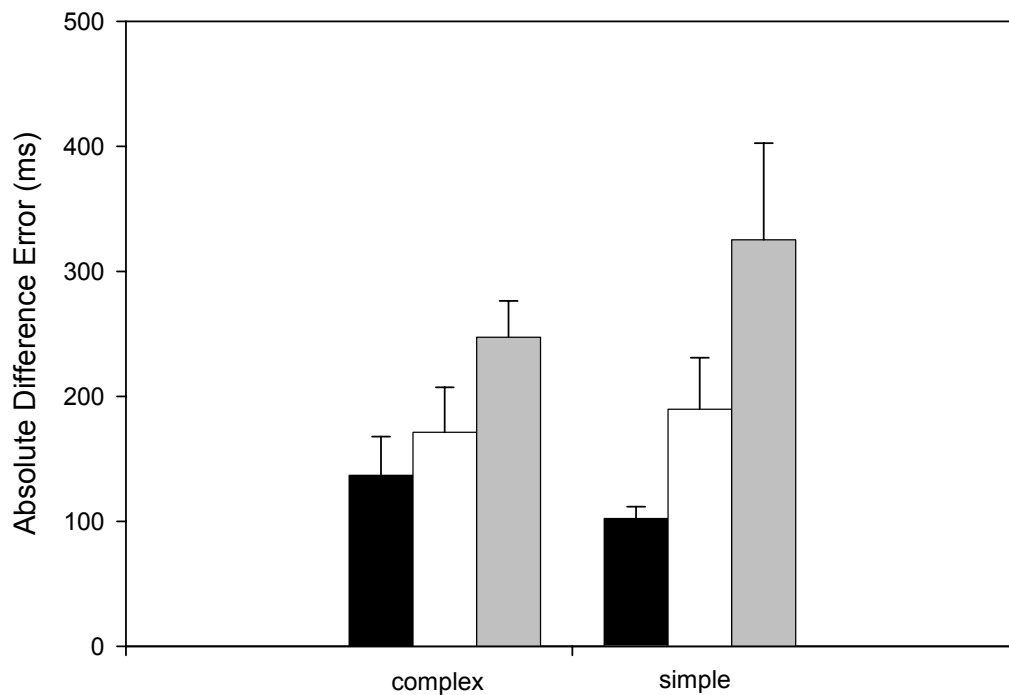
FIGURE 6. Mean absolute difference error during the retention phase of Experiment 2. Observational conditions were: physical practice (black), observational practice (white), or no practice (gray). N = 10 for all groups. Error bars represent standard error.

The analysis of ODE revealed a main effect of Condition, F (2, 54) = 14.1, $p <$

.05. Post-hoc analysis of the main effect of Condition revealed that ODE for physical

practice (*M* = 160 ms, *SD* = 70 ms) and observational practice (*M* = 213 ms, *SD* = 104 ms) were not different and were lower than the ODE for the no practice condition (*M* = 351 ms, *SD* = 165 ms). The main effect of practice schedule failed to reach significance, F (1, 54) = 1.9, p > .05, as did the interaction of practice schedule X condition, F (2, 54) = 1.8, p > .05.

The analysis of ADE revealed a main effect of condition, F (2, 54) = 7.9, p < .05. Post-hoc analysis of the main effect of condition revealed that ADE for physical practice (*M* = 119 ms, *SD* = 73 ms) and observational practice (*M* = 180 ms, *SD* = 119 ms) were not different and were lower than the ADE for the no practice condition (*M* = 286 ms, *SD* = 184 ms). The main effect of practice schedule failed to reach significance, F (1, 54) = 0.4, p > .05, as did the interaction of practice schedule X condition, F (2, 54) = 0.9, p > .05. Figure 6 presents ADE data for the retention session of Experiment 2.

Discussion

Results of the acquisition session confirmed that constant practice did in fact lead to lower RTE during practice compared to varied practice when knowledge of results were available. In addition, ODE was also lower for the participants who practiced with a constant practice schedule. This is not unexpected as the goal overall time was always 900 ms during constant practice, but fluctuated randomly between 700, 900, and 1100 ms during varied practice. Findings from the retention session showed that there was no difference between constant and varied practice in terms of long-term learning of the overall time dimension. Though previous findings suggest that varied practice is superior to constant practice for the learning of overall timing (Lai & Shea, 1998), this effect is

counterbalanced here by the fact that retention session consisted of only the 900 ms variation. In effect, the constant practice participants had three times the practice at this variation than did the varied practice participants.

Participants in the variable practice condition replicated the results of Black and Wright (2000) and Experiment 1 in all respects, specifically, observational practice participants were superior to the control condition and not different from the physical practice participants in producing the correct overall time and in estimating their overall time, but were not different from the controls and inferior to physical practice participants at producing the correct relative timing structure. Observers of models engaged in constant practice had significantly lower RTE on the retention test than did the no-practice participants, though they still had more error than did the physical practice participants. Unlike the simple task structure in Experiment 1 which allowed the no practice participants to produce the task with low RTE as well as those who practiced either physically or by observation, constant practice allowed observers to perform with less error that those who observed variable practice (means of 19.0 and 25.5 for observers of constant and variable practice, respectively) but did not affect performance by the no-practice control group (means of 28.2 for both control groups).

Once again the results supported the independence of relative and absolute timing production as there was no effect of practice schedule on ODE or ADE, only on RTE. In addition, these data support the finding by Black and Wright (2000) that observers can learn to both produce the overall duration of the movement and to estimate

their own overall timing performance as well as can those who physically practice, despite the prediction of Scully and Newell (1985).

Though the observers in the constant practice condition did show some ability to acquire the correct relative timing structure without receiving KR of their own performance, they were unable to perform the relative timing as effectively as those in the physical practice group who received KR of their performance during the acquisition session. A question that remains is whether some physical practice is required to learn the relative timing of a task that has a complex relative timing pattern or whether better models than the constant practice participants could allow learning of the complex relative timing pattern by observers. To further test this notion, it is desirable to find a manipulation that will further lower the relative timing error of the models during the acquisition session without altering the fundamental nature of the task.

Though Scully and Newell (1985) did not address the issue of model type, they made an implicit assumption that expert models would be used when they formed their predictions (K.M. Newell, personal communication, June 2002). Alternatively, Adams (1986) suggested the use of learning models. Indeed, a number of studies (e.g. McCullagh & Caird, 1990) support the use of learning models for acquiring skills. However, none of these studies revealed whether learning of the relative features of movement was achieved, instead variables that represent the absolute features of movement were measured. Recent experiments (Lai et al., 2002; Shea et al., 2001) found that a computer-generated auditory model facilitated the learning of the relative timing structure of a keypressing task by both physical practicers and observers. These

computer-generated models presented the criterion task with no error. The results of these experiments are important because they indicate that the relative timing structure of a sequential timing task can be learned without overt practice by repeated exposure to a correct-timing model.

Experiments 1 and 2 along with Black and Wright (2000) support the use of learning models for learning of absolute timing but not learning of relative timing. The results of Experiment 2 imply that models who produce relative timing with lower error facilitate the learning of relative timing by observers. If this is true, then expert models who are able to produce a skill with consistently minimal error, particularly if they are engaging in constant practice, may facilitate the ability of observers to acquire the relative timing of a skill without engaging in overt practice of that skill. Experiment 3 compared the use of expert models to the use of learning models.

CHAPTER IV

EXPERIMENT 3– THE INFLUENCE OF EXPERT MODELS ON LEARNING

BY PHYSICAL AND OBSERVATIONAL PRACTICE

Introduction

Experiments 1 and 2 have shown that observers can use the information available in learning model demonstrations with KR to develop an error correction mechanism that allows them to estimate their error on the overall duration of the movement and to produce movements that are generally performed at the correct speed. This finding is consistent with previous experiments that have used learning models (McCullagh & Caird, 1990; McCullagh & Meyer, 1997). On the other hand, our previous experiments have consistently shown that observers were unable to learn the relative timing as well as were those who physically practiced, except in the case of the simple relative timing task in which it appeared that the relative timing pattern was already available to the participants at the start of practice. This finding seems to be inconsistent with recent experiments that have examined the effects of modeling on the learning of relative and absolute timing (Lai et al., 2000b; Shea et al., 2001). It must be emphasized however that in these experiments, observers had access to a computer-generated model that presented perfect timing as well as to the performance of a learning model.

In addition to demonstrating the correct timing, the Lai et al. and Shea et al. experiments used an auditory model as opposed to the primarily visual model that was used by Black and Wright (2000) and in Experiments 1 and 2. Previous experiments have shown auditory models to be superior to visual models for learning of timing tasks

(Doody, Bird, & Ross, 1985; Lee, Wishart, Cunnningham, & Carnahan; 1997). The learning of the correct relative timing by observers in the Lai et al. and Shea et al. experiments may be due to either the use of an auditory model, the presence of a correct model, or both.

Experiment 2 showed that reducing the relative timing error of learning models (i.e. having them perform more correctly) allowed observers to show some learning of the relative timing, though the observers were not able to perform as well as did the models who had trained with physical practice. This implies that improving the performance of a visual model may improve learning by observers and that an expert model who consistently performs with low RTE may allow observers to learn to produce the correct relative timing without actually practicing the movement. Experiment 3 used an expert model to examine this proposal. This model had practiced the task extensively and displayed considerably less error during the acquisition session than did the learning models used in previous experiments. To further encourage the learning of relative timing by observers, constant rather than varied practice was used. It was predicted that observers of the expert model would have lower RTE than the observers of the learning models and that observers of the expert model would have equal RTE to the learning models.

Methods

Participants and Design

Fifty (23 males and 27 females) participants were recruited from undergraduate kinesiology classes and received course credit for their participation. Participants were

randomly assigned to one of four experimental conditions: physical practice-learning

(PL), observational practice-expert model (OE) observational practice-learning model

(OL), or no practice (NP). The experimenter served as the model for the participants and

as the physical practice-expert (PE) condition. Informed consent was obtained from all

participants prior to participation in the experiment. In some cases, more than one

observer witnessed the expert model at the same time, so the expert model performed the

acquisition and retention session only seven times. These data were used in the analysis

for purposes of comparison with the learning models and observers.

Apparatus and Task

The apparatus and task were identical to those used in Experiments 1 and 2.

Procedure

The PL and OL conditions were conducted as in Experiments 1 and 2, with each

observer paired with a PL participant for observation during the acquisition session. The

PL participants each performed 108 trials of the 900 ms version of the complex task.

Each participant in the OL group observed a participant from the PL group during the

acquisition session. Participants in the OE condition observed a model who had

considerable practice with the task (30+ acquisition sessions), allowing him to perform

with considerably less error than did the learning models used in previous experiments.

Participants in the OE group observed the expert model perform 108 trials of the 900 ms

version of the complex task.

Results

Acquisition Session

Along with the physical practice participants, the performance of the expert model (EM) during the acquisition session was included in the analysis. On some occasions, more than one participant observed the expert model at the same time. There were therefore only seven sets of expert model data. Acquisition data were analyzed with separate 2 (Model Type: expert or learning) X 6 (Block: 1-6) ANOVAs for RTE and ODE. The observation and no practice participants did not participate in overt practice during the acquisition session and so are not included in the analysis.

Analysis of RTE revealed significant main effects of Model Type, F (1, 90) = 154.8, $p < .05$ and Block, F (5, 90) = 4.2, $p < .05$. The expert model ($M = 7.2$, $SD = 1.6$) had lower RTE than did the learning models ($M = 17.0$, $SD = 5.4$). Post-hoc analysis of the main effect of practice block revealed that block 1 ($M = 17.2$, $SD = 8.5$) had higher RTE than did blocks 2 ($M = 12.1$, $SD = 6.6$), 3 ($M = 12.6$, $SD = 5.0$), 4 ($M = 12.5$, $SD = 5.9$), 5 ($M = 11.3$, $SD = 5.0$), and 6 ($M = 12.0$, $SD = 6.1$). The interaction of Model Type X Block failed to reach significance, F (5, 90) = 1.0, $p > .05$. Figure 7 presents RTE data for the acquisition and retention sessions of Experiment 3.
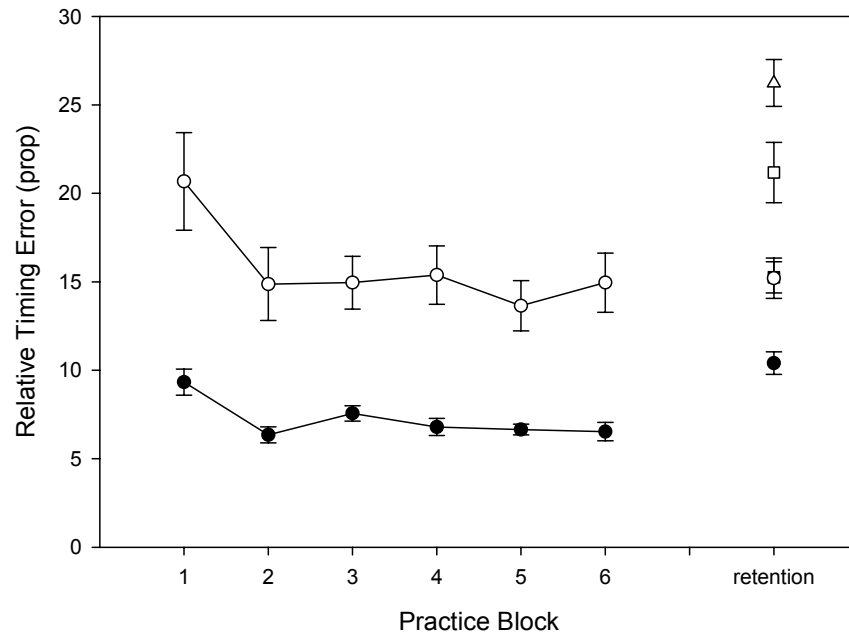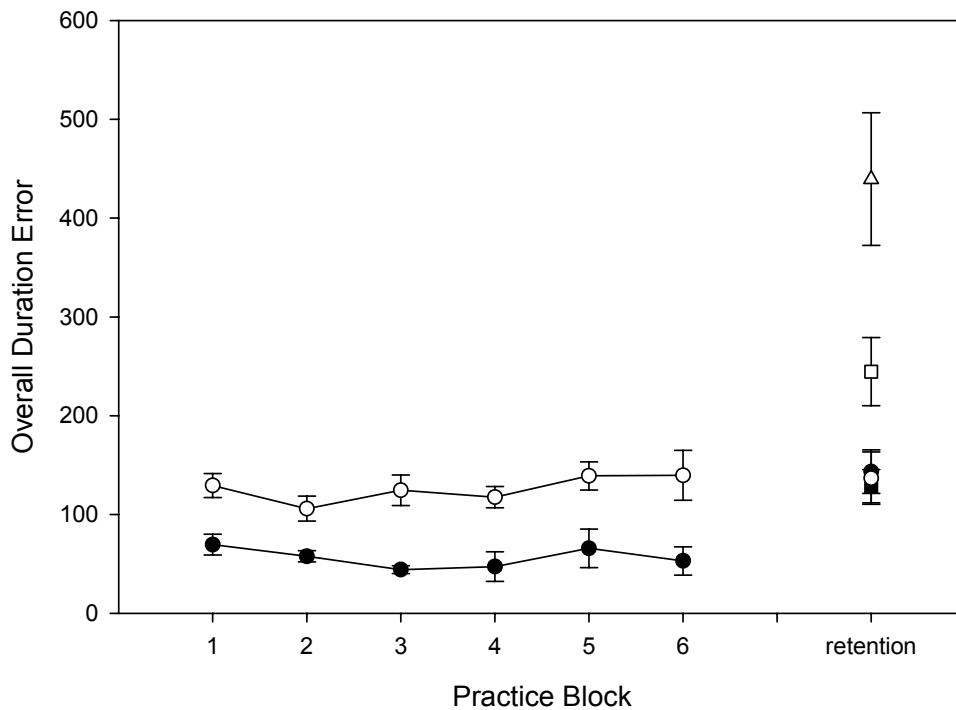
FIGURE 7. Mean relative timing error for acquisition and retention phases of Experiment 3. Experimental groups were: physical practice-expert (filled circle), physical practice-learning (open circle), observational practice-expert (filled square), observational practice-learning (open score), or no practice (open triangle). N = 10 for all groups. Error bars are standard error.

Analysis of ODE revealed significant main effects of model type, $F(1, 90) = 61.6$, $p < .05$. The expert model ($M = 56$ ms, $SD = 33$ ms) had lower ODE than did the learning models ($M = 126$ ms, $SD = 49$ ms). The interaction of Model Type X Block failed to reach significance, $\underline{F}(5, 90) = 0.4$, $\underline{p} > .05$. The main effect of Block also failed to reach significance, $F(5, 90) = 0.7$, $p > .05$. Figure 8 presents ODE data for the acquisition and retention sessions of Experiment 3.

Retention Session

Along with the four groups of participants, the performance of the expert model

(EM) on the retention test was included in the analysis. Separate 5-level (EM, EMO, PP,

LMO, NP) one-way ANOVAs were conducted for RTE, ODE, and ADE. Significant

main effects were found for RTE, $F (4, 42) = 22.7$, $p < .05$, ODE, $F (4, 42) = 11.7$, $p <$

FIGURE 8. Mean overall duration error for acquisition and retention phases of Experiment 3. Experimental groups were: physical practice-expert (filled circle), physical practice-learning (open circle), observational practice-expert (filled square), observational practice-learning (open score), or no practice (open triangle). N = 10 for all groups. Error bars are standard error.

.05, and ADE, F (4, 42) = 11.1, p < .05. Post-hoc analysis of RTE revealed that the EM

(M = 10.4, SD = 1.7) had lower RTE than PP (M = 15.2, SD = 3.6), and EMO (M = 15.3,

SD = 2.8). The latter two conditions did not reliably differ and had lower RTE than

LMO (M = 19.0, SD = 4.9), which in turn had lower RTE than the NP (M = 26.2, SD =

4.2) group.

Post-hoc analysis of ODE revealed that the EM (M = 143 ms, SD = 58 ms), LMO
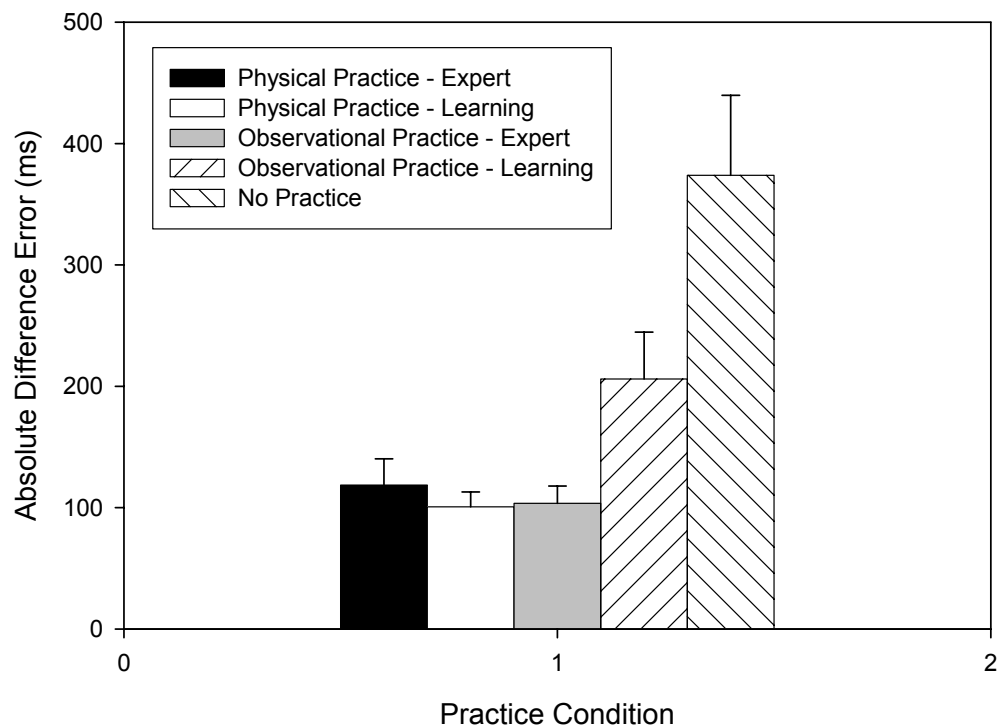
FIGURE 9. Mean absolute difference error for the retention phase of Experiment 3. N = 10 for all groups. Error bars represent standard error.

($\underline{M}$ = 210 ms, SD = 101 ms), PP (M = 137 ms, SD = 84 ms), and EMO (M = 129 ms, SD

= 53 ms) conditions did not differ and all had lower ODE than the NP (M = 439 ms, SD

= 212 ms) group. Post-hoc analysis of ADE revealed that the EM (M = 118 ms, SD = 57

ms), PP ($\underline{M}$ = 101 ms, SD = 39 ms), EMO (M = 133 ms, SD = 56 ms), and LMO (M =

166 ms, SD = 79 ms) conditions did not differ and had lower ADE than the NP (M = 374

ms, SD = 208 ms) condition. Figure 9 presents the results for ADE for the retention

session. Figure 9 presents ADE data for the retention session of Experiment 3.

Discussion

Not surprisingly, the expert model was able to produce both the relative timing

and absolute timing better than did the learning models during the acquisition session.

The expert model was also able to produce the relative timing better than the other

groups during the no-KR retention session. Somewhat surprisingly, physical practice

participants and all observers were able to perform the overall timing and to estimate

their overall time as well as the expert model during the retention session, though the

expert model was better at performing the correct relative timing structure of the

movement. This is likely because the absolute timing of the movement (and by inference

error detection ability) is typically learned more quickly than is the relative timing, based

on previous experiments similar sequential key-pressing tasks (Black & Wright, 2000;

Lai & Shea, 1998; Shea, Lai, Immink & Black, 2001; Wright, Black, Park & Shea,

2001). Thus, the 108 practice trials were sufficient for participants to minimize error in

ODE but not RTE. This is reinforced by the fact that ODE was minimized very quickly

in the constant practice condition. In fact there was no improvement in ODE across

practice (i.e. ODE was minimized within the first 18 practice trials). Relative timing, on the other hand, seems to take more than 108 practice trials to be minimized. The expert model had performed more than 3000 practice trials prior to serving as the model. The expert model was able to perform the relative timing on the retention test with considerably lower error than the physical practice participants.

The retention results of the PP, LMO, and NP groups replicated the findings of Experiment 2 for all variables. Participants who observed a learning model undergoing constant practice were able to produce the relative timing structure better than the no practice participants but not as well as those who learned via physical practice. Furthermore the observers of learning models were able to learn to produce the overall time as well as the physical practice participants and were also able to make estimates of their own overall timing performance as well as did the physical practice participants.

The expert model in Experiment 3 showed considerably lower relative timing error during acquisition than did the learning models used in the Black and Wright (2000) experiments and the learning models in Experiments 1 and 2. In contrast to Black and Wright (2000) and Experiments 1 and 2, observers of the expert model were able to produce the relative timing of the task as well as were those who learned through physical practice. This result implies that it is the nature of the model (correct versus learning) rather than the mode of presentation (auditory versus visual) that explains the ability of observers to learn the relative timing in Lai et al. (2000b) and Shea et al. (2001).

These results support the hypothesis that for observers to learn the relative timing structure of a sequential timing task, it is necessary to observe a model who is able to produce the task "correctly" (i.e. with consistently low error). These results also provide a partial reconciliation of the seemingly contradictory findings of Black and Wright (2000) and Shea et al. (2001). Black and Wright found that absolute timing but not relative timing was learned by observers. Shea et al., on the other hand, found that relative timing but not absolute timing of a sequential timing task was learned by observers. These previous experiments differed in that Black and Wright used a learning model and Shea et al. used a computer-generated correct model. In Experiment 3, an expert model enabled observers to produce the relative timing as well as participants who learned the task by physical practice. Blandin, Lhuisset, and Proteau (1999) also compared expert and learning models in a sequential barrier knock-down task. They found no differences between observers of learning and expert models after the observation session, but when the models began to practice the task with KR, the observers of the expert model quickly reduced their relative timing error while the observers of the learning models did not. All observers were able to reduce error on the overall timing error a similar amount. These results agree with the results of Experiment 3, though the learning by the observers in the Blandin et al. remained latent until physical practice on the task was commenced.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Learning of Relative Timing and Overall Duration by Observation

Scully and Newell (1985) proposed that research address "what" can be learned from observation before the issue of "how" it is learned is addressed. Using perception research (Johannson, 1973) they predicted that relative motion could be learned by observation, but that absolute motion could not. Along with Black and Wright (2000), Experiments 1-3 consistently found that observers were able to learn to produce the absolute timing of the movement as well as those who physically practiced. This generalization held true even as the task structure, amount of variability in practice, and skill of the model were manipulated.

Observers could learn to produce the relative timing structure by observing an expert model, but not by observing a learning model. This is compatible with the findings of Shea, Wulf, Park, & Gaunt (2001) and Lai, Shea, and Little (2000a) who found that the relative timing of a sequential timing task could be learned by observation without overt practice with the aid of a computer-generated model that displayed the criterion timing.

It must be recognized that relative motion as addressed by Scully and Newell (1985) was presented differently than the relative timing in these experiments and in Shea et al. (2001) and Lai et al. (2000b). Scully and Newell based their prediction on perception research using "point-light" visual displays of human joint motion (Johansson, 1973; Runeson & Frykholm, 1981). The model in Shea et al. and Lai et al.

was presented by sound rather than by vision. In Black and Wright (2001) and Experiments 1-3, observers watched the models perform the movement. The computer keys did make an audible sound, but the modeled performance was primarily a visual one. It has been suggested that rhythmic timing of movement is better learned by auditory models than visual ones (McCullagh & Weiss, 2001). "Relative timing" as defined in Experiments 1-3 is the rhythm of the movement. The results of Experiment 3 support the hypothesis that relative timing can be learned from a primarily visual model if the model performs the relative timing in a consistently correct fashion.

In addition, "relative motion" as discussed by Scully and Newell involved the relationship between multiple moving parts as well as the relationship in motion over the time of the movement. "Relative timing" as defined in the experiments included here involved only the relationship over time as a single limb moved. Thus as alternative explanation for the failure of observers to learn the relative timing in Experiments 1 and 2 may is that the information from one moving part may not be "rich" enough for observers to see the relative aspects of the movement. Arguing against this interpretation are the results of Shea et al. (2001), Lai et al. (2000a) and Experiment 3. These experiments all found that observers were able to learn the relative timing of a single moving segment if an expert or correct model was available. It is possible that the relative motion of a movement that involves multiple moving parts could be learned from an expert model and this hypothesis should be explored in future research.

Development of Error Detection Ability by Observation

One explanation for the ability to produce consistently correct movements is the development of an error detection mechanism that allows for movement correction. Schmidt (1975) proposed that a set of rules (recognition schema) that relate sensory consequences of movement to the movement outcome were learned through trial and error during practice along with another set of rules (recall schema) that were responsible for generating the motor commands for movement. These proposed schema allow for the generation of movements at different speeds, as were presented in Experiment 1. In Experiments 1-3, error detection ability was measured by the subjective estimates during the retention test. The development of such an error detection mechanism by observers was supported by the finding that observational practice participants were able to estimate their overall duration performance as well as were the physical practice participants and better than were the no practice participants. This ability of observers to estimate their own performance was developed regardless of the skill level of the model. Adams (1986) explained this ability with the proposal that observers undergo the same cognitive process as do the models of generating a corrected movement plan based on a comparison of the movement outcome to feedback information.

The Role of Expert and Learning Models in "Imitation" and "Observational Learning"

Schmidt (1975) predicted that increasing movement variability would improve learning of absolute features such as overall duration by allowing learners to develop rules that relate muscle commands to intended outcomes. This rule-based memory allows for flexibility in adapting movements to meet varied goals. Darden (1997) argued that this rule-based learning also applies to learning from observation and that the inherent variability of learning model demonstrations is beneficial for developing rule-based memory. He contrasted this process of "observational learning" to "imitation" or "mimicry" of a movement and concluded that a disadvantage of expert model demonstrations is the encouragement of imitation and discouragement of the more adaptable rule-based memory that is encouraged by learning model demonstrations.

In contrast to Darden's view, in Experiments 1-3 learning models were not found to have an advantage over expert models for learning of overall duration. Observers learned to produce the correct overall duration of the movement whether they had observed a learning or an expert model. This implies that observers are able to use the process of observational learning to develop a reference of correctness for the production of the absolute timing of a movement (Adams, 1986).

Observers were not able to use this observational learning process to generate an effective reference of correctness for producing the relative timing, however. They were only able to learn to produce the correct relative timing by observing an expert model

who produced performance near the criterion on every trial. This implies that the relative timing was acquired through a process of mimicry or imitation, rather than the observational learning process that allowed a reference of correctness to be established for absolute timing. These results further imply that observation may work very differently in the development of the memory structures for relative timing and absolute timing. These results also provide additional support for the independence of relative and absolute timing.

Expert Models and Practice Stability

Schmidt (1975) proposed that relative timing and absolute timing were separate memory structures and implicitly that the relative timing structure must be established prior to the development of the schema that allow generation of absolute timing (Roth, 1988). The independence of relative and absolute timing has been supported by numerous experiments (e.g. Shea, Lai, Wright, Immink & Black, 2001; Wulf, Lee & Schmidt, 1994; Wulf, Schmidt & Deubel, 1993).

Promoting trial-to-trial stability by such means as reduced feedback frequency, bandwidth feedback, and constant practice has been shown to enhance the learning of relative timing, while promoting variability has been shown to benefit parameter learning (Lai and Shea, 1998; Shea, Lai, Wright, Immink & Black, 2001). Lai, Shea, Wulf, and Wright (2000b) found that promoting trial-to-trial stability is particularly important early in the learning process when the relative timing pattern is being established. If, as suggested be Adams (1986), observers undergo the same cognitive activities as do the models, then increasing the stability of the modeled performance

should enhance the learning of relative timing as increased stability aids physical practicers.

Experiments 2 and 3 support the idea that increasing the trial-to-trial stability of the demonstration promotes learning of relative timing by observers. In Experiment 2, increasing the models' consistency by having them perform constant practice resulted in better learning of the relative timing by the observers. In Experiment 3, an expert model allowed observers to learn the relative timing better than did learning models. This ability to learn relative timing from an expert model may be due to the stability of the demonstration or due to the low error exhibited by the expert model. A future experiment should use an expert model engaged in the varied practice condition that was used in Experiment 2. If the models learn the relative timing in this condition, this would indicate that the correctness of the demonstration is what is critical for learning relative timing. If, on the other hand, they fail to learn the relative timing then this would indicate that stability of the demonstration is what is critical for learning relative timing.

Lai et al. (2000b) found that learning of both relative timing and overall duration were optimized by switching from stable (constant) practice to unstable (varied) practice half way through the practice session. Participants in this condition learned the relative timing as well as those who performed constant practice throughout the acquisition session and learned the overall duration as well as those who performed varied practice throughout the acquisition session. If an expert model provides a similar stability effect as constant practice, then the results of Experiment 3 imply that it is important to use expert models in the early stages of learning when the relative timing is developing.

Later in practice when emphasis is on scaling the correct movement speed, less able models may be as effective as long as the observer is privy to the model's KR about the overall timing of the movement. This hypothesis should be tested by comparing the results of observation of expert and learning models throughout practice to observation of an expert model early in learning and a learning model later in learning.

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