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The Effects of Practice Schedule and Self-Controlled Feedback Manipulations on the Acquisition and Retention of Motor Skills

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To the Graduate Council:

I am submitting herewith a dissertation written by Joao Augusto De Camargo Barros entitled "The Effects of Practice Schedule and Self-Controlled Feedback Manipulations on the Acquisition and Retention of Motor Skills." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Exercise and Sport Sciences.

Jeffrey T. Fairbrother, Major Professor

We have read this dissertation and recommend its acceptance:

Clare E. Milner, Craig A. Wrisberg, Daniela M. Corbetta

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Joao Augusto de Camargo Barros
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Abstract

In their challenge-point framework (CPF) Guadagnoli and Lee's (2004) argue that learning is maximized when a person faces an optimal level of challenge during practice. It is suggested that challenge level can be manipulated through the combination of different practice variables. The purpose of this study was to investigate how practice schedule and self-controlled feedback frequency manipulations affect performance and learning of motor skills. Participants (n=96) attempted to learn three versions of a key-pressing task. The task consisted of pressing five computer keys in specified sequences in a goal criterion time. Participants were assigned to either a blocked practice schedule with self-controlled feedback (BLK-SC), a random practice schedule with self-controlled feedback (RND-SC), a blocked practice schedule with yoked feedback (BLK-YK), a random practice schedule with yoked feedback (RND-YK), a blocked practice schedule and 100 percent feedback (BLK-100), or a random practice schedule with 100 percent feedback (RND-100). Participants in the blocked conditions practiced 30 trials of each task according to a blocked practice schedule. Participants in the random conditions practiced 30 trial of each task according to a random practice schedule. Participants in the self-controlled feedback condition were allowed to choose whether or not to receive feedback on each trial. Yoked participants had their feedback schedule matched to a participant with similar characteristics in the self-control condition. Participants in the 100% feedback condition received feedback after every trial.

Participants were also asked to complete the NASA Task Load Index (Hart & Staveland, 1988) and an adapted Perceived Competence for Learning scale (adapted from Williams & Deci, 1996) after the completion of the 5th and 90th trial. After 24 hr participants performed a retention test. The results indicated no difference between groups during retention or for the NASA-TLX and PCL scores. The feedback frequency analysis indicated no differences between BLK-SC and RND-SC groups. In general, the findings of the present study show that the effects of practice schedule conditions can be offset by self-controlled feedback manipulations. They also suggest that a number of different combinations of practice schedules and feedback frequencies can lead to similar challenge levels.

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CHAPTER 1

INTRODUCTION

Background of the Study

For over a century, researchers and practitioners have been interested in determining the ways in which the organization of practice can facilitate motor learning (Adams, 1987). During this time, a number of studies have shown that certain variables produce counter-intuitive effects on performance and learning (see Guadagnoli & Lee, 2004; Lee, & Wishart, 2005; Schmidt & Bjork, 1992). For example, practicing multiple tasks according to a random schedule has been shown to degrade performance during practice but enhance learning when compared to practicing the same tasks according to a blocked schedule (Shea & Morgan, 1979). Similarly, receiving a relatively low frequency of feedback (e.g., after every other trial) has also been shown to degrade immediate performance but enhance learning when compared to traditional high frequency conditions where participants receive feedback after every trial (Salmoni, Schmidt, & Walter, 1984). Recently, Guadagnoli and Lee (2004) attempted to reconcile these counterintuitive findings by placing them within a theoretical framework based on the idea that learning is directly related to the level of challenge imposed by a practice condition.

In their challenge-point framework (CPF) Guadagnoli and Lee (2004) argue that learning is maximized when a person faces an optimal level of challenge during practice. In contrast, learning is compromised if the challenge imposed is either too high or too low. The challenge-point created by any given motor learning situation is determined by the functional difficulty of the task, which according to Guadagnoli and Lee (2004) results from an interaction between nominal task difficulty, the learner's skill level, and the conditions of practice. The nominal difficulty of a task is a fixed characteristic based on the specific perceptual and motor requirements of the task. For example, juggling three tennis balls has a lower nominal task difficulty than juggling five tennis balls. For any given learner and practice setting, increasing nominal task difficulty is predicted to increase functional task difficulty and, as a result, raise the challenge-point of the learning situation.

In the CPF, the influences of the learner's skill level and the conditions of practice are both based on the assumption that functional task difficulty is directly related to observed performance. Low skill levels and practice conditions that produce low levels of performance (e.g., random practice and reduced feedback frequency) are presumed to create situations of high functional difficulty. High skill levels and practice conditions that facilitate high performance (e.g., blocked practice and feedback after every trial) represent situations of low functional difficulty. The interaction of nominal task difficulty, skill level, and practice condition can be understood by describing how the combination of these factors produces different levels of functional difficulty along a continuum from low to high. The low end of the continuum would be seen in situations in which high-skill individuals practice an “easy” task under a performance enhancing condition. An example might be a skilled juggler practicing a two-ball exercise to improve throwing consistency alone in a quiet and well-lit room. An increase in functional difficulty would occur if the learner was a novice, if the skilled juggler was surrounded by others who might interfere with his actions, or if the task was changed to five-ball juggling. Functional difficulty would be expected to increase even more by introducing more than one of these changes simultaneously (e.g., asking the novice to five-ball juggle or blindfolding the skilled juggler). The high end of the functional difficulty continuum would be seen in situations in which low-skill individuals practice a “hard” task under conditions that degrade performance. For example, if a novice practiced five-ball juggling in a crowded room.

Research on motor learning has identified a number of practice variables that influence performance in ways consistent with the CPF. Indeed, Guadagnoli and Lee (2004) based the CPF on observations that have emerged from research on the effects of contextual interference (e.g., Shea & Morgan, 1979), modeled information (e.g., Lee et al., 1997), and frequencies and schedules of feedback (e.g., Salmoni, Schmidt, & Walter, 1984). According to Guadagnoli and Lee (2004), the body of literature on these variables, especially the parts that present seemingly contradictory findings, can be understood by examining how the effects of any given variable have varied across different types of participants (e.g., children vs. adults) and tasks (e.g., simple laboratory tasks vs. complex ecologically valid tasks). Of the variables that contributed to the development of the CPF, the most widely researched have been those associated with contextual interference effects or the administration of feedback.

The first clear demonstration of the effects of contextual interference was reported by Shea and Morgan (1979). The study examined the effects of different practice schedules on the acquisition, retention, and transfer of motor skills. Participants were assigned to either random or blocked practice schedule conditions. In the random practice schedule condition, three tasks were presented in a random order (e.g., ABACBBCAC…) with the stipulations that each task be practiced the same number of times in each trial block. In the blocked practice schedule condition, each task was presented in its own block (e.g., AAA…, BBB…, CCC…) so that practice on one task was not intermingled with practice on another. The assumption was that the random and blocked schedules produced high and low levels of contextual interference, respectively (Battig, 1979; Shea & Morgan, 1979). Participants were tested either ten minutes or ten days after the acquisition phase. A transfer test was also administered after each retention test. The results indicated that during acquisition, participants in the blocked practice condition demonstrated fewer sequence errors and had faster reaction time (RT), movement time (MT), and total movement time (TT) than the participants in the random practice condition. During retention and transfer testing, however, participants who had practiced according to the random schedule outperformed those who had practiced according to the blocked schedule.

Shea and Morgan's (1979) study prompted numerous subsequent studies (for reviews, see Brady, 1998; Magill, & Hall, 1990), which have generally shown that high contextual interference conditions produce poor performance during acquisition but result in better retention and transfer when compared to low contextual interference conditions. In the language of Guadagnoli and Lee's (2004) CPF, high contextual interference conditions (e.g., random practice) increase functional task difficulty while low contextual interference conditions decrease functional task difficulty. Close examination of the contextual interference literature does, however, reveal that the effects appear to be sensitive to variations in tasks and learner characteristics. Wulf and Shea (2002) noted that although contextual interference effects have been consistently demonstrated using simple laboratory tasks, they have been shown less frequently when studies have used complex real-world tasks. Some studies using complex tasks have actually found that novices benefitted from a blocked practice schedule rather than a random practice schedule (Hebert, Landin, & Solomon, 1996). According to the CPF, random practice enhances learning of simple tasks because it elevates functional difficulty and raises the challenge-point when learning tasks that would otherwise be unchallenging. When random practice is combined with complex tasks, however, it creates a potentially overwhelming situation for the learner because of an extreme increase in functional task difficulty.

Research on the administration of feedback has a long history (for a review, see Salmoni, Schmidt, & Walter, 1984). One of the counterintuitive findings from this body of research has particular relevance for the CPF. Specifically, reduced frequency of knowledge of results (KR) has been shown to either degrade or have no effect on performance during acquisition (e.g., Bilodeau & Bilodeau, 1958; Ho & Shea, 1978). Interestingly, reduced KR frequency has also been shown to enhance retention when compared to conditions that receive KR after every trial. For example, Winstein and Schmidt (1990) compared the effects of two KR frequency conditions (100% and 50%) on performance during acquisition and retention of a sequential timing task (i.e., participants moved a lever to match a specified spatio-temporal pattern). No-KR retention tests were administered five minutes and 24 hours after acquisition. The results indicated no differences in performance during acquisition or on the five-minute retention test, but the 50% KR condition outperformed the 100% KR condition during the 24-hour test. Generally, the literature suggests that less frequent KR during acquisition enhances learning compared to more frequent KR (Salmoni, Schmidt, & Walter, 1984).

From the perspective of the CPF, reduced KR frequencies increase functional task difficulty while frequent KR decreases it. Guadagnoli and Lee (2004) argue that providing more frequent KR during acquisition for tasks of high nominal difficulty and less frequent KR for tasks of low nominal difficulty should facilitate learning. This idea is supported by evidence that KR frequency effects can differ depending upon the task used. Studies that have used relatively simple laboratory tasks (i.e., those of low nominal difficulty) have consistently shown that reduced KR frequency enhances learning (for a review, see Wulf & Shea, 2002). In contrast, Wulf, Shea, & Matschiner (1998), using a relatively complex ski-simulator task, found that a high-frequency feedback condition produced larger performance improvements during acquisition than a low-frequency condition. During a retention test, the high-frequency condition again showed improvement while the low-frequency condition did not. According to the CPF, reduced KR frequency enhances learning of simple tasks because it elevates functional difficulty and raises the challenge-point to an effective level. When reduced KR frequency is combined with complex tasks, however, functional difficulty and the challenge-point can rise to a level that undermines learning. The point here is similar to the one made earlier regarding practice schedules. Namely, the challenge-point introduced by either the learner's skill level or nominal task difficulty can be changed by manipulating KR frequency to elevate or reduce functional task difficulty.

The implications emerging from the CPF regarding motor learning have yet to be fully explored. The predictions that Guadagnoli and Lee (2004) forwarded were all based on the ways that variables such as practice schedules and KR frequency might independently interact with other components contributing to functional task difficulty (i.e., the learner's skill level and nominal task difficulty). Testing these predictions is problematic for a number of reasons. First, there is currently no accepted definition of nominal task difficulty. In addition, tasks can differ from one another along many dimensions, so the comparison of performance on any two tasks of differing nominal difficulty could potentially be confounded by other factors. The same is true for comparisons of performance between people of different skill levels. In contrast, variables such as practice schedule and KR administration offer a greater possibility of equating experimental conditions. Specifically, the idea that these variables influence functional difficulty, and thus performance and learning, can be directly assessed by examining them together. One way to do this has been suggested in recent research on the effects of self-controlled feedback.

Several studies have demonstrated that motor learning can be enhanced by allowing participants to control whether or not they receive feedback following a trial (Chiviacowsky, & Wulf, 2002; Janelle, Barba, Frehlich, Tennant, & Caurraugh, 1997; Janelle, Kim, & Singer, 1995). Typically, participants in the self-control conditions have requested a relatively low frequency of feedback and shown dramatic reductions in these requests as practice progressed. For example, Janelle et al. (1997) found that feedback was requested after only 11.15% of trials overall, and that frequency declined from 20.8% at the beginning practice to 6.70% at the end. From the perspective of the CPF, it is possible that participants in self-control conditions were using feedback frequency strategically to adjust the functional task difficulty of their practice experience. In this case, they were increasing functional task difficulty by reducing feedback requests. In other cases, it is possible that feedback requests might be increased to reduce functional task difficulty. For example, Chiviacowsky et al. (2008) found that when 10-year-old children learned a motor skill under a self-control feedback condition, those that requested more feedback performed better during retention than their counterparts who requested less feedback.

Janelle et al. (1997) and Chiviacowsky and Wulf (2002) both argued that self-controlled feedback may enhance learning because it affords the learner the opportunity to tailor the administration of feedback to individual needs or preferences. Combining this notion with the CPF leads to the question of whether or not an individual given self-control of feedback frequency would act in a way that would offset the effect of another practice variable (e.g., practice schedule) on functional task difficulty. The purpose of this study was, therefore, to examine the effects of practice schedule and self-control feedback manipulations on the acquisition and retention of motor skills.

In Chapter 2 the relevant literature regarding the purposes of this dissertation is reviewed. The first section describes the CPF (Guadagnoli & Lee, 2004). The second and third sections consist of a review of research on the effects of contextual interference and knowledge of results manipulations on motor learning as they pertain to the CPF. The fourth section contains a review of the research literature on the benefits of self-control for motor learning and a discussion of its relevance to the ideas presented in the CPF.

Statement of the problem

The purpose of this experiment was to determine if the effects of practice schedule and self-control feedback manipulations during acquisition interact to produce an optimal challenge point for the learning of motor skills.

Hypotheses

Based on the existing literature the following hypotheses were tested:

1. Self-control (SC) feedback groups would perform better than their yoked counterparts in retention.
2. Participants who did not have control over their feedback schedule and who practiced according to a blocked practice (BLK) schedule would perform better in acquisition and worse in retention compared to their random practice (RND) counterparts.
3. SC groups would perform similarly regardless of practice schedule.
4. Participants in the RND-SC group would request feedback more frequently than participants in the BLK-SC group.

Assumptions

1. Participants would perform the tasks to the best of their ability throughout the entire experiment.
2. Participants were naïve to the purposes of the study and had no prior experience with the experimental tasks.

Delimitations

1. The sample consisted of undergraduate students from the University of Tennessee – Knoxville.
2. Participation was voluntary.
3. The study was conducted in a laboratory setting.

Definitions of Terms

Absolute Constant Error

The absolute value of each participant's average constant error scores for each block of trials. Absolute constant error is considered to be a measure of response error without regard to direction of the error (Schmidt & Lee, 2005).

Acquisition

The initial period of motor skill practice.

Blocked Practice Schedule

Schedules in which all of the trials of one task are practiced before trials of any of the other tasks are introduced (e.g., AAA… BBB… CCC…).

Contextual Interference

"The degree of functional interference found in a practice situation when several tasks must be learned and are practiced together" (Magill, & Hall, 1990, p. 244).

Constant Error

The difference between actual movement time and the criterion time. Constant error was considered to reflect average response error (Schmidt & Lee, 2005)

Execution Errors

Trials in which participants failed to execute the key-pressing sequence correctly.

Knowledge of Results

Information regarding the constant error of a completed trial.

Percentage absolute constant error

Calculated for each trial by dividing absolute constant error by the criterion time and then multiplying by a hundred. Percentage absolute constant error is considered a measure response error without regard to direction of the error (Simon & Bjork, 2001).

Random Practice Schedule

A practice schedule in which the tasks are presented randomly with the stipulation that no task be repeated more than once in immediate succession (Morgan & Shea, 1979).

Retention

A period subsequent to acquisition in which subjects are tested to determine the degree to which they have learned the previously practiced tasks. During this period, knowledge of results is not provided.

Self-Control

An experimental manipulation that allows participants control over their own practice conditions.

Variable Error

The square root of the average of the squared differences between each trial-level CE score and the mean CE for the block of trials under consideration. Variable error is considered a measure of response inconsistency (Schmidt & Lee, 2005).

CHAPTER 2

REVIEW OF LITERATURE

The Challenge Point Framework

In 2004, Guadagnoli and Lee proposed a theoretical framework to explain the effects of different practice variables on motor performance and learning. Known as the Challenge Point Framework (CPF), Guadagnoli and Lee's (2004) explanation for a range of previous research findings in motor learning included a mechanism that linked learning to the specific levels of challenge the learner encounters during practice. According to Guadagnoli and Lee (2004), the acquisition of motor skills is optimized when individuals are faced with an optimal level of challenge during practice. In contrast, motor skill acquisition can be compromised when the challenge level imposed is either too high or too low.

A central tenet of the CPF (Guadagnoli & Lee, 2004) is the assumption that task difficulty can be categorized into two distinct dimensions: (a) nominal task difficulty and (b) functional task difficulty. Nominal task difficulty refers to the characteristics of a particular task regardless of the performer's skill level or the context in which the task is performed. Thus, nominal task difficulty depends on the perceptual and motor requirements of a task. For example, juggling three tennis balls has lower nominal task difficulty than juggling five tennis balls regardless of who completes the task or when and where the task is completed. When nominal task difficulty is too low, both experts and novices are expected to perform well. If nominal task difficulty increases to a level that is too high, neither experts nor novices are expected to perform well.

Although the nominal difficulty of any given task is fixed, functional difficulty varies based on three factors: (a) the nominal difficulty of the task; (b) the skill level of the performer; (c) and the context in which the task is performed. The idea of functional difficulty relates directly to how challenging a task is for a given individual performing it under certain conditions. Continuing with the juggling example, functional difficulty can be illustrated by comparing the different challenge presented to expert and novice jugglers when they are asked to juggle three tennis balls. This task represents a relatively high level of functional difficulty for the novice but a relatively low level for the expert. Functional difficulty is also influenced by the performance context such that, for example, juggling indoors in a controlled environment presents a lower functional difficulty than juggling outdoors on a windy day. In both of these examples, the nominal difficulty of the task (juggling three tennis balls) has not changed, but the functional difficulty is different because of the changes to the characteristics of the performer and the conditions under which the task is performed.

Guadagnoli and Lee (2004) proposed that the functional difficulty of a task is closely related to expected performance. Specifically, high functional task difficulty is associated with low levels of performance and low functional task difficulty is associated with high levels of performance. Accordingly, the relatively low levels of performance produced by either low-skill learners or under certain practice conditions (e.g., random practice and reduced feedback frequency) represent situations of high functional difficulty. Low functional difficulty is represented by the relatively high levels of performance produced by either high-skill learners or facilitative practice conditions (e.g., blocked practice and increased feedback frequency). Any combination of task demands, learner characteristics, and practice conditions that increase performance will simultaneously decrease the challenge level of the learning situation. In contrast, any combination of these three factors that decreases performance will increase challenge level. For example, an expert executing a simple task under favorable conditions should perform very well, indicating a low challenge situation. In contrast, a novice performing a complex task under challenging conditions is expected to perform poorly, indicating a high challenge situation.

Research on motor learning has identified a number of practice conditions that influence performance in ways consistent with the CPF (Guadagnoli & Lee, 2004). Indeed, the CPF itself is largely based on observations that have emerged from research on the effects of contextual interference introduced through practice schedule manipulations (e.g., Shea & Morgan, 1979), modeled information (e.g., Lee et al., 1997), and feedback schedules (e.g., Salmoni, Schmidt, & Walter, 1984) on the performance and learning of motor skills. According to Guadagnoli and Lee, the often counterintuitive effects of these practice condition variables can be understood by examining how the effects of any specific variable vary across different types of participants (e.g., children vs.

adults) and tasks (e.g., simple laboratory tasks vs. complex ecologically valid tasks). Of the practice condition variables that contributed to the development of the CPF, the most widely researched have been those related to examinations of the effects of contextual interference and feedback schedules. As will be discussed in the following sections, Guadagnoli and Lee (2004) suggest that the manipulations of these variables have impacts on the challenge level faced by the learner.

Creating optimal challenge points

As discussed in the previous section, the CPF (Guadagnoli & Lee, 2004) stipulates that learning will be facilitated when individuals face an optimal challenge point and that the challenge point is influenced by certain variables operating during skill acquisition. The two most prominent of these variables are practice schedules and feedback manipulations. Guadagnoli and Lee (2004) forwarded specific predictions regarding how manipulations of practice scheduling (i.e., contextual interference) and feedback frequency would affect the challenge level and, in turn, influence performance and learning.

In terms of contextual interference, Guadagnoli and Lee (2004) argued that for low nominal difficulty tasks, higher (more difficult) levels of contextual interference conditions (e. g., random practice) would facilitate learning compared to lower levels (e. g., blocked practice). The opposite would be expected for tasks with high nominal difficulty. Blocked practice would lead to better learning than random practice. These predictions were based on the idea that different levels of contextual interference interact with nominal task difficulty to create different levels of functional task difficulty and, thereby, influence the challenge level faced by the learner. In addition, Guadagnoli and Lee postulated that lower levels of contextual interference would facilitate learning for novices by reducing the challenge imposed by a task of any given nominal difficulty while higher levels of contextual interference conditions would facilitate learning for experts by preventing a low level of challenge. These predictions were based on numerous previous reports indicating that high levels of contextual interference decreased immediate performance (Magill, & Hall, 1990; Brady, 1998) while facilitating learning. Guadagnoli and Lee interpreted these results to be consistent with their assumption that random practice increases the functional difficulty of a task.

With regards to feedback, Guadagnoli and Lee (2004) predicted that for high nominal difficulty tasks frequent and immediate feedback would enhance learning. For low nominal difficulty tasks, they predicted that learning would be facilitated by less frequent feedback or delayed feedback. In previous research, both frequent and immediate feedback manipulations have been shown to increase immediate performance (Salmoni, Schmidt, & Walter, 1984). According to the CPF, this improved performance results because increasing the frequency and decreasing the delay of presentation of augmented feedback act to decrease functional task difficulty.

The predictions emerging from the CPF regarding the roles for contextual interference and augmented feedback manipulations have yet to be directly tested. Nevertheless, they are based on Guadagnoli and Lee's (2004) review of a relatively large body of research that has produced the so-called counter-intuitive effects of feedback frequency and contextual interference manipulations. A more extensive discussion of the CPF and its relation to the contextual interference and feedback literature follows in the next two sections, respectively.

Contextual Interference

Contextual interference has been described as "the degree of functional interference found in a practice situation when several tasks must be learned and are practiced together" (Magill, & Hall, 1990, p. 244). The effects of high levels of contextual interference are characterized by low performance during acquisition but high performance on later retention and transfer tests (e.g., Shea & Morgan, 1979). Thus, even though it typically causes a decrement in immediate performance, high contextual interference during practice enhances long-term learning. The effects of contextual interference have been extensively investigated (for reviews, see Brady, 1998; Magill & Hall, 1990). Typically, experiments have introduced high levels of contextual interference by scheduling to-be-learned tasks in a random order (e. g., ABCBBACCA…) and low levels of contextual interference by scheduling each task in its own block for repeated practice (e. g., AAA…BBB…CCC…). Conditions thought to produce intermediate levels of contextual interference, such as serial practice schedules (e. g., ABCABCABC…), have also been investigated (Lee & Magill, 1982).

Contextual interference effects were originally identified in the verbal learning literature. Battig (1972) investigated the effects of task scheduling on the learning of multiple lists of paired-associates. Participants were assigned to conditions that varied in terms of contextual interference. The study compared a practice schedule with high contextual interference (random practice) to five conditions of lower contextual interference, differing in the size of the blocks. The results indicated that participants in the lowest contextual interference condition (the block containing the largest amount of repeated practice) performed better than those in all other conditions during acquisition, but were the least accurate during a free recall test. In contrast, the random practice condition performed poorly during acquisition but was the most accurate during the free recall test.

Shea and Morgan (1979) reported the first examination of so-called contextual interference effects on the learning of motor skills. Participants were assigned to either a high contextual interference condition (random practice) or a low contextual interference condition (blocked practice). The tasks required participants to knock down three wooden barriers with their preferred limb in a specified sequence as fast as possible. Three different sequences were practiced during the acquisition phase. Participants were tested ten minutes and ten days after acquisition. Each testing session consisted of a blocked retention test, a random retention test, and a transfer test. The results showed that during acquisition, participants assigned to the blocked practice schedule condition demonstrated fewer sequence errors and had faster times (reaction time, movement time, and total movement time) than the participants assigned to the random practice condition. During testing, however, participants who had practiced according to the random schedule showed superior performance compared to those who had practiced according to the blocked schedule.

Shea and Morgan's (1979) study prompted several investigations of the contextual interference effects on motor learning, the majority of which have corroborated the initial findings (for reviews see Brady, 1998; Magill, & Hall, 1990).

Possible Explanations for the Contextual Interference Effect

There are two prominent explanations for the effects of contextual interference on motor skill learning. Lee and Magill (1983, 1985) proposed what came to be known as the action-plan reconstruction hypothesis. According to this hypothesis, a learner can only hold in working memory the action-plan for the task being currently practiced and during that time the action-plans for the other tasks are partially forgotten. When switching to another task, the learner must reconstruct the forgotten action-plan required to complete the to-be-performed current task. In a random practice schedule, the learner must frequently reconstruct the action-plans for the to-be-learned tasks because the schedule involves extensive switching between tasks. Lee and Magill argued that the process of action-plan reconstruction is effortful, requiring the learner to reassess the environment, search memory for possible solutions for the proposed motor problem, and organize the response. Increased cognitive effort, in turn, produces stronger memory representations for the tasks. During a blocked practice schedule, action-plan reconstruction is typically not required because each task is performed in an uninterrupted sequence. The relatively superficial processing required by a blocked practice schedule is thought to produce weaker memory representations for each of the tasks being practiced compared to those produced via a random schedule.

The second prominent explanation for contextual interference effects is known as the elaboration explanation (Shea & Zimny, 1983; 1988). According to this explanation, a learner following a random practice schedule holds the different to-be-learned tasks together in working memory. The concurrent presence of all tasks in working memory promotes comparisons of each task to the others and to other existing knowledge. This type of processing is thought to establish multiple retrieval routes to task information stored in long-term memory. In contrast, the practice of one task at a time as in blocked practice prevents such comparisons and the resulting memory advantages that are thought to underlie random practice.

Both explanations of contextual interference effects emphasize the cognitive processes associated with the learning of multiple motor skills during the same practice setting. In effect, both views argue that practice conditions that challenge the learner (either by causing effortful reconstruction or promoting task comparisons) will facilitate learning. A key difference between the two explanations, however, relates to how the nature of the to-be-learned tasks is thought to influence cognitive processing. According to the action-plan reconstruction hypothesis (Lee & Magill, 1983), the nature of the tasks should not matter as long switching to one task causes the action-plans for the other tasks to be partially or completely forgotten. In contrast, the elaboration explanation (Shea & Zimny, 1983, 1988) suggests that the benefits of random practice would be decreased as tasks become less similar (thereby reducing the effectiveness of inter-task comparisons). Despite their marked differences in the purported role of working memory, both explanations have received considerable empirical support. This has led some researchers to argue that the processes forwarded by the two explanations might not be mutually exclusive (Jelsma, & Pieters, 1989; Young, Cohen, & Husak, 1993).

Contextual Interference and the Challenge Point Framework

Despite a large body of research supporting the robustness of contextual interference effects, literature reviews (Brady, 1998; Magill & Hall, 1990) have revealed that the effects can be influenced by various characteristics of the learners and to-be-learned tasks.

Magill and Hall (1990) classified the tasks used in contextual interference studies into two major categories: laboratory and non-laboratory tasks. Laboratory tasks were described as being relatively simple, promoting rapid improvements in performance, and lacking in ecological validity. Examples of laboratory tasks used in previous studies include rapid barrier knockdown (Shea & Morgan, 1979; Lee & Magill, 1983), anticipation timing (Del Rey, Whitehurst, & Wood, 1983; Smith, & Rudisill, 1993), rotary pursuit (Whitehurst, & Del Rey, 1983), computer-based tasks (Jelsma, & Pieters, 1989; Sekiya, Magill, & Anderson, 1996), and linear positioning (Husak, Cohen, & Schandler, 1991). Research employing these types of tasks has consistently shown typical contextual interference effects on motor learning.

According to Magill and Hall (1990), non-laboratory tasks are more complex, requiring longer periods of time to show improvement, and possessing greater ecological validity compared to laboratory tasks. Examples of non-laboratory tasks used in previous research include various skills from the sports of badminton (Goode, & Magill, 1986; Wrisberg, 1991), target shooting (Boyce, & Del Rey, 1990), volleyball (French, Rink, & Werner, 1990), baseball (Hall, Domingues, Cavazos, 1994), golf (Brady, 1997; Goodwin, & Meeuwsen, 1996), and tennis (Farrow, & Maschette, 1997). In contrast to the studies that have used simple laboratory tasks research on contextual interference effects using non-laboratory tasks has yielded mixed results.

Some non-laboratory studies (Wrisberg, 1991; Wrisberg, & Liu, 1991) have reported an advantage for learning with a random practice schedule compared to a blocked practice schedule. Other studies, however, have provided only qualified support for the advantage of random practice. For example, Goode and Magill (1986) reported that learning badminton serves tended to be more effective under a random practice schedule than under a blocked practice schedule, but only for one of the three serves practiced. In other studies, results have indicated that a blocked practice schedule facilitates the learning of tennis strokes to a greater extent than a random practice schedule (Hebert, Landin, & Solmon, 1996).

Wulf and Shea (2002) argued that simple tasks differ from complex tasks in terms of the cognitive and information processing demands imposed on the learners. Accordingly, the mixed results seen in studies that have used non-laboratory tasks may be due to interactions between cognitive demands and the levels of contextual interference introduced by the various practice schedules used. For example, the relatively high level of complexity of tasks such as tennis strokes might be so demanding for a novice that learning would be facilitated by practicing each one in isolation. In addition to task demands, learner characteristics might also interact with contextual interference created by practice schedules. For example, Hebert, Landin, and Solmon (1996) found that while novices benefitted from a blocked practice schedule, experts performed similarly under either blocked or random schedules. Similarly, Farrow and Maschette (1997) found that older children (10-12 years old) who had practiced according to a random schedule showed superior retention compared to those who had followed a blocked schedule. For younger children (9-10 years old), however, this pattern of results was reversed, with those who had practiced according to a blocked schedule showing superior retention compared to those who practiced according to a random schedule. Pinto-Zipp and Gentile (1995) also found that practice according to a blocked schedule facilitated learning for children while a random schedule facilitated learning for adults.

These results suggest that when tasks are complex or learners are relatively inexperienced, random practice might not be as beneficial to learning as blocked practice (Wulf & Shea, 2002). The CPF (Guadagnoli & Lee, 2004) offers an alternative explanation for these findings. As discussed earlier, the CPF posits that there is an optimal challenge point for learning. This optimal challenge point is determined by what is referred to as functional difficulty of the task. The functional difficulty of the task is determined by the interaction of task characteristics, learner characteristics, and practice conditions. If functional task difficulty is too high or too low, learning will be impaired. When a given task is practiced under blocked schedules immediate performance is better than when tasks are practiced under a random schedule, suggesting that blocked practice lowers functional task difficulty while random practice increases functional task difficulty. According to the CPF, the mixed results found in studies of contextual interference effects on non-laboratory tasks simply reflect the fact that the low functional task difficulty of a blocked schedule can offset the relatively high functional task difficulty created when inexperienced learners practice a complex task. Similarly, a random schedule might compound functional task difficulty to a point that learning is degraded. In short, complex tasks and new learners are likely to require a blocked practice schedule to achieve an optimal challenge point. In contrast, simple tasks and skilled learners are likely to require a random schedule to achieve an optimal challenge point.

Knowledge of Results

Feedback is thought to play a central role in motor skill learning because it provides critical information that allows learners to make adjustments as needed to achieve a desired performance. For example, a child practicing baseball pitches might learn from an older sibling or parent whether or not a particular pitch was a ball or a strike. A figure skater might use the scores obtained on a routine to evaluate performance strengths and weaknesses. A stroke patient can usually rely on the information provided by a physical therapist to reinforce correct movements. There are two main categories of augmented feedback. Knowledge of performance (KP) refers to augmented feedback related to the pattern of the movement (e.g., the position of a swimmer's elbow during the recovery phase of the front crawl) while knowledge of results (KR) refers to feedback about the outcome of the movement (e.g., a swimmer's time in a 50 meter freestyle event). Despite KP being the predominant type of feedback used in applied settings (Lee, Keh, & Magill, 1993), researchers have primarily investigated the effects of KR on performance and learning of motor skills. As Magill (2001) noted, this discrepancy is largely due to limitations in technology (i.e., outcomes are easier to record) and the inherent usefulness of KR in learning simple outcome-based laboratory tasks.

Research on KR

KR is thought to serve three main functions in motor learning. KR motivates learners (Magill, 1989; Schmidt, 1988), provides them with information that indicates the appropriate response (Adams, 1971), and provides reinforcement for relationships between motor commands and responses (Schmidt, 1975). There has been a longstanding interest in research on the effects of KR on motor learning. However, Salmoni, Schmidt, and Walter (1984) noted that the majority of the studies conducted until the time of their review had not incorporated retention or transfer tests, which are needed to separate the immediate and temporary effects of KR on performance from the relatively lasting effects on motor learning. In examining the smaller number of studies that included retention and transfer tests, Salmoni, Schmidt, and Walter observed that relatively high frequencies of KR (e.g., after every trial) enhanced performance during practice but also hindered performance during retention and transfer tests.

Salmoni, Schmidt, and Walter's (1984) observation about KR frequency effects was contrary to traditional views that maintained higher frequencies of KR are needed to enhance the learning of motor skills (Adams, 1971; Bilodeau, & Bilodeau, 1958; Bilodeau, Bilodeau, & Schumsky, 1959). Because early research (e.g., Bilodeau & Bilodeau, 1958) revealed that conditions that differed in terms of the relative frequency of KR administration (e.g., on 10% of trials vs. 33%) did not perform differently on the KR trials, many researchers thought that attempts without the presentation of KR would have no impact on learning.

Subsequent studies using retention and transfer designs (Baird & Hughes, 1972; Chiviacowsky & Tani, 1993; Taylor & Noble, 1962; Winstein & Schmidt, 1990) showed that the relative frequency of KR can be an important variable affecting motor skill learning. Moreover, these investigations indicated that lower frequencies of KR degrade immediate performance during acquisition, but facilitate learning as indicated by performance during tests of retention and transfer.

Schmidt (1991) forwarded the idea of maladaptive short-term corrections to explain KR frequency effects on motor learning. According to this notion frequent KR leads to instability during practice because the learner corrects the movement after every trial, even when the previous response was essentially correct. Since feedback acts as a de facto instruction to change behavior more frequent feedback encourages the learner to engage in corrections even when errors are small enough to be attributed to the inherent variability of the neuromuscular system (Newell & Corcos, 1993). Another explanation forwarded by Schmidt and colleagues (Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991) has become known as the guidance hypothesis. This explanation posits that learners can become dependent on KR, which in turn can discourage them from processing information from other important sources (e.g., proprioception and kinesthesia) needed to support learning.

Evidence from erroneous feedback studies (Buekers, Magill, & Sneyers, 1994) has indicated that participants orient their performance based on the information provided extrinsically rather than on their own intrinsic feedback. The guidance hypothesis assumes that information provided externally can become a "crutch" that prevents the learner from performing as well when that information is not available. Evidence supporting the guidance hypothesis was reported by Winstein, Pohl, and Lewthwaite (1994), who showed that higher KR frequencies during practice led to poorer retention performance compared to lower KR frequency conditions.

KR and the Challenge Point Framework

In general, KR frequency studies tend to support the idea that less frequent feedback enhances learning. However, these studies have typically used simple motor tasks (Magill, 2001; Salmoni, Schmidt, & Walter, 1984; Wulf & Shea, 2002). As mentioned earlier, simple tasks differ from complex tasks in terms of cognitive and information processing demands (Wulf & Shea, 2002). Thus, it might be expected that KR frequency effects would depend upon task complexity. Although this prediction has not been systematically investigated, studies that have examined KR frequency using relatively complex tasks have revealed possible support. For example, Wulf, Shea and Matschiner (1998) found that novices benefitted from receiving concurrent feedback on every trial when learning to use a ski simulator (compared to conditions that received feedback on half the trials or no feedback at all). The authors suggested that the frequent feedback facilitated the development of effective error detection and correction mechanisms, and noted that this occurred without the participants becoming dependent on the feedback (which commonly occurs in concurrent feedback studies).

According to the CPF (Guadagnoli & Lee, 2004), complex tasks present higher nominal task difficulty compared to simple tasks. Therefore, it would be expected that the feedback schedule that provides the optimal challenge point for a complex task would be different from the feedback schedule that provides the optimal challenge point for a simple task. Specifically, it is possible that for the learning of complex tasks higher feedback frequencies would be better than lower feedback frequencies because it lowers functional task difficulty. In the Wulf, Shea, and Matschiner (1998) study, the interaction of task complexity and the high frequency of feedback might have produced a near optimal challenge point, increasing learning benefits. A similar case can be made with respect to learner characteristics. Novices experience higher functional task difficulty than experts when performing similar tasks (Guadagnoli & Lee, 2004). Thus, conditions that decrease functional task difficulty (e. g., more frequent feedback) should benefit novices, whereas conditions that increase functional task difficulty (e. g., less frequent feedback) should benefit experts.

Self-Control and Motor Learning

The predictions forwarded in the CPF (Guadagnoli & lee, 2004) are all based on the ways that variables such as practice schedules and KR frequency might interact with other components (i.e., the learner's skill level and nominal task difficulty) to influence functional task difficulty. However, testing these predictions is problematic for a number of reasons. First, there is currently no accepted definition of nominal task difficulty. In addition, tasks can differ from one another along many dimensions, so the comparison of performances on any two tasks of differing nominal difficulty are potentially confounded by other factors. The same is true for comparisons between the performances of people of different skill levels. In contrast, variables such as practice schedules and KR frequency offer greater potential to equate experimental conditions. Specifically, the idea that these variables can interact to influence functional difficulty, and thus performance and learning, can be directly assessed by examining them simultaneously. One way to do this is has been suggested in recent research on the effects of self-control on motor learning.

Janelle and colleagues (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995) were the first to use a self-control protocol to investigate motor learning. Janelle, Kim, and Singer (1995) investigated the influence of self-controlled feedback about the mechanics of an underhand tossing movement (knowledge of performance) and found that the tosses of learners who had control over knowledge of performance (KP) were significantly more accurate during a retention test than those of participants in a yoked condition (each of whom was matched or “yoked” to the schedule of requests of a participant in the self-control condition). Janelle, Barba, Frehlich, Tennant, and Cauraugh (1997) also examined the effects of self-controlled KP on the learning of a throwing skill and found that the self-control condition demonstrated superior form and accuracy scores during a retention test compared to a yoked condition.

Researchers have argued that allowing learners some control over one or more aspects of the instructional setting increases learners' perceptions of self-efficacy (Chen & Singer, 1992; Wulf et al., 2001; Wulf & Toole, 1999). Bund and Wiemeyer (2004) measured the self-efficacy of individuals learning the topspin forehand shot in table tennis. Participants were assigned to self-control conditions, where they were allowed to control a preferred aspect of the task (i.e., model presentation) or a non-preferred aspect (i.e., task variability), or to control groups yoked to each of the self-control conditions. Performance was measured in terms of accuracy and form scores. In addition, self-efficacy was measured five times throughout the experiment. The results indicated that both self-control conditions demonstrated better form scores in retention and had higher self-efficacy scores than their respective yoked control conditions. These findings support the notion that self-control increases self-efficacy and enhances learning. In addition, some contend that perceptions of higher self-efficacy can, in turn, enhance learning by promoting deeper processing of relevant information (Bandura, 2001; Chen & Singer, 1992; Chiviacowsky & Wulf, 2002, 2005; Wulf, Clauss, Shea, & Whitacre, 2001; Wulf, Raupach, & Pfeiffer, 2005; Wulf & Toole, 1999). Janelle et al. (1997) and Chiviacowsky and Wulf (2002) have also argued that self-controlled feedback may enhance learning because it affords the learner the opportunity to tailor the administration of feedback to individual needs or preferences. Chiviacowsky and Wulf (2002) found enhanced learning of a sequential timing task for participants who had control over their feedback schedule compared to yoked participants. In addition, post-experimental interviews revealed that self-control participants primarily chose to receive feedback after “good” trials and yoked participants would have preferred to receive feedback after good trials. Chiviacowsky and Wulf (2002) interpreted this finding to mean that participants had a clear strategy, possibly knowing what they needed in order to learn the task, and acted to meet those needs.

Research on the beneficial effects of self-control on motor learning has focused on numerous variables including physical guidance (Wulf & Toole, 1999; Wulf, Clauss, Shea, & Whitacre, 2001), modeled demonstrations (Wrisberg & Pein, 2002; Wulf, Raupach, & Pfeiffer, 2005), practice schedules (Keetch, & Lee, 2007), and feedback frequency (Chiviacowsky, Godinho, & Tani, 2005; Chiviacowsky, & Wulf, 2002; 2005; Janelle, Barba, Frehlich, Tennant, & Caraugh, 1997; Janelle, Kim, & Singer, 1995). In general, the results of these studies have indicated that allowing participants to have control over some aspect of the skill acquisition process facilitates retention and transfer of motor skills.

The research on self-control manipulations has produced results that appear to be consistent with the CPF (Guadagnoli & Lee, 2004). Participants usually request assistance more frequently early in practice but reduce their requests dramatically as practice progresses. For example, Janelle et al. (1997)

found that self-control participants requested feedback after only 11.15% of trials overall, and that requests declined from 20.8% at the beginning practice to 6.70% at the end. Similarly, Chiviacowsky and Wulf (2002) reported a reduction in feedback requests from the beginning (44.7% of the trials) to the end (28% of the trials) of acquisition. From the perspective of the CPF, it is possible that participants in the self-control conditions were using feedback frequency strategically to adjust the functional difficulty of their practice experience. Specifically, as practice progressed and participants became more skilled, they reduced feedback requests to increase functional task difficulty.

It is also possible that feedback requests might not decrease if doing so increases functional difficulty to a level that undermines learning. For example, Chiviacowsky, Wulf, Medeiros, Kaefer, and Tani (2008) found that the average frequency of feedback requests in a self-control condition was much higher for children learning a bean bag tossing task compared those reported for adults in earlier studies. Specifically, the children requested feedback after 28.3% of trials (Chiviacowsky et al., 2008) whereas adults practicing similar tasks requested feedback after about 10% of the trials (e.g., Janelle et al., 1995, 1997). In addition, the Chiviacowsky et al. (2008) study revealed that children who requested feedback more frequently performed better than those who requested it less frequently. According to the CPF, if the bean bag toss presents a greater challenge to children they might request more frequent feedback in order to achieve the optimal challenge level for learning.

Since it is suggested that self-controlled feedback allows participants to match the practice conditions to their needs (Chiviacowsky & Wulf, 2002; Janelle et al., 1997) and since it appears that participants organize their practice conditions to achieve an optimal level of challenge for learning self-control manipulations could be a potentially fruitful approach to examining predictions of the CPF. In addition, self-control feedback manipulations would allow an examination of the predictions forwarded by Guadagnoli and Lee (2004) in regards to skill level, while controlling for participant characteristics. Moreover, combining practice schedule manipulations and self-control feedback manipulations might reveal whether individuals given self-control act in a way that offsets the effect of another practice variable (e.g., practice schedule) on functional task difficulty. The purpose of this study was, therefore, to examine the effects of practice schedule and self-control feedback manipulations on the acquisition and retention of motor skills.

CHAPTER 3

METHODS

Participants

Participants were 96 University of Tennessee undergraduate students (mean age = 18.8 years; standard deviation = 1.2 years) recruited from a participant pool managed by the Psychology Department. All participants were naïve to the purposes of the study and had no prior experience with the experimental tasks. All participants provided informed consent (Appendix A) acknowledging that they participated voluntarily. The consent document was approved by the University of Tennessee Institutional Review Board (IRB #8016 B).

Apparatus and Task

The apparatus consisted of a Pentium-class PC-compatible micro-computer interfaced with a color display monitor and standard keyboard. The numbers on the numeric pad of the keyboard were covered with black stickers. The experimental procedures were controlled using a customized computer program written with E-Prime version 1.2.

Participants learned three sequential timing tasks. Each task consisted of the sequential pressing of five computer keys in a particular criterion time. Figure 1 depicts the three key-press sequences (labeled Blue, Red and White) used in this study and their respective criterion times.

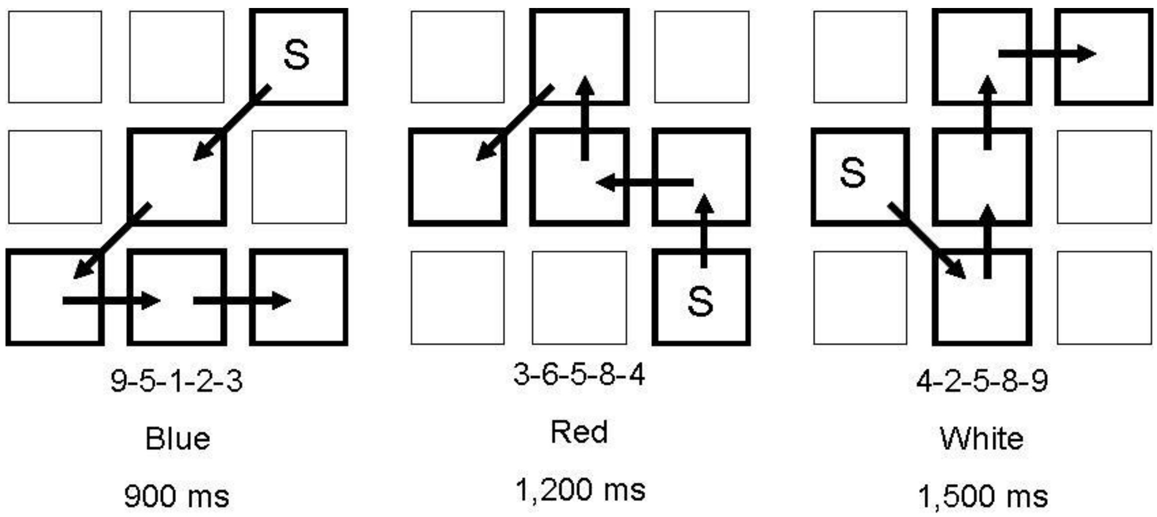

Figure 1. Diagrams depicting the three sequences of key-presses and their respective criterion times. The key labeled with an “S” denotes the starting position and the arrows indicate the order of key–presses. The numbers below the sequences correspond to the actual keys used.

The NASA Task Load Index (Hart & Staveland, 1988) and an adapted Perceived Competence for Learning scale (adapted from Williams & Deci, 1996) were also used in this study (Appendix B and C, respectively). The NASA Task Load Index (NASA-TLX) is a multi-dimensional rating scale that is used to assess the overall workload associated with a given performance situation, which made it a useful instrument to explore the conceptually similar challenge-point idea. The instrument is composed of six items that assess respondents’ perceptions of the mental, physical, and temporal demands of the performance situation and their estimations of their own performance, effort, and frustration. Participants are asked to read the questions carefully then rate on a scale from one (being the least) to five (being the most) the contribution of each specific component of the instrument (i.e., physical, mental, temporal demands, performance, effort, and frustration) to the overall work load (Hart & Staveland, 1988). After weighting each of the components, participants are asked to rate on the 20-point scales their perception of the task.

The adapted Perceived Competence for Learning (PCL) scale is comprised of four statements regarding one's confidence in his/her ability to learn the tasks, achieve their goals, and meet the challenge imposed by the tasks. The scores provide an estimate of participants' perceived competence for learning the experimental tasks. Participants rate each of the statements on a Likert-type seven-point scale.

Procedures

Upon arriving at the laboratory, participants completed informed consent forms and were assigned to one of six experimental groups representing the various combinations of practice schedules (blocked or random) and feedback frequency (self-controlled, yoked, or 100%). Specifically, the conditions were as follows: blocked practice schedule with self-controlled feedback (BLK-SC); random practice schedule with self-controlled feedback (RND-SC); blocked practice schedule with yoked feedback (BLK-YK); random practice schedule with yoked feedback (RND-YK); blocked practice schedule with 100% feedback (BLK-100); and random practice schedule with 100% feedback (RND-100). During group assignment, participants in the Yoked groups were matched to equate sex and handedness with their respective counterpart in the Self-Control groups. After group assignment, participants were seated in front of the apparatus and given written instructions, which the experimenter read aloud. Participants were then allowed to ask questions. During acquisition, participants in the RND-100, RND-SC, and RND-YK groups completed 30 trials of each task (90 trials total) presented in a random order with the stipulation that each task was presented the same number of times in each trial 15-trial block. Participants in the BLK-100, BLK-SC, and BLK-YK groups performed all 30 trials of one task before moving to the next task (e.g., 30 trials of the Blue Task, then 30 trials of Red Task, then 30 trials of White Task). The order of task presentation for the blocked practice groups was counterbalanced across participants using a Latin-square design. Participants in the BLK-100 and RND-100 groups received KR after every trial. Participants in the BLK-SC and RND-SC groups were allowed to choose whether or not to receive feedback after a trial. Participants in BLK-YK and RND-YK groups had their feedback schedule determined by matching it to the schedule created by a counterpart in their respective self-control group (i.e., BLK -SC or RND -SC).

Each trial was initiated by a warning screen displaying the criterion movement time for that particular trial (e.g., 1200 ms). The warning screen was followed by a display of the diagram indicating the task to be performed (e.g., the Red Task). When ready, the participant used their preferred hand and pressed the required keys in the proper sequence, attempting to match the criterion time for the particular task. Two seconds after the last key was pressed, a screen with an asterisk was displayed. At this point, participants in the RND-100 and BLK-100 groups were provided feedback, participants in the RND-SC and BLK-SC groups were asked if they wished to receive feedback or not, and participants in the RND-YK and BLK-YK groups were either provided feedback or told that they would not receive feedback (depending upon the schedule determined by their SC group counterpart). Feedback consisted of knowledge of results (KR) regarding the accuracy of the key-pressing sequence (“Correct” or “Incorrect”) and, for correct trials, the accuracy in meeting the criterion time. KR regarding timing accuracy was displayed for two seconds in the form of constant error (CE), which was the difference between actual movement time and the criterion time. Participants did not receive feedback after the last trial of acquisition. The inter-trial interval was 2 s. To assess the participants’ subjective impression of the challenge imposed by the practice setting and their perceived competence about their capability to perform the tasks, the NASA TLX (Hart & Staveland, 1988) and PCL were administered after the 5th and 90th trials of acquisition. Acquisition phase lasted around 40 minutes.

After 24 hours, participants returned to the laboratory for retention testing. Participants completed two 9-trial no-KR retention tests (three trials for each task), one consisting of a blocked presentation of the tasks and the other consisting of a random presentation. The order of these two tests was counterbalanced across participants. All procedures were similar to those used during acquisition with the exception that no feedback was provided. Retention testing lasted about 15 minutes. During both acquisition and retention phases, data collection was conducted individually in a private room.

Data Treatment and Analysis

The time elapsed from the depression of the first key in a task sequence (the ‘S’ key) until the depression of the final key was recorded for each trial. Constant error (CE) was calculated as the difference between the actual elapsed time and the criterion time for a particular trial. Trials for which CE was greater than 1000 ms were considered execution errors and were removed. Execution errors were also recorded for trials on which participants pressed an incorrect sequence of keys. Only 24 execution errors were identified out of a total of 10,368 trials completed by all participants. After execution errors were removed, 22 additional data points were removed as outliers (i.e., values greater than 2-½ standard deviations beyond the group mean for a given block of scores). Average CE was considered to reflect average response error (Schmidt & Lee, 2005).

Variable error (VE), absolute constant error (ACE), and percent absolute constant error (PACE) were calculated from CE scores. VE was the square root of the average of the squared differences between each trial-level CE score and the mean CE for the block of trials under consideration. VE was considered a measure of response consistency (Schmidt & Lee, 2005). ACE was calculated by taking the absolute value of each participant's average CE scores for each block of trials. ACE was considered a measure of response error without regard to direction (Schmidt & Lee, 2005). Percentage absolute constant error (PACE) was calculated for each trial by dividing ACE by the criterion time and then multiplying by one hundred. The analysis procedure of PACE scores was identical to those of Simon and Bjork (2001, 2002) and only included the BLK-100 and RND-100 groups. For acquisition, PACE was averaged into blocks of 15 trials (five of each task). For retention, PACE was averaged into a single block of 18 trials. The PACE analysis served to observe if the tasks and procedures used in the study would lead to contextual interference effects. In that sense, the analysis of PACE was a manipulation check. As a manipulation check, the analysis procedures were identical to the ones used by Simon and Bjork (2001, 2002). For acquisition, a 2 (group: BLK-100 vs. RND-100) x 6 (Block) analysis of variance with repeated measures on the second factor was used to identified differences in performance between groups across trial blocks in acquisition. For retention, a one-way ANOVA was used to identify differences in retention.

A multivariate analysis of variance (MANOVA) was used to compare CE, VE and ACE scores across the 10 blocks of trials of acquisition for each of the experimental groups (BLK-SC, RND-SC, BLK-YK, RND-YK, BLK-100 and RND-100). If significant results were found, separate follow-up analyses for CE, ACE, and VE were conducted using separate 6 (group) x 10 (block) analyses of variance with the last factor as a repeated measure. For retention, performance measures were again analyzed using a MANOVA to compare CE, VE and ACE scores across the 2 retention tests for each of the experimental groups (BLK-SC, RND-SC, BLK-YK, RND-YK, BLK-100 and RND-100). In the case of significant results, separate follow-up 6 (group) x 2 (test schedule: random vs. blocked) analyses of variance with the last factor as a repeated measure for CE, ACE, and VE were performed. When violations of the sphericity assumption were detected in repeated measures analyses, *F*-ratios and *p*-values were reported with the Greenhouse-Geisser *df* adjustment. Follow-up analyses to detect the source of significant differences were conducted using Sidak post hoc procedures.

A chi-square analysis was conducted to examine differences in the total number of feedback requests between BLK-SC and RND-SC groups during acquisition. An overall workload score for each participant was calculated from the NASA TLX by averaging the weighted contribution of each component of the instrument to overall workload. Overall scores for the PCL ratings were obtained by adding the points for each statement. The scores were then analyzed by a 6 (group) x 2 (administration: first vs. second) analysis of variance with the last factor as a repeated measure. For all analyses, alpha level was set at .05.

CHAPTER 4

RESULTS

Only the significant *F*-ratios are reported in this chapter. Complete summary tables for all analyses are included in Appendix D. Means and standard deviations for CE, VE and ACE are included in Appendix E. The results for the manipulation check involving PACE are presented first followed by the results for the primary dependent measures.

Percentage Absolute Constant Error

During acquisition, there was a noticeable improvement in PACE across early trial blocks for both groups, with a more pronounced change for the BLK-100 group than for the RND-100 group (Figure 2). These observations were supported by significant main effects for block, F (5, 150) = 36.56, $p < .001$ (η^2 = .56), and group, F (1, 30) = 8.462, p = .007 (η^2 = .22). PACE decreased across blocks, especially in the first couple of blocks, and the BLK-100 group had lower PACE than the RND-100. During retention, no significant differences were detected. Subsequent analysis including task as a factor revealed a main effect of group only for the 900 ms task (p = .025), in which the RND-100 group had a lower PACE than the BLK-100 group (Figure 2).

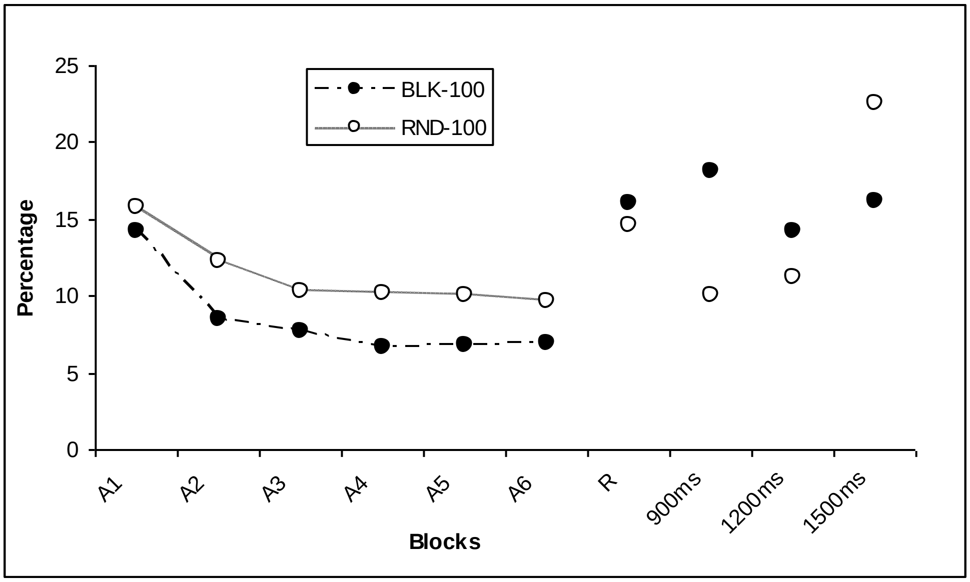

Figure 2. Percentage Absolute Constant Error (PACE) in acquisition and retention for the BLK-100 and RND-100 experimental groups.

Acquisition

The MANOVA showed significant effects for group, Pillai's Trace = .389, *F* = 1.26 *df* = (150, 306.758), *p* = .001 (η^2 = .13), and block, Pillai's Trace = .884, *F* = 18.02 *df* = (27, 64), *p* < .001 (η^2 = .884). The follow-up analyses are described below.

Constant error

All groups tended to respond faster than the criterion times. There was also a noticeable improvement in CE across the trial blocks for all groups except the RND-100 group, which showed little change (Figure 3). These observations were supported by a significant Block × Group interaction, *F* (45, 810) = 2.02, *p* =

.002 (η^2 = .10). Post hoc procedures revealed that the source of the interaction was due to significant differences in CE scores across at least two trial blocks (all *p*-values < .034) for all groups except the RND-100 group.

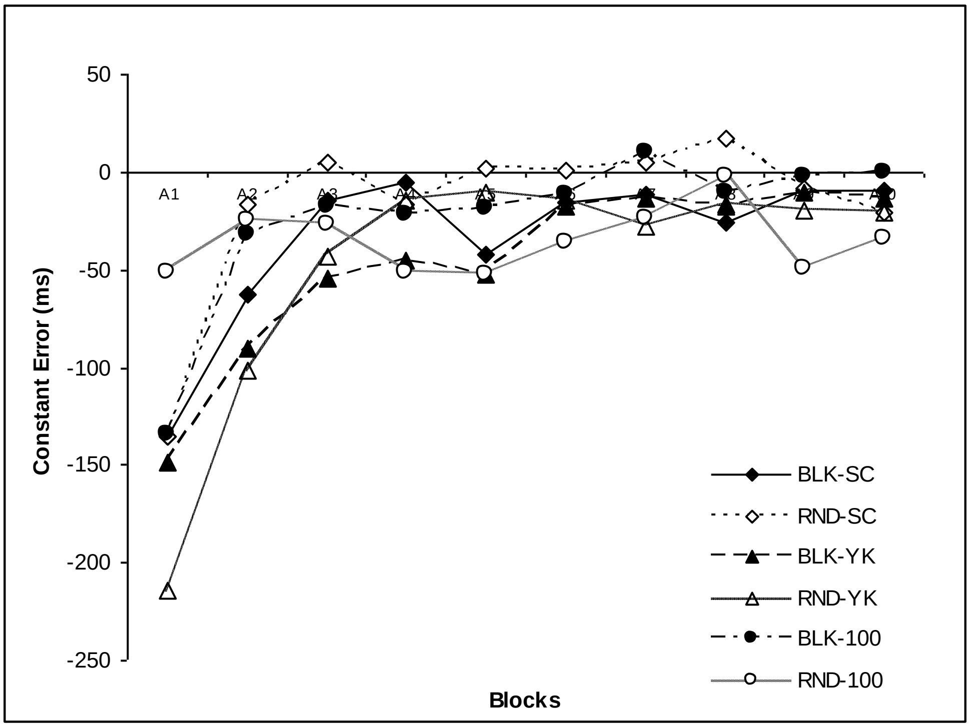

Figure 3. Constant Error (CE) in milliseconds across acquisition blocks for all groups.

Variable Error

Performance for all groups became progressively more consistent across trial blocks. By the end of acquisition groups that practiced according to a blocked schedule seemed to display smaller VE scores than the groups that practiced according to a random schedule (Figure 4). These observations were supported by a significant main effect of block, F (9, 810) = 71.48, $p < .001$ (η^2 = .443), and group, F (5, 90) = 5.92, $p < .001$ (η^2 = .25). Post hoc analyses of the block effect indicated that VE scores decreased progressively across acquisition. The post hoc analysis following the group effect indicated that the BLK-SC was less variable than the RND-SC ($p = .018$), the BLK-YK and BLK-100 groups were less variable than the RND-SC group ($p < .018$), the BLK-100 group was less variable than the RND-YK group ($p = .014$), and the BLK-100 was less variable than the RND-100 group ($p < .035$.

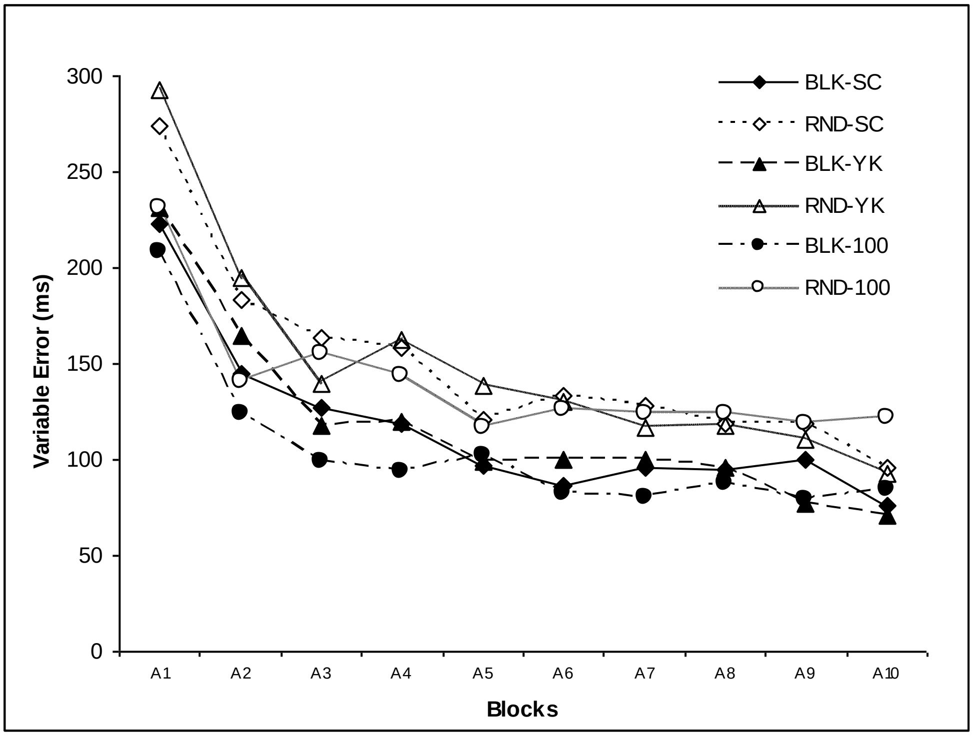

Figure 4. Variable Error (VE) in milliseconds across acquisition blocks for all groups.

Absolute Constant Error

ACE scores for all groups decreased progressively across trial blocks. By the end of acquisition, groups that practiced according to a blocked schedule displayed smaller ACE scores than the groups that practiced according to the random schedule (Figure 5). These observations were supported by the significant main effects of block, F (9, 810) = 111.56, $p < .001$ ($\eta^2 = .553$), and of group, F (5, 90) = 5.30, $p < .001$ ($\eta^2 = .28$). Post hoc analyses of the block effect confirmed that ACE scores generally decreased throughout acquisition. The post hoc analysis following the group effect indicated that the BLK-100 group was more accurate than the RND-SC, RND-YK, and RND-100 groups ($p < .045$).

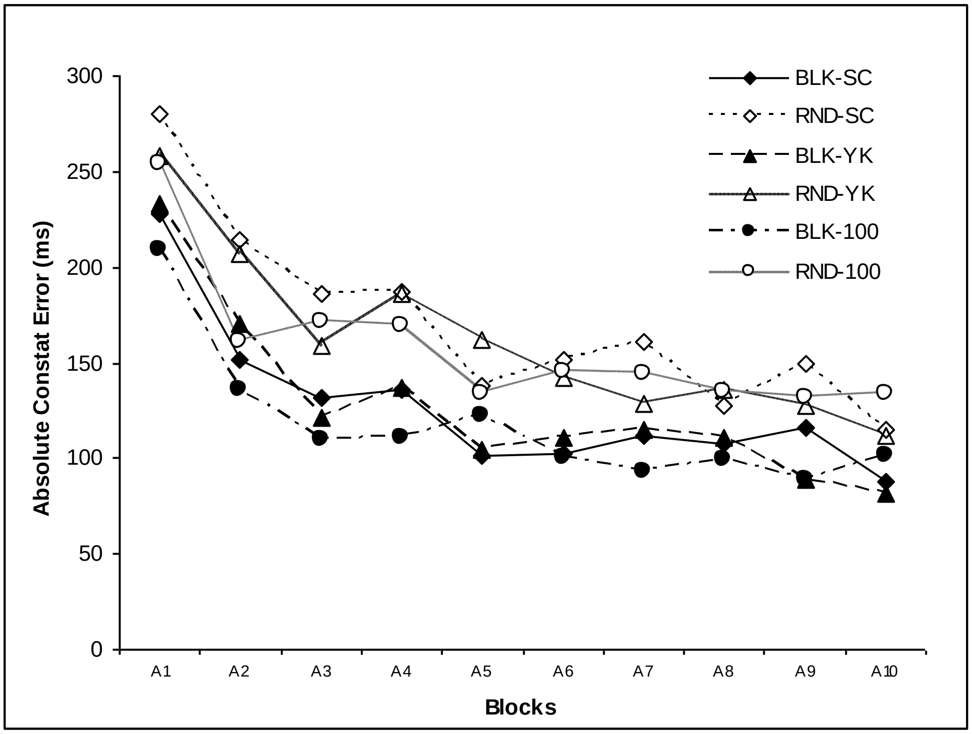

Figure 5. Absolute Constant Error (ACE) in milliseconds across acquisition blocks for all groups.

Retention

For retention, the MANOVA showed significant effects for group, Pillai's Trace = .272, F = 1.794 *df* = (15, 270), *p* = .035 (η^2 = .91). The follow-up analyses are described below.

Constant error

The analysis of variance indicated no significant main effects of group and test, and no Group x Test interaction (Figure 6).

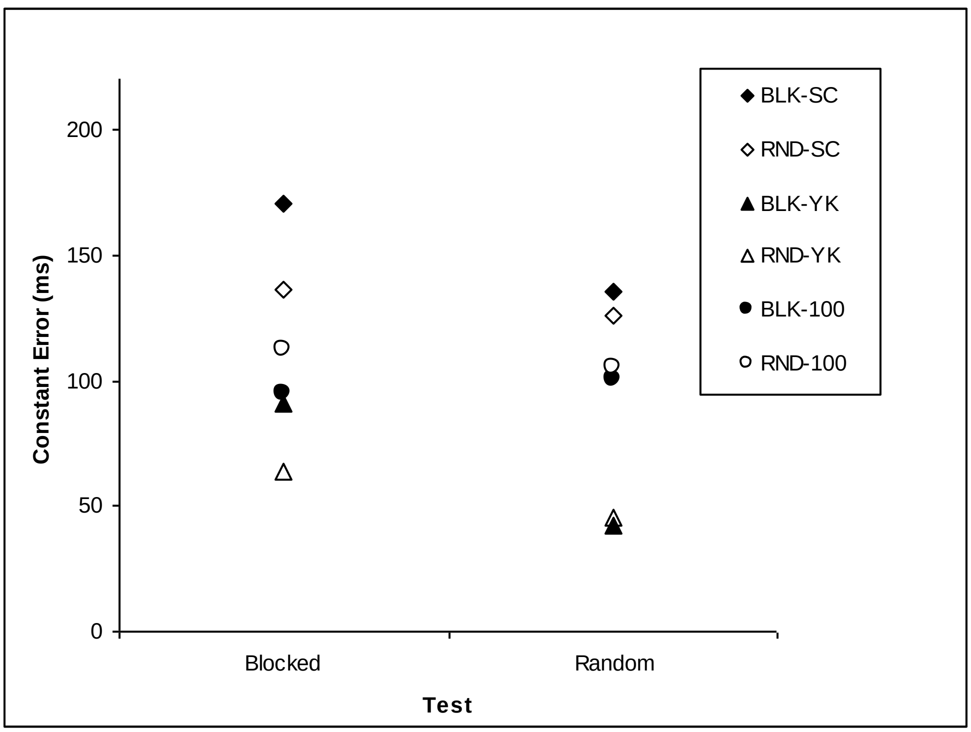

Figure 6. Constant Error (CE) in milliseconds for the Blocked and Random retention tests for all groups.

Variable error

The analysis of variance indicated no significant main effects of group and test, and no Group x Test interaction (Figure 7).

Absolute Constant Error

ACE on the Blocked retention test was higher than ACE on the Random retention test (Figure 8). This observation was supported by a significant main effect of test, F (1, 90) = 4.79, p = .031 (η^2 = .051). The analysis of variance did not reveal significant differences between groups or a Group x Test interaction.

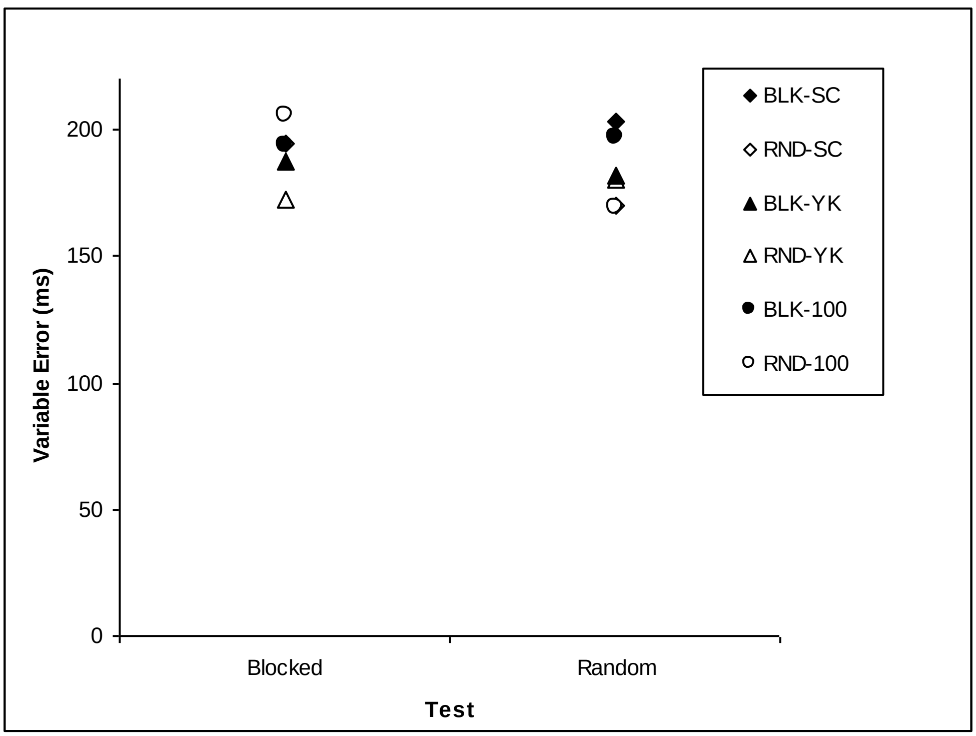

Figure 7. Variable Error (VE) in milliseconds for the Blocked and Random retention tests for all groups.

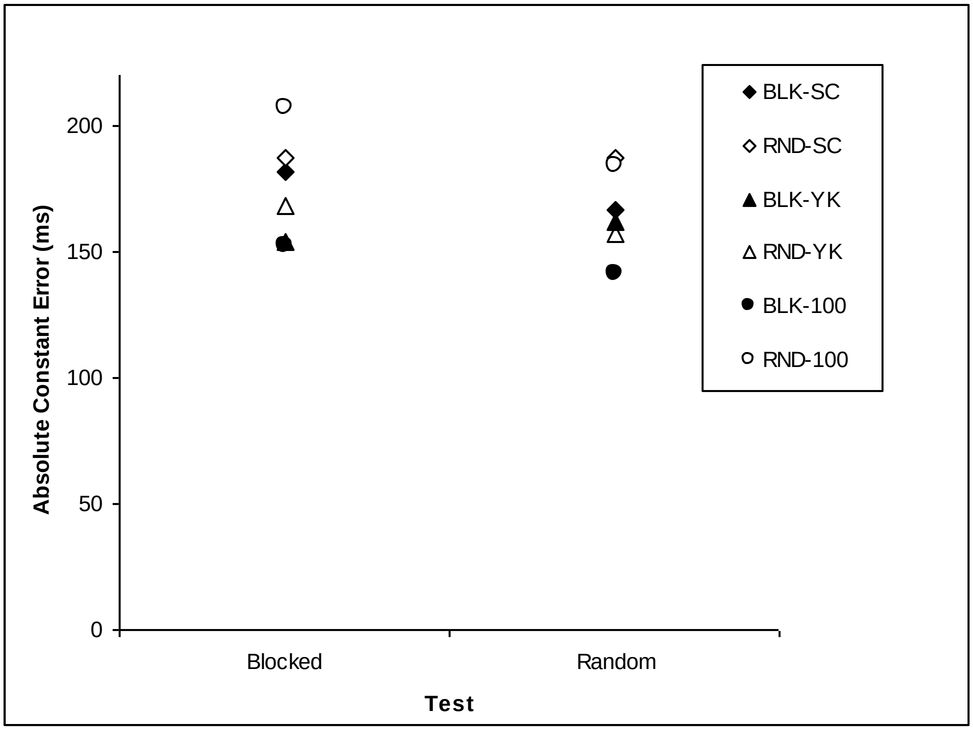

Figure 8. Absolute Constant Error (ACE) in milliseconds for the Blocked and Random retention tests for all groups.

Feedback Requests

The maximum number of feedback requests possible for any single participant in the SC groups was 89. On average, participants in the BLK-SC group asked for feedback after 77% of the trials (*SD* = 20%) while participants in the RND-SC group asked for feedback on 93% of the trials (*SD* = 10%). Feedback frequencies for the BLK-SC group ranged from 28% (25 requests) to 100% (89 requests) of the trials. During the first half of acquisition, participants in the BLK-SC group asked for feedback after 72% of trials. During the second half, these participants requested feedback after 82% of the trials. For the RND-

SC group, feedback frequencies ranged from 64% (57 requests) to 100% (89 requests). During the first half of acquisition, participants in the RND-SC group asked for feedback after 92% of trials. During the second half, these participants requested feedback after 93% of the trials. Despite the greater number of requests by the RND-SC group, the results of the chi-square analysis were not significant ($X^2 = 2.03$, $df = 1$).

NASA-TLX and PCL Scales

For the NASA-TLX, higher scores indicated a perception of higher challenge by the participant. No differences between groups were observed, but scores did increase across the two assessments (Figure 9). This latter observation was supported by a significant main effect of assessment, $F\ (1, 90) = 36.29$, $p < .001$ ($\eta^2 = .287$). For the PCL, lower scores indicated a lower perceived competence for learning the tasks. No differences were detected between groups, but the scores decreased across the two assessments (Figure 9). This latter observation was supported by a significant main effect of assessment, $F\ (1, 90) = 51.31$, $p < .001$ ($\eta^2 = .363$).

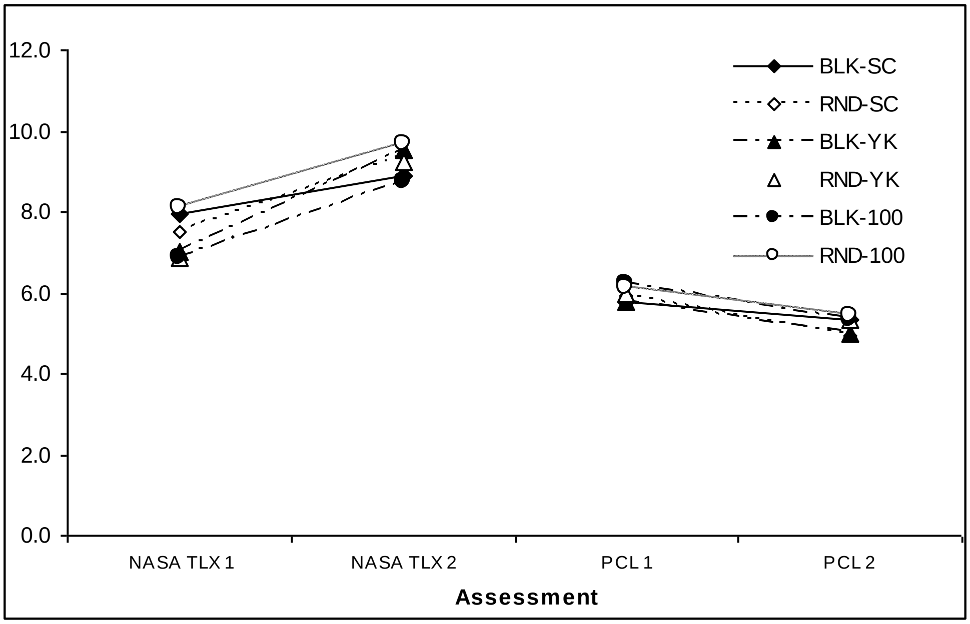

Figure 9. Initial and final assessments for NASA TLX and PCL scores for all groups.

CHAPTER 5

DISCUSSION

Guadagnoli and Lee (2004) proposed a theoretical framework to explain the effects of different practice variables on motor performance and learning, known as the Challenge Point Framework (CPF). According to the CPF learning is linked to the specific levels of challenge the learner encounters during practice. Despite a strong rationale for their explanation of a large number of findings in the motor learning literature related to the effects of contextual interference, feedback frequency, and modeled information, Guadagnoli and Lee's (2004) predictions had not been directly tested prior to the present study. The lack of previous direct investigation is probably due to the problems arising from the comparisons between individuals of different skill levels and tasks of different difficulty levels. One potential solution involves combining practice variables that are thought to influence the challenge level faced by the learner within a protocol that allows the learner to specify the level of one variable in response to the level of the other (so as to create an individualized "optimal" challenge). The purpose of this study was, therefore, to examine the effects of practice schedule and self-control feedback manipulations on the acquisition and retention of motor skills. A summary of the experiments and the conclusions are presented next.

Summary of Procedures

Participants were 96 undergraduate students from the University of Tennessee – Knoxville, recruited from the Department of Psychology participant pool. Participation was voluntary and conditioned to the provision of signed informed consent. Participants were naïve to the purposes of the study and had no prior experience with the tasks. Participants were assigned to one of six groups (i.e., BLK-SC, RND-SC, BLK-YK, RND, YK, BLK-100, or RND-100). Participants in the yoked groups were matched in terms of sex and handedness to their self-control counterparts.

Data collection was conducted individually in the Motor Behavior Laboratory. After consent and group assignment participants were seated in front of a computer. Written instruction were handed to the participants and read aloud by the experimenter. The task consisted of pressing five computer keys in a specified sequence trying to match the respective criterion time. Three key pressing sequences/criterion times combinations were used. Each trial was initiated by a warning screen displaying the criterion movement time for that particular trial (e.g., 1200 ms). The warning screen was followed by a display of the diagram indicating the sequence to be pressed (e.g., the Red Task). When ready, the participant pressed the required keys, attempting to match the criterion time for the particular task. Two seconds after the last key was pressed, a screen with an asterisk was displayed. At this point, participants in the RND-SC and BLK-SC groups were asked if they wished to receive feedback or not, participants in the RND-100 and BLK-100 groups were provided feedback, and participants in the RND-YK and BLK-YK groups were either provided feedback or told that they would not receive feedback (depending upon the schedule determined by their SC group counterpart). Feedback consisted of knowledge of results (KR) regarding the accuracy of the key-pressing sequence (“Correct” or “Incorrect”) and, for correct trials, the accuracy in meeting the criterion time. KR regarding timing accuracy was displayed for two seconds in the form of constant error (CE). Participants did not receive feedback after the last trial of acquisition. The inter-trial interval was 2 s. To assess the participants’ subjective impression of the challenge imposed by the practice setting and their perceived competence about their capability to perform the tasks, the NASA TLX (Hart & Staveland, 1988) and PCL were administered after the 5th and 90th trials of acquisition. The acquisition phase lasted approximately 40 minutes.

After 24 hours, participants returned to the laboratory for retention testing. The first test consisted of a Free-Recall test (Appendix D) that required participants to indicate the key sequence for each task by drawing arrows on a blank keypad template. Below each diagram, participants also wrote the associated criterion movement time for the task. Participants then completed two 9-trial no-KR retention tests (three trials for each task), one consisting of a blocked presentation of the tasks and the other consisting of a random presentation. The order of these two tests was counterbalanced across participants. Retention testing lasted approximately 15 minutes. All procedures were similar to those used during acquisition with the exception that no feedback was provided.

Summary of Findings

Hypotheses

1. Self-control (SC) feedback groups would perform better than their yoked (YK) counterparts in retention.

This hypothesis was not supported. No differences between SC and YK groups were identified.

2. Participants who did not have control over their feedback schedule and who practiced according to a blocked practice (BLK) schedule would perform better in acquisition and worse in retention compared to their random practice (RND) counterparts.

This hypothesis was partially supported. Blocked practice schedule led to better performance in acquisition, especially in terms of VE, ACE and PACE, compared to random practice schedule. However, there were no differences between groups in retention.

3. SC groups would perform similarly regardless of practice schedule.

This hypothesis was partially supported. The BLK-SC and RND-SC groups differed in acquisition in terms of VE but not in retention. However, since there were no differences between any of the groups in retention it is not possible to state that the SC groups were using feedback frequency to offset the challenge imposed by the practice schedules.

4. Participants in the RND-SC group would request feedback more frequently than participants in the BLK-SC group.

   This hypothesis was not supported.

Additional findings:

1. Performance improved in terms of CE, VE and ACE across trial blocks for all groups.
2. There were no differences between groups in NASA-TLX or PCL scores.
3. NASA-TLX scores increased with practice.
4. PCL scores decreased with practice.

Discussion and Conclusions

The purpose of this study was to investigate how practice schedule and self-controlled feedback frequency manipulations affected the performance and learning of motor skills. Based on the CPF (Guadagnoli & Lee, 2004) and the self-controlled feedback literature, it was expected that: 1) self-controlled feedback groups would perform better than their yoked counterparts in retention; 2) participants who did not have control over their feedback schedules practicing according to a blocked practice schedule would perform more accurately in acquisition and less accurately in retention compared to their random schedule counterparts; 3) self-control feedback groups would perform similarly regardless of practice schedule; and 4) participants in the RND-SC group would request feedback more frequently than participants in the BLK-SC group.

The results indicated improved performance (CE, ACE, and VE) across trial blocks during acquisition. Group differences in acquisition, primarily in VE and ACE, were also identified. In general participants practicing according to a random schedule performed less accurately and less consistently than participants practicing according to a blocked schedule, regardless of feedback condition. There were no significant group differences for any of the measures during retention. Analyses of the feedback frequency requests of the BLK-SC and RND-SC groups also revealed no significant differences.

In terms of the first hypothesis, the results indicated that self-control feedback frequency did not lead to better performance in retention compared to yoked controls. Beneficial effects of self-control in motor learning have been widely reported (e.g., Condon & Collier, 2002; Chiviacowsky & Wulf, 2002; Wulf & Toole, 1999; Wrisberg & Pein, 2002, Wulf, Raupach & Pfeiffer, 2005), however the explanations for these beneficial effects have varied considerably. They range from providing a more enjoyable experience for learners (Condon & Collier, 2002) to tailoring practice conditions to meet learners' individual needs (Janelle et al., 1997) to providing positive reinforcement (Chiviacowsky & Wulf, 2002). Despite considerable evidence suggesting that self-control manipulations enhance motor learning, a few previous studies have failed to show such effects. For example, Keetch and Lee (2007) examined the effects of a self-controlled practice schedule on the performance and learning of a sequential aiming task and found no differences between self-control and yoked groups during retention. This suggests that the mechanisms underlying the beneficial effects of self-control manipulations are sensitive to factors that have yet to be identified.

Regarding the second hypothesis of this study, the results showed degraded performance during acquisition, primarily in VE, ACE and PACE, for participants who practiced according to a random schedule compared to participants who practiced according to a blocked schedule. However, there were no differences between these groups during retention. Since the task and procedures chosen for this study were identical to ones previously used to demonstrate contextual interference effects (Simon & Bjork, 2001, 2002), a manipulation check analysis was conducted on PACE (the same measure used by Simon & Bjork) to determine whether differences existed within any of the three versions of the key-pressing task. The results indicated differences in retention between the random and blocked practice schedule groups for the Blue task (900 ms goal time), but not for the Red (1200 ms goal time) or White (1500 ms) tasks. This finding suggests that contextual interference effects were indeed operating during the present study, despite the fact that they were not pronounced enough to be clearly manifested in the primary dependent measures. Nevertheless, the fact that performance was diminished by random practice during acquisition supported Guadagnoli and Lee’s (2004) CPF.

Perhaps the most important contribution of this study related to the third and fourth hypotheses. According to the third hypothesis participants in the self-control groups should have performed similarly during retention because they had the freedom to adjust their feedback frequencies to offset the challenge imposed by the practice schedules and thereby achieve optimal challenge levels for learning. The retention results indicated that the BLK-SC and RND-SC groups performed similarly in terms of CE, ACE and VE. However, neither group performed more accurately than any of the other groups. The similar performance in retention for all groups does not allow the conclusion that the self-control feedback manipulations were used to offset the effects of practice schedule conditions in order to achieve an optimal challenge. One possible reason for these unexpected results is the level of perceived difficulty of the task, which resulted in a high frequency of feedback requests for all groups.

According to the fourth hypothesis, the RND-SC group should have requested feedback more frequently in order to offset the more difficult random practice schedule. The results indicated no differences in terms of feedback requests between the BLK-SC and RND-SC groups and this might have led to the lack of differences in NASA TLX scores. However, no differences in NASA TLX scores were identified for any of the groups. From a challenge point perspective, this finding indicates that the combination of practice schedules and self-controlled feedback manipulations used in this study led to similar perceptions of work load. If so, this would suggest that even though the concepts of work load and challenge level, as presented by Hart and Staveland (1988) and Guadagnoli and Lee (2004), are similar, a valid and specific instrument to assess challenge may need to be developed. It might also be speculated that performance is not a proper indication of challenge level since some differences in group performance (i.e. random practice groups tended to perform worse than blocked practice groups) were obtained during acquisition.

In the present study participants in the BLK-SC and RND-SC groups requested feedback on 77% and 93% of the trials respectively, which was not appreciably less than those of the 100% feedback frequency groups. In addition, the frequency of feedback requests observed in this study differed considerably from the frequency observed in previous research using a similar task. Chiviacowsky and Wulf (2002) reported that self-control participants requested feedback on only 35% of the trials during acquisition of a sequential key-pressing task. The lower frequency of feedback requests by self-control participants in that study might have been due to practice condition since Chiviacowsky and Wulf (2002) used a single-task learning protocol, which according to the CPF, is associated with lower levels of challenge. Another possible cause for the difference in feedback requests in the two studies might have been the perceived difficulty of the tasks used. In Chiviacowsky and Wulf (2002) the task required participants to produce the same relative timing patterns throughout acquisition and retention. In the present study four different relative timing patterns were used. In addition, participants were asked to match criterion times, which is arguably not a common demand of most everyday activities. The higher number of task variations and the type of timing involved (i.e. absolute vs. relative) could have led participants to request feedback more frequently. These observations are merely speculative since no attempt was made by previous researchers to determine participants' perceptions of task challenge. Interestingly, the magnitude of absolute constant error, which might be used to infer challenge level (Guadagnoli & Lee, 2004), was similar in both studies, ranging from 300 ms to 150 ms in the Chiviacowsky and Wulf (2002) study and from 275 ms to 100 ms in the present study.

Although the results of the present study did not provide direct support for the notion that functional task difficulty produced by a practice schedule condition would prompt self-control participants to choose feedback frequencies to offset this difficulty (e.g., high frequencies under a random practice schedule condition), they are still consistent with the CPF when viewed within the broader context of the research literature. Perhaps the nature of the task (i.e. absolute timing) and the number of variations used led to a ceiling in terms of challenge level, as suggested by the NASA TLX scores. The high challenge level imposed by the practice conditions in this study led to higher frequencies of feedback request, as suggested by the CPF, compared to similar studies (Chiviacowsky & Wulf, 2002). The study, however, raises some interesting questions for the future, which are presented next.

Recommendations for Future Studies

1. Complete control over feedback frequency did not lead to a better performance of the BLK-SC and RND-SC groups compared to the BLK-YK, RND-YK, BLK-100 and RND-100 groups. It seems that the lack of benefits of self-control over “non-self-control” conditions in this study happened because participants given self-control chose a high frequency of feedback. Perhaps allowing participants to choose to receive feedback in up to 30% of the trials would lead to learning benefits since that feedback frequency matches what is expected for similar tasks based on the previous literature.
2. The relatively high feedback requests in this study might have led to the lack of differences observed. It is possible that using a task with lower nominal task difficulty (a simpler task or a task that focuses on relative timing rather than absolute timing) might produce the predicted effects.
3. Participants in this study arguably chose an inefficient feedback frequency/practice schedule combination. An alternative to investigating how the interaction of these variables impacts the challenge level would include fixed rather than self-control feedback frequencies. This would guarantee that low feedback frequencies would be compared to high feedback frequencies conditions.
4. Findings in the self-control literature tend to more robustly indicate that participants benefit from self-controlled feedback than from self-controlled

practice schedule. However, based on the results of this study and previous literature, it seems that practice schedule manipulations have a greater impact on immediate performance than do feedback frequency manipulations. It is possible that allowing participants to adjust their practice schedule rather than their feedback frequency would yield different results.

5. This study used college aged students as participants. It is safe to assume that these participants had received some form of previous motor skill training. These experiences might have impacted the participants' decisions regarding feedback or their perceptions of challenge and competence for learning. Children, who arguably have less exposure to motor skill training, perhaps would respond to the conditions posed in this study differently.
6. Along the same lines proposed in the previous item, it would be interesting to observe how training in self-control would impact learner's performance and learning. The educational psychology literature suggests that self-control (or self-regulation) is a skill that can be learned. Perhaps including experimental conditions that provide participants with information about how to evaluate their own performance and goal setting would lead to different results.

References

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

Adams, J. A. (1987). Historical review and appraisal of research on learning, retention and transfer of human motor skills. *Psychological Bulletin, 101*, 41-74.

Baird, I. S., & Hughes, G. H. (1972). Effects of frequency and specificity of information feedback on acquisition and extinction of a positioning task. *Perceptual and Motor Skills, 34*, 567-572.

Bandura, A (2001). Social cognitive theory: An agentic perspective. *Annual Review of of Psychology, 52*, 765-771.

Battig, W. F. (1979). The flexibility of human memory. In L. S. Cermak & F. I. M. Craik (Eds.), *Levels of processing in human memory* (pp. 23-44). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Bilodeau, E. A., & Bilodeau, I. M. (1958). Variable frequency of knowledge of results and the learning of a simple skill. *Journal of Experimental Psychology, 55*, 379-383.

Bilodeau, E. A., Bilodeau, I. M., & Schumsky, D. A. (1959). Some effects of introducing and withdrawing knowledge of results early and late in practice. *Journal of Experimental Psychology, 58*, 142-144.

Boyce, B. A., & Del Rey, P. (1990) Designing applied research in a naturalistic setting using a contextual interference paradigm. *Journal of Human Movement Studies, 18*, 189-200

Brady, F. (1997). Contextual interference and teaching golf skills. Perceptual and Motor Skills, 84, 347-350.

Brady, F. (1998). *A theoretical and empirical review of the contextual interference effect and the learning of motor skills. Quest, 50*, 266-293.

Buekers, M. J., Magill, R. A., & Sneyers, K. M. (1994). Resolving a conflict between sensory feedback and knowledge of results, while learning a motor skill. *Journal of Motor Behavior, 26*, 27-35.

Bund, A., & Wiemeyer, J. (2004). Self-controlled learning of a complex motor skill: Effects of the learner's preferences on performance and self-efficacy. Journal of Human Movement Studies, 47, 215-236.

Chen, D., & Singer, R. N. (1992). Self-regulation and cognitive strategies in sport participation. International Journal of Sport Psychology, 23, 277-300.

Chiviacowsky, S., & Wulf, G. (2002). Self-controlled feedback: Does it enhance learning because performers get feedback when they need it? *Research Quarterly for Exercise and Sport, 73*, 408-415.

Chiviacowsky, S., & Wulf, G. (2005). Self-controlled feedback is effective if it is based on the learner's performance. *Research Quarterly for Exercise and Sport, 76*, 42-48.

Chiviacowsky, S., Godinho, M., & Tani, G. (2005). Self-controlled knowledge of results: effects of different schedules and task complexity. Journal of Human Movement Studies, London, 49, 277-296.

Chiviacowsky, S., Medeiros, F. L., & Kaefer, A. (2007). “Feedback” auto-controlado e aprendizagem de uma tarefa motora com demanda de forca. *Revista Brasileira de Educacao Fisica e Esporte, 21*, 1, 27-33.

Chiviacowsky, S., Wulf, G., Medeiros, F. L., Kaefer, A., & Tani, G. (2008). Learning benefits of self-controlled knowledge of results in 10-year old children. *Research Quarterly for Exercise and Sport, 79*, 405-410.

Chiviacowsky, S., Wulf, G., Medeiros, F. L., Kaefer, A., & Wally, R. (2008). Self-controlled feedback in 10-year old children: Higher feedback frequencies enhance learning. *Research Quarterly for Exercise and Sport, 79,* 122-127.

Chiviakowsky, S., & Tani, G. (1993). Efeitos da frequencia de conhecimento de resultados na aprendizagem de uma habilidade motora em criancas. *Revista Paulista de Educacao Fisica, 11*, 1, 15-26.

Condon, R., & Collier, C. S. (2002). Student choice makes a difference in physical education. *Journal of Physical Education, Recreation & Dance, 73*, 2, 26-30.

Del Rey, P.; Whitehurst, M. & Wood, J.M. (1983). Effects of experience and contextual interference on learning and transfer by boys and girls. *Perceptual and Motor Skills, 56*, 581 – 582.

Farrow, D. & Maschette, W. (1997). The effects of contextual interference on children learning forehand tennis groundstrokes. *Journal of Human Movement Studies, 33,* 47 - 67.

French, K. E., Rink, J. E., & Werner, P. H. (1990). Effects of contextual interference on retention of three volleyball skills. *Perceptual and Motor Skills, 71*, 179 – 186.

Goode, S., & Magill, R. A. (1986). Contextual interference effects in learning three badminton serves. *Research Quarterly for Exercise and Sport, 57*, 308 – 314.

Goodwin, J. E., & Meeuwsen, H. J. (1996). Using bandwidth knowledge of results to alter relative frequencies during motor skill acquisition. *Research Quarterly for Exercise and Sport, 66*, 99-104.

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 36*, 212-224.

Hall, K. G., Domingues, D. A., & Cavazos, R. (1994). The effects of contextual interference on extra balling practice. *Perceptual and Motor Skills, 78*, 835 - 831.

Hart, S. G. (2006). NASA-Task Load Index (NASA-TLX); 20 Years Later. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, (pp. 904-908), Santa Monica, CA: Human Factors and Ergonomics Society.

Hebert, E. P., Landin, D., & Solomon, M. A. (1996). Practice schedule effects on the performance and learning of low- and high- skilled students: an applied study. *Research Quarterly for Exercise and Sport, 67*, 52-28.

Ho, L., & Shea, J. B. (1978). Effects of relative frequency of knowledge of results on retention of a motor skill. *Perceptual and Motor Skills, 46*, 859-866.

Husak, W.S., Cohen, M.J., & Schandler, S.L., 1991. Activation peaking during the acquisition of a motor task under high and low contextual interference conditions. *Perceptual and Motor Skills, 72*, 1075–1088.

Janelle, C. M., Barba, D. A. Frehlich, S. G., Tennant, L. K., & Caurraugh, H. (1997). Maximizing performance feedback effectiveness through videotape replay and self-controlled learning environment. *Research Quarterly for Exercise and Sport, 68*, 269-279.

Janelle, C. M., Kim, J., & Singer, R. N. (1995). Subject-controlled performance feedback of a closed motor skill. *Perceptual and Motor Skills, 81*, 627-634.

Jelsma, O., & Pieters, J. M. (1989). Practice schedule and cognitive-style interaction in learning a maze task. *Applied Cognitive Psychology, 3*, 73 – 83.

Keetch, K. M., & Lee, T. D. (2007). The effect of self-regulated and experimenter-imposed practice schedules on motor learning for tasks of varying difficulty. Research Quarterly for Exercise and Sport, 78, 476-486.

Lee, T. D., & Magill, R. A. (1983). The locus of contextual interference in motor-skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 730 – 746.

Lee, T. D., & Magill, R. A. (1985). Can forgetting facilitate skill acquisition? In D. Goodman, R. B. Wilberg, & I. M. Franks (Eds.), *Differing perspectives in motor learning, memory, and control* (pp. 3-22). Amsterdam: Elsevier.

Lee, T. D., & Wishart, L. R. (2005). Motor learning conundrums (and possible solutions). *Quest, 57*, 67-78.

Lee, T. D., Keh, N. C., & Magill, R. A. (1993). Instructional effects of teacher feedback in physical education. *Journal of Teaching in Physical Education, 12*, 228-243.

Lee, T. D., Wishart, L. R., Cunningham, S., & Carnahan, H. (1997). Modeled timing information during random practice eliminates the contextual interference effects. *Research Quarterly for Exercise and Sport, 68*, 100-105.

Magill, R. A. (1989). *Motor Learning: concepts and applications* (3rd ed.) Iowa: Wm. C. Brown.

Magill, R. A., & Hall, K. G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Sciences, 9*, 241-289.

Magill, R. A., (2001). Augmented feedback in motor skill acquisition. In R. N. Singer, H. A. Hausenblas & C. M. Janelle (Eds.), *Handbook of Sport Psychology* (pp. 86-114) New York, NY: John Wiley & Sons, Inc.

Newell, K. M., & Corcos, D. M. (1993). Issues in variability and motor control. In K. M. Newell & D. M. Corcos (Eds.), *Variability and motor control*. Champaign, IL: Human Kinetics.

Pinto-Zipp, G., & Gentile, A. M. (1995). Practice schedules in motor learning: Children vs. adults. *Society of Neuroscience: Abstracts, 21*, 1620.

Salmoni, A., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin, 95*, 355-386.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*, 225-260.

Schmidt, R. A. (1988). *Motor control and learning: a behavioral emphasis* (2nd ed.). Champaign, IL: Human Kinetics.

Schmidt, R. A. (1991). Frequent augmented feedback can degrade learning: evidence and interpretations. In. J. Requin & G. E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 59-75). Amsterdam: Kluwer Academic.

Schmidt, R. A., & Bjork, R. A. (1992). New conceptualizations of practice – common principles in 3 paradigms suggest new concepts for training. *Psychological Science, 3*, 207-217.

Schmidt, R. A., & Lee, T. D. (2005). *Motor control and learning: A behavioral emphasis* (4th ed.) Champaign, IL: Human Kinetics.

Schmidt, R. A., Lange, C., & Young, D. E. (1990). Optimizing summary knowledge of results for skill learning. *Human Movement Science, 9*, 325-348.

Sekiya, H., Magill, R. A., & Anderson, D. I. (1996). The contextual interference effect in parameter modification of the same generalized motor program. *Research Quarterly for Exercise and Sport, 67*, 59 – 68.

Shea, J. B., & Zimny, S. T. (1983). Context effects in memory and learning movement information. In R. A. Magill (Ed.), *Memory and control of action* (pp. 345 – 366). Amsterdam: Elsevier.

Shea, J. B., & Zimny, S. T. (1988). Knowledge incorporation in motor representation. In O. G. Meijer & K. Roth (Eds.), *Complex movement behaviour: "The" motor-action controversy* (pp. 289- 314). Amsterdam:Elsevier.

Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory, 5*, 179-187.

Simon, D. A., & Bjork, R. A. (2001). Metacognition in motor learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 907-212.

Simon, D. A., & Bjork, R. A. (2002). Models of performance in learning multisegment movement tasks: Consequences for acquisition, retention, and judgements of learning. *Journal of Experimental Psychology: Applied, 8*, 222 – 232.

Smith, P. J., & Rudisill, M. E. (1993). The influence of proficiency level, transfer distality, and gender on the contextual interference effect. *Research Quarterly for Exercise and Sport, 64*, 151- 157.

Taylor, A., & Noble, C. E. (1962). Acquisition and extinction phenomena in human trial-and error learning under different schedules of reinforcing feedback. *Perceptual and Motor Skills, 15*, 31-44.

Whitehurst, M., & Del Rey, P. (1983). Effects of contextual interference, task difficulty and levels of processing on pursuit tracking. *Perceptual and Motor Skills, 57*, 619-628.

Williams, G. C, & Deci, E. L. (1996). Internalization of biopsychological values by medical students: A test of self-determination theory. Journal of Personality and Social Psychology, 70, 767-779.

Winstein, C. J., & Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 677-691.

Winstein, C. J., Pohl, P. S., & Lewthwaite, R. (1994). Effects of physical guidance and knowledge of results on motor learning: support for the guidance hypothesis. *Research Quarterly for Exercise and Sport, 65*, 316-323.

Wrisberg, C. A. (1991). A field test of the effect of contextual variety during skill acquisition. *Journal of Teaching in Physical Education, 11*, 21 – 30.

Wrisberg, C. A., & Liu, Z. (1991). The effect of contextual variety on the practice, retention, and transfer of an applied motor skill. *Research Quarterly for Exercise and Sport, 62*, 406 – 412.

Wrisberg, C. A., & Pein, R. L. (2002). Note on learners' control of the frequency of model presentation during skill acquisition. Perceptual and Motor Skills, 94, 792-796.

Wulf, G., & Schmidt, R. A. (1989). The learning of generalized motor programs: reducing the relative frequency of knowledge of results enhances memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 15*, 748-757.

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalized to complex skill learning. *Psychonomic Bulletin and Review, 9*, 185-211.

Wulf, G., Clauss, A., Shea, C. H., & Whitacre, C. (2001). Benefits of self-control in dyad practice. *Research Quarterly for Exercise and Sport, 72*, 299-303.

Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport, 76*, 107-111.

Wulf, G., Shea, C. H., & Matschiner, S. (1998). Frequent feedback enhances complex motor skill learning. *Journal of Motor Behavior, 30*, 180-192.

Wulf, G., & Toole, T. (1999). Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. *Research Quarterly for Exercise and Sport, 70*, 265-272.

Young, D. E., Cohen, M. J., & Husak, W. S. (1993). Contextual interference and motor skill acquisition: On the processes that influence retention. *Human Movement Science, 12*, 577-600.

Appendix

APPENDIX A

The effects of practice schedule and self-control feedback manipulations on the acquisition and retention of motor skills

The purpose of this study is to investigate how people learn new motor skills. You will participate in two separate data collection sessions held on two consecutive days. Each session will last about 30 minutes. Data from your performance will be stored on a personal computer for later analysis.

The information in the study records will be kept confidential. Data will be stored securely and no information that can be used to identify you will be made available to anyone other than the persons conducting the study unless you specifically give permission in writing to do otherwise. No reference will be made in oral or written reports which could link you to the study.

The tasks you will be learning will require you to press five computer keys in a prescribed order within a specified goal movement time. You will learn three different tasks, each consisting of a different order of movement in pressing the keys. During the first session of data collection, you will perform 90 trials (30 of each task).

During the second session of the data collection, you will perform 18 trials (6 of each task), after which you will have the opportunity to learn about the research project if you so desire.

If you have questions at any time about the study or the procedures, you may contact the researcher, Joao Barros or his faculty advisor, Dr. Jeffrey T. Fairbrother. If you have any questions about your rights as a participant, contact the Research Compliance Services section of the Office of Research at (865) 974-3466.

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned or destroyed.

I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant's name (please print) ____

Participant's signature_____________________________________ Date:___/___/_____

Joao Barros, MS.	Jeffrey T. Fairbrother, Ph.D.
PhD Candidate	Faculty Advisor
jbarros@utk.edu	jfairbr1@utk.edu
(865) 974-8768	(865) 974-3616

APPENDIX B

Perceived Competence for Learning

Please respond to each of the following items in terms of how true it is for you with respect to your learning in this course. Use the scale:

1. I feel confident in my ability to learn these tasks.

    1 2 3 4 5 6 7
    not at all true somewhat true very true

2. I am capable of learning the task.

    1 2 3 4 5 6 7
    not at all true somewhat true very true

3. I am able to achieve my goals regarding these tasks.

    1 2 3 4 5 6 7
    not at all true somewhat true very true

4. I feel able to meet the challenge of performing these tasks well.

    1 2 3 4 5 6 7
    not at all true somewhat true very true

APPENDIX C

NASA Task Load Index

Mental Demand

How mentally demanding was the task?

Very Low Very High

Physical Demand

How physically demanding was the task?

Very Low Very High

Temporal Demand

How hurried or rushed was the pace of the task?

Very Low Very High

Performance

How successful were you in accomplishing what you were asked to do?

Very Low Very High

Effort

How hard did you have to work to accomplish your level of performance?

Perfect Failure

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

APPENDIX D

STATISTICAL ANALYSES TABLES

Table 1. Acquisition analysis: A (Group) x B (Block) for PACE

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A	1	397.356	8.462	.007
Within-Subjects				
B	5	326.713	36.559	.000
AB	5	7.167	.802	.550

Table 2. Acquisition analysis: Post hoc comparisons for Block

1	2	.000
	3	.000
	4	.000
	5	.000
	6	.000
2	1	.000
	3	.377
	4	.034
	5	.041
	6	.010
3	1	.000
	2	.377
	4	.853
	5	.979
	6	.736
4	1	.000
	2	.034
	3	.853
	5	1.000
	6	1.000

5	1	.000
	2	.041
	3	.979
	4	1.000
	6	1.000
6	1	.000
	2	.010
	3	.736
	4	1.000
	5	1.000

Table 3. Retention analysis: A (Group) for PACE

Source	*Df*	*MS*	*F*	*p*
A	1	16.839	.484	.492

Table 4. Retention analysis with task as a factor: A (Group) for PACE

Source	*Df*	*MS*	*F*	*p*
Blue Task				
A	1	525.645	5.603	.025
Red Task				
A	1	67.966	1.729	.199
White Task				
A	1	330.673	2.760	.107

Table 5. Acquisition analysis: A (Group) x B (Block) for CE

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A	5	24416.375	1.681	.147
Within-Subjects				
B	9	239946.437	33.398	.000
AB	45	14491.596	2.017	.002

Table 6. Acquisition analysis: Post hoc comparisons for Group x Block Interaction

Condition	Block	Block	Sig
1	1	2	.560
		3	.012
		4	.005
		5	.176
		6	.009
		7	.003
		8	.086
		9	.005
		10	.003
	2	1	.560
		3	.889
		4	.532
		5	1.000
		6	.852
		7	.894
		8	.999
		9	.769
		10	.643
	3	1	.012

	2	.889
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
4	1	.005
	2	.532
	3	1.000
	5	.750
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
5	1	.176
	2	1.000
	3	1.000
	4	.750
	6	.999
	7	.996
	8	1.000
	9	.945
	10	.943
6	1	.009
	2	.852
	3	1.000
	4	1.000
	5	.999
	7	1.000

	8	1.000
	9	1.000
	10	1.000
7	1	.003
	2	.894
	3	1.000
	4	1.000
	5	.996
	6	1.000
	8	1.000
	9	1.000
	10	1.000
8	1	.086
	2	.999
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	9	1.000
	10	1.000
9	1	.005
	2	.769
	3	1.000
	4	1.000
	5	.945
	6	1.000
	7	1.000
	8	1.000
	10	1.000
10	1	.003
	2	.643

		3	1.000
		4	1.000
		5	.943
		6	1.000
		7	1.000
		8	1.000
		9	1.000
2	1	2	.007
		3	.001
		4	.018
		5	.002
		6	.001
		7	.000
		8	.001
		9	.005
		10	.012
	2	1	.007
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		9	1.000
		10	1.000
	3	1	.001
		2	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000

	9	1.000
	10	1.000
4	1	.018
	2	1.000
	3	1.000
	5	1.000
	6	1.000
	7	1.000
	8	.995
	9	1.000
	10	1.000
5	1	.002
	2	1.000
	3	1.000
	4	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
6	1	.001
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
7	1	.000
	2	1.000
	3	1.000

	4	1.000
	5	1.000
	6	1.000
	8	1.000
	9	1.000
	10	.998
8	1	.001
	2	1.000
	3	1.000
	4	.995
	5	1.000
	6	1.000
	7	1.000
	9	.997
	10	.741
9	1	.005
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	.997
	10	1.000
10	1	.012
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	.998
	8	.741

		9	1.000
3	1	2	.920
		3	.159
		4	.080
		5	.125
		6	.003
		7	.001
		8	.010
		9	.001
		10	.001
	2	1	.920
		3	.999
		4	.944
		5	.998
		6	.097
		7	.153
		8	.175
		9	.070
		10	.051
	3	1	.159
		2	.999
		4	1.000
		5	1.000
		6	.998
		7	.993
		8	.999
		9	.937
		10	.946
	4	1	.080
		2	.944
		3	1.000
		5	1.000

	6	1.000
	7	.994
	8	1.000
	9	.933
	10	.900
5	1	.125
	2	.998
	3	1.000
	4	1.000
	6	.951
	7	.900
	8	.965
	9	.586
	10	.715
6	1	.003
	2	.097
	3	.998
	4	1.000
	5	.951
	7	1.000
	8	1.000
	9	1.000
	10	1.000
7	1	.001
	2	.153
	3	.993
	4	.994
	5	.900
	6	1.000
	8	1.000
	9	1.000
	10	1.000

	8	1	.010
		2	.175
		3	.999
		4	1.000
		5	.965
		6	1.000
		7	1.000
		9	1.000
		10	1.000
	9	1	.001
		2	.070
		3	.937
		4	.933
		5	.586
		6	1.000
		7	1.000
		8	1.000
		10	1.000
	10	1	.001
		2	.051
		3	.946
		4	.900
		5	.715
		6	1.000
		7	1.000
		8	1.000
		9	1.000
4	1	2	.014
		3	.000
		4	.000
		5	.000
		6	.000

	7	.000
	8	.000
	9	.000
	10	.000
2	1	.014
	3	.597
	4	.020
	5	.024
	6	.014
	7	.235
	8	.042
	9	.058
	10	.031
3	1	.000
	2	.597
	4	.999
	5	.999
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
4	1	.000
	2	.020
	3	.999
	5	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
5	1	.000

	2	.024
	3	.999
	4	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
6	1	.000
	2	.014
	3	1.000
	4	1.000
	5	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
7	1	.000
	2	.235
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	8	1.000
	9	1.000
	10	1.000
8	1	.000
	2	.042
	3	1.000
	4	1.000
	5	1.000
	6	1.000

		7	1.000
		9	1.000
		10	1.000
	9	1	.000
		2	.058
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		10	1.000
	10	1	.000
		2	.031
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		9	1.000
5	1	2	.041
		3	.019
		4	.033
		5	.021
		6	.007
		7	.000
		8	.022
		9	.003
		10	.001
	2	1	.041
		3	1.000

	4	1.000
	5	1.000
	6	1.000
	7	.994
	8	1.000
	9	1.000
	10	1.000
3	1	.019
	2	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
4	1	.033
	2	1.000
	3	1.000
	5	1.000
	6	1.000
	7	.995
	8	1.000
	9	1.000
	10	1.000
5	1	.021
	2	1.000
	3	1.000
	4	1.000
	6	1.000
	7	.998
	8	1.000

	9	1.000
	10	1.000
6	1	.007
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
7	1	.000
	2	.994
	3	1.000
	4	.995
	5	.998
	6	1.000
	8	.999
	9	1.000
	10	1.000
8	1	.022
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	.999
	9	1.000
	10	1.000
9	1	.003
	2	1.000
	3	1.000

		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		10	1.000
	10	1	.001
		2	1.000
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		9	1.000
6	1	2	1.000
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	.999
		9	1.000
		10	1.000
	2	1	1.000
		3	1.000
		4	1.000
		5	1.000
		6	1.000
		7	1.000
		8	1.000
		9	1.000

	10	1.000
3	1	1.000
	2	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	1.000
	9	1.000
	10	1.000
4	1	1.000
	2	1.000
	3	1.000
	5	1.000
	6	1.000
	7	1.000
	8	.592
	9	1.000
	10	1.000
5	1	1.000
	2	1.000
	3	1.000
	4	1.000
	6	1.000
	7	.999
	8	.321
	9	1.000
	10	1.000
6	1	1.000
	2	1.000
	3	1.000
	4	1.000

	5	1.000
	7	1.000
	8	.692
	9	1.000
	10	1.000
7	1	1.000
	2	1.000
	3	1.000
	4	1.000
	5	.999
	6	1.000
	8	.999
	9	1.000
	10	1.000
8	1	.999
	2	1.000
	3	1.000
	4	.592
	5	.321
	6	.692
	7	.999
	9	.148
	10	.948
9	1	1.000
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	.148
	10	1.000

10	1	1.000
	2	1.000
	3	1.000
	4	1.000
	5	1.000
	6	1.000
	7	1.000
	8	.948
	9	1.000

Table 7. Acquisition analysis: A (Group) x B (Block) for VE

Source	*Df*	*MS*	*F*	*p*
Between-Subjects				
A	5	80789.145	5.920	.000
Within-Subjects				
B	9	223421.007	71.479	.000
AB	45	2290.910	1.045	.394

Table 8. Acquisition analysis: Post hoc comparisons for Block

Block	Block	Sig.
1	2	.000
	3	.000
	4	.000
	5	.000
	6	.000
	7	.000
	8	.000
	9	.000
	10	.000
2	1	.000
	3	.003
	4	.472
	5	.000
	6	.000
	7	.000
	8	.000
	9	.000
	10	.000
3	1	.000

	2	.003
	4	1.000
	5	.022
	6	.118
	7	.148
	8	.000
	9	.005
	10	.000
4	1	.000
	2	.472
	3	1.000
	5	.000
	6	.001
	7	.002
	8	.000
	9	.000
	10	.000
5	1	.000
	2	.000
	3	.022
	4	.000
	6	1.000
	7	1.000
	8	.999
	9	.985
	10	.000
6	1	.000
	2	.000
	3	.118
	4	.001
	5	1.000
	7	1.000

	8	1.000
	9	.996
	10	.007
7	1	.000
	2	.000
	3	.148
	4	.002
	5	1.000
	6	1.000
	8	1.000
	9	.999
	10	.033
8	1	.000
	2	.000
	3	.000
	4	.000
	5	.999
	6	1.000
	7	1.000
	9	1.000
	10	.246
9	1	.000
	2	.000
	3	.005
	4	.000
	5	.985
	6	.996
	7	.999
	8	1.000
	10	.896
10	1	.000
	2	.000

	3	.000
	4	.000
	5	.000
	6	.007
	7	.033
	8	.246
	9	.896

Table 9. Acquisition analysis: Post hoc comparisons for Group

Group	Group	Sig.
1	2	.018
	3	1.000
	4	.133
	5	1.000
	6	.269
2	1	.018
	3	.018
	4	1.000
	5	.001
	6	.997
3	1	1.000
	2	.018
	4	.135
	5	1.000
	6	.271
4	1	.133
	2	1.000
	3	.135
	5	.014
	6	1.000

5	1	1.000
	2	.001
	3	1.000
	4	.014
	6	.035
6	1	.269
	2	.997
	3	.271
	4	1.000
	5	.035

Table 9. Acquisition analysis: A (Group) x B (Block) for ACE

Source	*Df*	*MS*	*F*	*p*
Between-Subjects				
A	5	59637.386	5.298	.000
Within-Subjects				
B	9	191522.277	111.562	.000
AB	45	2435.437	1.419	.039

Table 10. Acquisition analysis: Post hoc comparisons for Group

Group	Group	Sig.
1	2	.098
	3	1.000
	4	.094
	5	.995
	6	.529
2	1	.098
	3	.125
	4	1.000
	5	.004
	6	1.000
3	1	1.000
	2	.125
	4	.121
	5	.989
	6	.606
4	1	.094
	2	1.000
	3	.121
	5	.004

	6	1.000
5	1	.995
	2	.004
	3	.989
	4	.004
	6	.045
6	1	.529
	2	1.000
	3	.606
	4	1.000
	5	.045

Table 11. Acquisition analysis: Post hoc comparisons for Block

Block	Block	Sig.
1	2	.000
	3	.000
	4	.000
	5	.000
	6	.000
	7	.000
	8	.000
	9	.000
	10	.000
2	1	.000
	3	.006
	4	.006
	5	.000
	6	.000
	7	.000
	8	.000

	9	.000
	10	.000
3	1	.000
	2	.006
	4	1.000
	5	.005
	6	.012
	7	.003
	8	.000
	9	.000
	10	.000
4	1	.000
	2	.006
	3	1.000
	5	.004
	6	.001
	7	.001
	8	.000
	9	.000
	10	.000
5	1	.000
	2	.000
	3	.005
	4	.004
	6	1.000
	7	1.000
	8	1.000
	9	.291
	10	.000
6	1	.000
	2	.000
	3	.012

	4	.001
	5	1.000
	7	1.000
	8	1.000
	9	.803
	10	.003
7	1	.000
	2	.000
	3	.003
	4	.001
	5	1.000
	6	1.000
	8	1.000
	9	.997
	10	.044
8	1	.000
	2	.000
	3	.000
	4	.000
	5	1.000
	6	1.000
	7	1.000
	9	1.000
	10	.025
9	1	.000
	2	.000
	3	.000
	4	.000
	5	.291
	6	.803
	7	.997
	8	1.000

	10	.466
10	1	.000
	2	.000
	3	.000
	4	.000
	5	.000
	6	.003
	7	.044
	8	.025
	9	.466

Table 12. Retention analysis: A (Group) x B (Test) for CE

Source	*Df*	*MS*	*F*	*p*
Between-Subjects				
A	5	44940.396	1.079	.377
Within-Subjects				
B	1	17121.167	3.875	.052
AB	5	3141.624	.711	.617

Table 13. Retention analysis: A (Group) x B (Test) for VE

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A	5	11008.128	1.773	.126
Within-Subjects				
B	1	3555.139	1.399	.240
AB	5	951.815	.375	.865

Table 14. Retention analysis: A (Group) x B (Test) for ACE

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A	5	7712.032	.573	.720
Within-Subjects				
B	1	10399.469	4.790	.031
AB	5	3052.215	1.406	.230

Table 15. NASA TLX scores analysis: A (Group) x B (Assessment)

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A	5	4.495	.303	.910
Within-Subjects				
B	1	167.361	36.293	.000
AB	5	2.788	.605	.032

Table 16. PCL scores analysis: A (Group) x B (Assessment)

Source	*df*	*MS*	*F*	*p*
Between-Subjects				
A				
Within-Subjects				
B	1	26.626	51.311	.000
AB	5	.309	.596	.703

APPENDIX E

MEAN AND STANDARD DEVIATION TABLES

Table 17. Mean and standard deviation CE in acquisition and retention

	A1	sd	A2	sd	A3	sd	A4	sd	A5	sd	A6	sd	A7	sd	A8	sd	A9	sd	A10	sd	Blocked	sd	Random	sd
BLK-SC	-135	105	-63	111	-14	89	-5	56	-42	44	-15	36	-11	47	-26	37	-9	53	-10	37	171	198	135	149
RND-SC	-135	134	-17	82	5	92	-17	67	2	54	1	62	5	52	17	73	-8	55	-21	32	136	105	126	84
BLK-YK	-149	86	-91	95	-55	89	-46	59	-52	72	-18	74	-14	71	-18	58	-11	45	-14	46	90	159	42	168
RND-YK	-214	142	-101	93	-44	68	-14	72	-10	86	-14	79	-28	74	-16	56	-20	57	-21	39	64	171	46	162
BLK-100	-134	94	-31	74	-18	56	-21	55	-19	45	-11	45	11	55	-10	63	-3	52	0	52	94	166	101	175
RND-100	-52	114	-25	73	-26	97	-52	58	-53	71	-36	58	-23	66	-2	80	-49	62	-34	75	112	132	105	111

Table 18. Mean and standard deviation VE in acquisition and retention

	A1	sd	A2	sd	A3	sd	A4	sd	A5	sd	A6	sd	A7	sd	A8	sd	A9	sd	A10	sd	Blocked	sd	Random	sd
BLK-SC	228	100	151	72	132	50	136	53	101	43	102	35	111	32	107	41	116	48	88	31	182	80	167	69
RND-SC	280	71	214	85	186	74	187	53	138	35	151	52	161	60	128	32	149	67	115	39	187	81	187	96
BLK-YK	233	75	170	63	121	49	137	45	105	39	111	66	115	58	110	44	89	56	81	53	154	46	162	53
RND-YK	258	54	207	69	159	50	186	101	162	53	142	47	128	48	136	52	128	54	112	35	168	50	157	52
BLK-100	209	83	136	67	110	55	111	55	122	62	101	38	93	52	100	60	89	43	101	52	152	57	142	35
RND-100	254	67	161	60	171	70	170	66	134	55	146	58	144	55	135	53	132	57	133	62	208	66	185	82

Table 19. Mean and standard deviation ACE in acquisition and retention

	A1	sd	A2	sd	A3	sd	A4	sd	A5	sd	A6	sd	A7	sd	A8	sd	A9	sd	A10	sd	Blocked	sd	Random	sd
BLK-SC	223	98	145	68	128	44	119	48	97	37	87	29	96	30	95	36	100	34	76	28	237	137	203	102
RND-SC	274	61	183	75	164	65	158	51	121	36	134	41	128	47	118	43	119	42	96	35	195	74	170	74
BLK-YK	232	71	164	66	118	58	120	46	99	40	100	55	100	51	95	37	77	46	71	41	187	81	182	88
RND-YK	293	78	194	63	140	49	162	73	138	46	131	51	116	40	118	39	111	29	93	27	173	59	181	81
BLK-100	209	71	124	60	99	47	94	40	102	46	82	32	81	45	88	55	79	37	85	43	194	96	197	97
RND-100	231	67	140	44	155	69	144	59	117	51	126	49	124	44	124	47	119	55	121	60	206	64	169	80

Vita

Joao Barros was born September 18, 1980 in Nashville, Tennessee to his loving parents Jose Maria and Lucilia de Camargo Barros. Prior to attending the University of Tennessee, he obtained his Bachelor’s and a Master’s of Science degrees in Physical Education from the University of Sao Paulo, in Sao Paulo, Brazil. In May 2010, he received his Doctor of Philosophy degree in Exercise and Sport Sciences with a specialization in Motor Behavior.