EFFECTS OF AMOUNT AND TYPE OF SELF-REGULATION OPPORTUNITY DURING SKILL ACQUISITION ON MOTOR LEARNING

BY

ANDREA MARIE JONES, HONS. B.SC.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree

Master of Science

McMaster University

MASTER OF SCIENCE (2010) McMaster University

(Kinesiology) Hamilton, Ontario

TITLE: Effects of Amount and Type of Self-Regulation Opportunity during Skill Acquisition on Motor Learning

AUTHOR: Andrea Jones, Hons. B.Sc. (McMaster University)

SUPERVISOR: Tim Lee, Ph.D.

NUMBER OF PAGES:

ABSTRACT

This study examined the effects of varying levels and type of self-control on the acquisition and retention of a motor task. Four sequence timing tasks were used, each with their own sequence order and target time. The goal of the task was to complete the sequence with a movement time as close to the target time as possible. An experimental group was given self-control over the practice variable of task ordering as well as constrained self-control over feedback scheduling. Three control groups were yoked to certain aspects of the experimental group. Control group A was yoked to the task order decisions made by the experimental group but permitted to self-control their feedback schedule. Control group B was yoked to the experimental group's chosen feedback schedule but permitted to control their trial order. The last control group, C, was yoked to both the feedback and task order schedule of the experimental group. Groups that self-controlled their own feedback schedules; the experimental group and control group A, were slower to demonstrate decreases in absolute constant error at the beginning of acquisition. Throughout acquisition, these same groups were able to utilize the feedback requested after a given trial to significantly improve performance on the following trial of the same sequence type. During acquisition, and retention, the self-controlled feedback groups had average movement times that were more accurate to the average target time than did other groups. No further differences between groups were found during retention or transfer. These results suggest that the self-controlled conditions used in this study affect performance during acquisition but do not necessarily enhance the amount of information retained in the long term.

ACKNOWLEDGEMENTS

I am one lucky duck. Having been granted access to higher education and the opportunity to learn and discover for knowledge's sake; places me amongst some of the most privileged people in the world. I am grateful for this and hope to be able to share my acquired skills and comprehensions both within and outside of the academic institution.

I'd like to thank Dr. Tim Lee, for being an attentive supervisor, a unique intellectual and an overall great person. Tim I think you do a great job of leading by example and I respect you a lot. Maybe if I train for the next decade, I can rival you in golf. I'd also like to thank my committee Dr. Jim Lyons, Dr. Ramesh Balasubramaniam and Dr. Jae Patterson for their guidance throughout the development and completion of this project.

In addition to having been afforded an educational opportunity that simply does not exist for most, I am also lucky in other ways. First and foremost, I am lucky to have had the accompaniment of friends and family that loved me along the way. I cannot undermine the support of my parents, siblings, relatives and life-long friends.

To my grad school friends from various places; the lab, the office, my housemates, and everybody else: thanks for sharing the experience and for all the laughter along the way!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: REVIEW OF LITERATURE

Motor learning, defined as a set of internal processes associated with practice or experience leading to relatively permanent changes in the capability of motor skill (Schmidt & Lee, 1999), is a phenomenon of unequivocal necessity to the human being. Some motor learning is quite easy and does not pose a noticeable challenge to the system. However, under many circumstances, the nervous system does not easily adapt to new challenges and the necessary skills must be acquired through practice; a process that can at times be challenging, time consuming, and repetitive. Given the importance of motor skills for basic living as well as the opportunities that the mastery of exceptional motor skills gives rise to, it is not surprising that much of motor learning research has focused on the optimal structuring of the practice session. It is well known that the practice structure can have a profound effect on the learning of a skill as certain structures lead to greater amounts of learning than do others. Certain elements of the practice structure, known as practice variables can be manipulated to vary the experience of learning. Examples of practice structure variables include modeling, spacing of practice, the use of assistive devices, frequency of practice, level of instruction, the ordering of multiple tasks and the use of augmented feedback (AF). The current work will focus on the latter two practice variables: task ordering (TO) and AF.

Traditionally motor learning researchers have examined ways that teachers or experimenters can enforce the manipulations of practice variables to create a learning experience that allows for the learner to learn as effectively as is possible. Recently however, some researchers have begun to examine the effects of giving such control to the learner. The results in many instances have shown to be beneficial to the processes of learning and also of great theoretical importance to the motor learning community.

Promising effects related to the learner control of both the TO or AF variables have been shown, however the effects of giving simultaneous control of both variables to the learner have not yet been documented. The purpose of the present thesis is to examine how learners control the TO and AF variables in both isolated and simultaneous conditions as well as to examine the impact of these conditions on delayed motor learning.

Practice Variables

Practice Scheduling. Several circumstances of learning require that the learner practice more than one task within a session. When practicing multiple tasks within a session, these tasks can be ordered in a blocked, random or an intermediary hybrid of these two extremes. Blocked practice occurs when all trials of a given task are completed before moving onto the next task, and so on, until all tasks have been practiced. Random practice occurs when a trial of a given task can be followed by a trial of another task despite the fact that trials of the first task may still remain to be practiced. In random practice, the trials of each task type are distributed randomly or pseudo-randomly across the practice schedule. Thus blocked and random practice may consist of the same number of tasks and number of trials per task but differ in the scheduling of those trials.

The practice scheduling of task order is very important as blocked and random schedules have varying levels of contextual interference (CI). CI refers to the interference effects during performance and learning that arise from practicing one task in the context of another (Schmidt & Lee, 1999). The effects of varying levels of CI during acquisition on long term retention were first demonstrated in the motor learning domain by Shea and Morgan (1979). Participants were divided into blocked (low CI) or random (high CI) groups and instructed to learn three motor tasks according to a set schedule. Although the blocked group demonstrated dramatically faster improvements during acquisition, the random groups outperformed the blocked group on immediate retention, delayed retention and high and low complexity transfer tests. The results of this study were profound as they showed that although practice conditions with low CI (blocked) led to greater temporary changes in performance than did practice conditions of high CI (random), it was the high CI conditions that resulted in long term retention of performance improvements. Since these original findings, extensive amounts of further research by various authors have replicated, extended and further developed theoretical explanations for the CI effect (for reviews see Brady, 2004; Magill & Hall, 1990). From this research we know that the fast and large performance increases observed in blocked practice can be misleading in terms of learning; a concept that for some teachers and learners may at first seem counterintuitive.

Two predominant hypotheses exist to explain the CI effect. The Elaborative and Distinctive Processing Hypothesis, states that higher CI effects during practice engage learners in a higher degree of multiple and variable processing opportunities (Shea & Morgan, 1979; Shea and Zimny, 1983, 1988). In a randomized schedule, the various skills being practiced reside together in working memory simultaneously, thereby allowing for greater encoding of the unique aspects of each task. In contrast the

Forgetting and Reconstruction Hypothesis states that the benefits of random practice are not due to all tasks existing in working memory simultaneously, but rather to the absence of a given task from working memory prior to the beginning of a trial for that task. This hypothesis was proposed by Lee and Magill (1983, 1985) who explain that during blocked practice, prior to beginning a trial, an action plan of the task to be performed is already present in working memory because the same task had been performed on the previous trial. In random practice however a different task was performed in the previous trial. Thus, an action plan for the present trial is not present in working memory, having temporarily been forgotten, and must be reconstructed (for review see Magill & Hall, 1990). Both of these hypotheses are similar however, in that they both suggest an increase of cognitive processing operations during random learning as the root cause of the CI effect.

Augmented Feedback. In addition to practice scheduling, AF is a practice variable that can have a strong impact on the processes of motor learning. AF is provided in addition to the knowledge of results and/or performance that the performer is already intrinsically aware of based on their own perceptual abilities. It can be divided into two main categories: knowledge of performance and knowledge of results. Knowledge of performance pertains to the movement pattern made by the learner (e.g., "Your knees were not bent"). It can be used to draw the learner's attention to aspects of their movement that they may otherwise not have been consciously aware. Knowledge of results is a delivery of information to the learner about the outcome of the movement in regards to an overall environmental goal (e.g. your time to race completion was 10.5s).

Much like practice scheduling, a large amount of research has gone into developing a model for the ideal delivery of AF during practice. The inclusion of this variable in a practice structure does not always enhance learning. In some cases, the information provided by AF is already intrinsically apparent to the learner and redundant presentation of it does not aid learning (Rose & Christina, 2006). In other cases, AF can cause temporary improvements in performance that disappear after stopping the task for a period of time or transferring to a new task (Rose & Christina, 2006). Temporary changes in performance that are not permanent are not instances of learning. Practice structures that neglect to include AF are not the most efficient for learning (Viitasalo, Era, Kontinnen, Mononen, Mononen, & Norvapolo, 2001), and neither are structures that provide feedback after every attempt at performance. Many studies have shown that less than 100% feedback during acquisition best facilitates the learning process (Salmoni, Schmidt, & Walter, 1984; Schmidt, Young, Swinnen, & Shapiro, 1989; Viitasalo et al., 2001; Winstein & Schmidt, 1990). In addition, research suggests that to delay the knowledge of results feedback after the completion of the trial facilitates learning (Swinnen, Schmidt, Nicholson & Shapiro, 1990), as does providing the knowledge of results in a summary format (Schmidt et al., 1989).

Given that AF is less effective when provided in large amounts, the question arises as to how best to provide and distribute the delivery of this feedback across the practice structure. Fading frequency schedules have been shown to facilitate learning (Winstein & Schmidt, 1990). These types of practice structures deliver feedback at very high frequencies at the beginning of practice and then begin to gradually phase out the incorporation of feedback by decreasing the frequency as learning progresses. Another effective feedback schedule, which also serves as a feedback fading procedure, is the bandwidth knowledge of results technique where the learner is only provided with feedback when their performance lies within a pre-determined range of accuracy (Lee & Carnahan, 1990; Reeve, Dornier & Weeks, 1990; Sherwood, 1988).

Learners as Individuals

In practice, learning is most often directed by the teacher and learner through an open communication environment. In situations of learning, the learner may express a concern of difficulty to the teacher over a certain aspect of the task to be learned. The teacher would then help guide the learner to overcome this difficulty. Likewise, when the learner feels they have reached sufficient mastery of a skill being practiced, they may inform the teacher that they are ready to move on. In research however, learning paces, conditions and structures are typically dictated by the experimenter to the participant. By doing this, researchers have been able to identify practice structures that, when applied identically to all learners, result in the highest average main effect of learning for the group as a whole. This has been very helpful in developing recommendations for learning such as: "random practice is better than blocked practice," a blanket prescription for practice directed at a population rather than considering individual need. These approaches of complete experimenter control may however have missed out on characterizing conditions of learning that best maximize the potential of each individual learner. A better option might consider that in order to maximize the potential of each individual learner, each learner's corresponding practice structure must be carefully tailored to match their exact needs and characteristics: a process that can be difficult and consuming.

It is generally accepted that there is no universal practice structure that will be the best practice structure for all tasks (or task sets). Strong evidence for this was shown by Albaret and Thon (1998) when they varied the practice order across multiple task sets, each set with a different level of complexity. They found that blocked practice schedules were better suited to task sets of high complexity while random practice was better suited to task sets of low complexity. What was not considered by Albaret and Thon but was later brought to surface by other researchers (Guandagnoli & Lee, 2004) is that depending on the baseline abilities and intrinsic capabilities of each participant, what might be a simple task set to one participant may be a complex task set to another.

In their Challenge Point Framework, Guadagnoli and Lee (2004) introduced the concept of the learner as a central element around which practice should be structured. They explained that motor skills not only have a nominal task difficulty (an amount that remains relatively constant across individuals and conditions) but also a functional task difficulty (a value that fluctuates according to the skill level of the individual performing the task as well as the conditions under which it is being performed). Given that functional task difficulty can vary between people and conditions, their suggestion that the practice structure should also fluctuate seems appropriate. They identify contextual interference and knowledge of results as practice variables that can be manipulated to create varying levels of nominal task difficulty. For example, a random practice schedule with a low frequency of AF would have a high nominal task difficulty that would impede the learner's performance during acquisition. A blocked practice schedule with a high frequency of AF would have a low task difficulty and make high levels of performance during acquisition more achievable. With practice, as the learner becomes more efficient at processing performance related information (decreased functional task difficulty) the nominal task difficulty must be increased (by manipulating the practice variables) in order to maintain practice at an optimum challenge point. However in the framework, the authors bypass the tricky issues of defining task complexity and the unknown nature of the exact nominal and functional task complexity relationship in terms for the greatest potential benefit for learning.

Self-Control and Regulation in Motor Learning

The use of self-controlled learning has been incorporated into various types of motor learning experiments and aspects of the corresponding practice structures. The results of such research have revealed a general learning benefit. These have been shown in learner control over: the frequency of AF presentation for both knowledge of performance (Janelle, Barba, Frehlich, Tennant & Cauraugh, 1997; Janelle, Kim & Singer, 1995) and knowledge of results (Chiviacowsky & Wulf, 2002; 2005); the use of physical assistance devices to develop efficient whole body movement patterns (Wulf, Clause, Shea & Whitacre, 2001; Wulf & Toole, 1999) or to learn a balancing task (Hartman, 2007); frequency of model presentation for the learning of a badminton serve (Wrisberg & Pein, 2002) as well as a basketball jump shot (Wulf, Raupach & Pfeiffer, 2005); the task ordering of multiple tasks (Keetch & Lee, 2007; Titzer, Shea & Romack, 1993; Wu, 2007) and; the online regulation of feedback during a continuous perceptual-motor task (Huet, Camachon, Fernandez, Jacobs & Montagne, 2009).

A common practice used in self-control research is the yoking of a control group to the experimental group. Each individual from the yoked group is matched to the choices made by an individual from the experimental group. The result is that two participants in the study will have undergone acquisition using the exact same practice structure, with the exception that one individual chose the practice structure while the other was assigned to it. Yoking ensures that it is the elements of self-control and or regulation that cause an experimental self-control group to learn more or less than groups without self-control. Otherwise it could be argued that it was not self-control per say that caused the effects but rather the general effectiveness or ineffectiveness of the chosen practice structures.

Mechanisms of Self-Controlled Learning

Despite the overall robustness of self-controlled learning, the exact mechanisms and underlying reasons for its effectiveness are not entirely understood. In order to better understanding the self-controlled or regulated motor learning, descriptions are often taken from the verbal and or cognitive domains. In regards to academic performance, self regulated learning has been described as the degree to which learners are metacognitively, motivationally and behaviourally active participants in their own learning (Zimmerman, 1986 in Zimmerman & Schunk, 1989). Self-regulated learning consists of self-generated thoughts, feelings and actions which are systematically oriented toward the attainment of a goal (Schunk & Zimmerman, 1994). In general, self-control is associated with an increased sense of motivation (Bandura, 1993), allows learners to have a sense of command over their learning situation (eg. Ferrari, 1996), and if applied appropriately can enable opportunity for the use of self-regulation. Self-regulation varies from self-control in that it not only consists of the learner assuming a role of command over their learning situation, the learner must actively be exercising such command and making appropriate adjustments in a cyclic manor throughout learning. Zimmerman (1989) described self-regulation as a process involving an interaction of goal attainment, forming and steering strategies, feedback and self-evaluation. This process (feedback loop) requires ongoing monitoring and changes in strategy based on the comparison of performance to the requirements of the goal. However, not all situations of learner control afford the conditions necessary for the processes of self-regulation to occur.

Self-Control of AF

There are a variety of practice structures where AF may be used to supplement learning. In general, knowledge of results should be used to guide the person to the correct performance without developing dependence (Salmoni et al., 1984) and the same can be said of knowledge of performance. Using a ball throwing task where the subject was instructed to throw the ball to a single set target, Janelle et al. (1995) compared five different types of feedback schedules: control group receiving no performance feedback, 50% relative performance feedback, summary performance feedback, subject-controlled performance feedback and yoked control group. Feedback was used to describe the quality of performance using verbal statements that provided reference to errors in speed, trajectory or direction of ball toss. During acquisition, subjects in the subject-controlled performance feedback group requested feedback at a frequency that was extremely low (only 7% of all trials) relative to the frequencies assigned to all other groups. During retention, the subject-controlled performance feedback group outperformed all other groups including the group that was yoked to their exact pattern of feedback requests. The authors suggested that members of the subject –controlled group processed information more deeply and more effectively than those who were given a fixed schedule of feedback delivery (Janelle et al., 1995). A second study (Janelle et al. 1997) extended the results of Janelle et al. (1995) to a more variable skill (a skill that can be successfully performed more than one way) with multiple degrees of freedom; a non-dominant arm ball throw task. This study also indicated the benefits of a self-controlled knowledge of performance schedule over more traditional schedules.

The self-control over knowledge of results has also been studied. Chiviacowsky and Wulf (2002) tested the hypothesis that self-controlled schedules are more effective than assigned ones because the self-controlled participants receive feedback when they actually need it. Learners without self-control (yoked) do not necessarily receive feedback at the most critical time points in learning. Participants performed a sequence timing task that had relative time goals for the amount of elapsed time between motor events as well as an absolute time goal for the completion of the entire sequence. During acquisition the self-controlled group requested feedback on 35% of the practice trials on average and showed learning benefits on a delayed transfer task. Questionnaire results revealed that self-control participants primarily requested feedback after good trials and that yoked participants would have preferred to receive feedback after good trials. A qualitative analysis revealed that for the self-controlled group: error was lower on trials where feedback was requested than on trials where it was not requested. This was not the case for the yoked group. The results showed that learners based their decision to either request or not request feedback based on their performance of the trial, with preferences being given to trials judged as good by the learner.

Chiviacowsky and Wulf (2005) used a similar task and methodology to compare a group that decided after every trial whether or not they would like to receive feedback for that trial (after-trial group) and a group that made the same decision before each trial (before-trial group). The after-trial group outperformed the before-trial group on a delayed transfer test. As both groups were given the same degree of self-control, the author's concluded that it is not self-control alone that is responsible for the benefits often found in these types of studies. Rather, the only difference between the two groups was that the after trial-group was aware of the subjective outcome of their performance prior to making a feedback request decision for that trial while the before-trial group was not. The stronger transfer performance of the after-trial group indicated that the opportunity to request feedback as a function of one's performance was a critical factor for the benefits of self-control.

The concurrent use of self-controlled feedback was studied usingof a walking task in a virtual environment with the goal of displacing the body from the original start position to the other side of a moving door. Huet et al. (2009) found that concurrent feedback, when unambiguous, can be used to yield higher levels of performance and learning. Ambiguous feedback on the other hand may prevent the processes of learning.

They suggested that the self-controlled use of unambiguous concurrent feedback can be used to more rapidly educate attention towards more useful perceptual invariants and to calibrate the relation between perceptual invariants and action parameters (Huet et al., 2009).

Self-Control of Trial Order

The effects of self-control over trial order were first examined by Titzer et al. (1993). They used a virtual barrier knock down task to compare blocked, random and self-regulated trial order conditions. As was expected, during acquisition the random group exhibited a greater level of contextual interference than the blocked group and, during retention the random group performed better than the blocked group. However, the self-regulated group demonstrated low contextual interference levels that were equivalent to the blocked group during acquisition but performed as strongly as the random group during acquisition.

Additional work on the effects of self-regulating trial order by Wu (2007) compared a self-regulation group to a yoked control group in the ordering of a golf putting task to targets of various distances. Although results were statistically insignificant, the means generally favored the hypothesis of self-regulation of trial order being beneficial to learning. A second experiment (Wu, 2007) also examined the same hypothesis but used the sequence-timing task that was used to examine the self-regulation of feedback (Chiviacowsky & Wulf, 2002; 2005). In this experiment self-control participants chose to switch tasks (i.e. after completing task A, decided to practice task B or C on the following trial instead of repeating task A) after "good" trials and gradually increased the level of CI as practice progressed. The self-control participants performed better than their yoked counterparts during delayed retention. A third experiment using the same sequence timing task compared self-control participants who chose their entire practice schedule in advance to commencing practice to those who chose it throughout practice on a trial by trial basis. Interestingly, participants who chose their schedules in advance, favored a blocked task schedule with very few switches (ten of twenty participants chose the minimum number of task switches possible) while participants who chose their schedule throughout practice chose a mixed style of practice (task types were divided into mini blocks of varying size). The self-control throughout group outperformed the self-control before group in delayed retention.

The effects of self-regulation over practice scheduling for task sets of both high and low complexity were examined by Keetch and Lee (2007). Participants were assigned to the practice of either high or low complexity task sets. They found that a wide array of strategies and task switch patterns were used by self-regulators regardless of which task complexity group they were assigned to. There was no effect of self-regulation on acquisition in terms of performance. More interestingly however, they found that irrespective of self-regulation strategy used or level of task set complexity, self-regulators demonstrated the higher levels of improvement than their yoked counterparts during retention. These findings suggest that it may be self-regulation in general and not the control of a specific aspect of the learning context that is beneficial (Keetch & Lee, 2007).

CHAPTER 2: INTRODUCTION

Statement of the Research Problem

The aim of the present study was two–fold. The first was to examine how learners control the task-order and AF variables in both isolated and concurrent conditions. The second was to examine the impact of these conditions on motor learning. Promising effects related to the learner control of both the task ordering or AF, separately, have been shown (task order: Keetch & Lee, 2007; Wu, 2007; AF: Chiviacowsky & Wulf, 2002, 2005; Janelle et al., 1995, 1997) to benefit when applied in a manner that allows for self-regulation in addition to control and is congruent with the learner's needs. However, the effects of giving simultaneous control of *both variables* to the learner have not yet been documented. Several studies have examined the effects of learner control on single practice variables but none have studied the effects of increased learner control over more than one. It is unknown whether increased learner control has additive, interactive, or possibly even detrimental effects on motor learning. It is also unknown whether or not there will be an interaction between the processes governing the control (or self-regulation) of one practice variable with those of another when ample opportunity to control both is available. Lastly, given how much we know about the effectiveness of experimenter imposed manipulations of the trial order and AF variables, it is important to discover if subjects choose schedules that match those of the most effective experimenter imposed schedules. It is possible that there will be a wide array of self-control strategies used by participants and that these could vary between experimental and control groups. Should effective self-control strategies exist, they should be identified and characterized.

In order to control for the main effects of each self-controlled variable as well as a possible interaction between them, one experimental group and three control groups were used. The experimental group, referred to as the *Self-Self* group was given self-control of both variables. The three control groups were each yoked to one or both aspect(s) of the Self-Self group's performance. The *Yoked-FB* (feedback) group was given self-control over practice order but was yoked to the Self-Self group's pattern of feedback selection. The *Yoked-TO* (trial order) group was given self-control over feedback selection but was yoked to the Self-Self group's pattern of trial order. Lastly, the *Yoked-Yoked* group was yoked to the Self-Self group's patterns of both trial order and feedback selection.

Predictions Based on the Literature

The primary hypothesis was that the Self-Self group would perform superior to the three control groups during retention and translation. Translation is a measure of learning that examines the generalizability of an acquired skill set. It tests how the previous practice of a learned task affects the learner's ability to perform on a new task that is often similar to but not the same as the learned task. The predicted superior performance of the Self-Self group during retention and transfer would be attributable to not only an increased opportunity to self-regulate during acquisition but also due to the interaction of AF and TO variables. It was thought that the AF variable would be used to access performance in a more objective manor than relying on perception of performance. The objective information received through feedback would then allow the Self-Self individuals to make more well-informed decisions regarding how to manipulate the level of CI across the practice structure. The self-control of both practice variables would enable Self-Self individuals to coordinate the presentation of feedback and the event of task switching in a time effective manner that was dependent on their own learning progress. An alternative hypothesis to the primary one was that the Yoked-FB and Yoked-TO groups would outperform the Self-Self and Yoked-Yoked groups. The Yoked-Yoked group was expected to perform lower on retention than the two single variable self-regulation groups because past research has shown the single variable learner-control of both the trial order and feedback presentation variables to be beneficial to learning. However should the Self-Self group (a double variable self-control group) also perform lower on retention than the single variable self-control groups then this would be attributable to the Self-Self condition being too attention-demanding. In other words, the responsibility of controlling two practice variables when learning a sequential timing task would be considered too great for a learner who wants to perform under an optimal practice structure.

CHAPTER 3: METHODS

Participants

Forty young adults (20 male, 20 female) between the ages of 18 and 26 (avg. age = 20.2 yrs, SD = 1.9) from the McMaster University community participated in this study. Participants were naïve to the purpose of the study, provided written and informed consent prior to beginning the first session and received $15 in compensation upon completion. The study was approved by and conducted in accordance of the guidelines determined by the McMaster University Research Ethics Board.

Apparatus and Task

Individuals sat in front of a computer monitor (16'') and a button sequence box (manufactured by E-prime) placed on a standard tabletop at approximately elbow height. The button sequence box was used as the primary input device and consisted of five buttons in a horizontal row labeled one through five (from left to right). Using a standard CPU (Intel Pentium 4, 3.00 GHz, 960 MB of Ram), the software tool E-Prime, version 2.0 was used to initiate stimuli displays and record dependent measures of interest.

Individuals were required to complete a sequential finger movement task that consisted of five button presses on the button sequence box. All button presses were made using the index finger only. Movement time (MT) was defined as the elapsed time between the first and last button presses of each sequence. Four tasks (A through D) were learned, each of which had a corresponding target movement time from start to completion (Task A: button order 4-3-5-1-2, target MT = 1000ms; B: 3-2-4-5-1, target MT = 1500ms; C: 2-5-4-3-1, target MT = 2000ms and D: 1-5-2-4-3, target MT =

2500ms). The goal of each task was to accurately complete the sequence with a MT that was as close to the target MT as possible.

Procedure

Participants were assigned to one of four practice groups; the Self-Self group, the Yoked-FB group, Yoked-TO group or the Yoked-Yoked group. Group assignment was randomized with the exception that a gender balanced was maintained across groups. Control group individuals were gender matched to individuals in the Self-Self group.

The experiment consisted of two sessions held on consecutive days. During the first session (the "acquisition" phase) all participants performed 32 practice trials of each task (32 x 4 = 128 trials total). Practice was divided into 16 blocks of 8 trial groupings. Participants were notified of a block completion by the experimenter and were responsible for initiating the next block upon their readiness.

At the beginning of the first session, individuals were presented with a series of instructional screens describing the task to be performed, performance goals and overall structure of the experiment. Each of the four tasks to be learned and their target MTs were introduced but not practiced. Groups with self-regulation components were informed of the variables that they would be given choice over and the guidelines with which they were to self-regulate these variables. Groups given control over AF selection were required to select feedback on exactly four trials per block (of 8 trials) while groups given control over task order selection were required to perform each task exactly thirty-two times throughout the timeline of the session. The groups who were yoked to the feedback variable were informed that feedback would be provided on four trials per block according to a predetermined order. The groups who were yoked to the task order variable were informed that the experiment would assign each task thirty-two times in an order that was also pre-determined. Once individuals confirmed that they understood the instructions and had no further questions, the experiment moved forth into the first trial of the first block.

At the beginning of each trial, groups who were in control of determining task order were presented with the number of trials remaining for each sequence (e.g. at the beginning this would read as 32 trials for each of sequences A, B, C and D). The assignment of task name (A, B, C or D) (Fig. 1d) to a given task (1000ms, 1500ms, 2000ms, and 2500ms) was counterbalanced across participants such that each task was assigned to each name exactly 10 times. This was done to prevent a possible participant preference of alphabetical task selection from having an effect on the data. After being presented with the number of trials remaining for each task, participants were then required to choose the task that they would like to perform on the upcoming trial. These participants were allowed to organize the task order in any manner of their choosing with the exception that each task had to be practiced exactly 32 times. No additional restrictions were placed on either the number of times that a task could be consecutively (or not) practiced or on the distribution of tasks chosen across blocks. This allowed the participants to structure practice in either a blocked, random, or hybrid fashion.

Groups who were not in control of determining task order (Yoked-TO and Yoked-Yoked groups) were yoked to the choices made by one individual in the Self-Self group. For three seconds at the beginning of each trial they were presented with information regarding the number of trials remaining for each task but unlike the groups who self-controlled TO, the yoked TO groups were not prompted to choose a task for the next practice trial.

For each trial after the task to be practiced had been either chosen or assigned, individuals were presented with the sequence order and time goal (Fig. 1a). After three seconds this information was replaced by a white-cross centered on a black background while a tone was given to indicate that the individual should begin performing the task when ready (Fig. 1b). Incorrect button presses were detected by the program (which then reset the trial such that it could be performed correctly). Once the individual had accurately pressed the last button in a sequence, a text message regarding feedback was presented. For groups who were in control of their feedback selection (Self-Self and Yoked- TO), the text message contained information regarding the number of feedback opportunities remaining for the current block and then asked if they would like to receive feedback or not (Fig. 1c). If they answered yes, they were provided with values for the trial target movement time and their actual movement time (Fig. 1d). If they answered no, the trial ended. For these groups, the manner in which feedback was distributed amongst trials within a block was restricted only with respect to the frequency of the requests. Feedback had to be requested on exactly 4 of the 8 trials in a trial block (a similar methodology to Chiviacowsky & Wulf, 2005). If near the end of a block, the number of remaining feedback opportunities was equivalent to the number of remaining trials, the option to decline feedback in response to the feedback prompt was removed such that the only possible answer was yes. This ensured that feedback was received on exactly 4 trials of each block. Likewise, should the maximum number of feedback requests be reached before the end of a block, the option to request feedback in response to the feedback prompt was removed such that the only possible answer was no.

Groups who were not in control of their feedback selection (Yoked-FB and Yoked-Yoked groups) were yoked to the choices made by individuals in the Self-Self group. Depending on whether or not the corresponding Self-Self individual had chosen feedback for the given trial, the yoked individual was presented with either one of the following messages: "There will be feedback for this trial" or "There will be no feedback for this trial," for three seconds. For trials where feedback was assigned, the initial message indicating so was followed by a feedback screen identical to what the self-regulated feedback groups received but with the yoked individual's performance data.

The second session "the retention and transfer phase" was identical for all groups. This session was separated from the first one by 24 hrs. At the beginning of the second session each participant was given a declarative knowledge recall test where they were asked to recall the button press order and corresponding target time for each sequence. This test was performed with pen and paper. On the paper, four sets of five horizontally sequential boxes were filled in by the participants. At the end of each box sequence, was a space to indicate the movement time for that sequence (See Appendix). During the declarative recall test, the experimental equipment was removed from view and participants were prevented from pantomiming the actions of a sequence. After this test, all participants performed a motor recall test. The motor recall test consisted of sixteen trials (four trials of each of the four sequences learned during the previous day) presented in a random order. For the transfer portion of the second session, participants performed four trials of a new sequence (5-1-4-2-3) with a new target time (1750ms). No performance feedback was given for either of the motor retention test or the transfer test. All participants were given a questionnaire at the end of the second session.

Dependent Measures

Movement time (MT) was recorded as the time elapsed between the first and last button depressions of each sequence. Four different performance measures were calculated from the differences between the observed MTs and the respective MT goals: absolute constant error (| CE |), variable error (VE), total variability (E) and absolute error (AE). Constant error; used to measure the bias of performance about the target, was calculated with the following formula: CE = $\frac{\Sigma(x_i - T)}{n}$ where x_i represents movement time for trial i, T is the target movement time and, n represents the number of trials. In general, when calculating group means for CE, the overall magnitude of this variable can be masked by a cancelling that occurs between participants with positive performance bias (average movement time greater than the target time) and negative performance bias (average movement time less than the target time). A frequently-used measure to prevent this is to express mean CE scores as absolute values (referred to as |CE|) before being included in the calculation of a group mean. Thus only |CE| was presented in the analysis. VE was used to measure variability of performance, and was defined as the variability of an individual's performances about the mean. It was calculated with the following formula: VE = $\sqrt{\frac{\Sigma(x_i - M)^2}{n}}$ where xi and n are defined as before and, M represents the subjects average movement time for all trials of the given sequence. Together |CE| and VE describe two separate and independent aspects of performance; performance bias and performance variability respectively.

Overall measures of performance accuracy were measured using E and AE. Both CE and VE are represented in the overall measure of total variability (or E) which is defined by the formula: $E = \sqrt{VE^2 + CE^2}$ or for a more direct calculation, $E = \sqrt{\frac{\Sigma(x_i - T)^2}{n}}$. Absolute Error (AE) is a similar measure to E in that it also provides an overall measure of performance and is comprised of a combination of CE and VE. However, unlike E, it is difficult to be certain of the relative contribution of CE and VE to AE (Schmidt & Lee, 1999). AE measures the average absolute difference between movement times and the target and is defined as $AE = \frac{\Sigma|x_i - T|}{n}$. A major benefit of AE as a variable is that much like CE, it measures the quantitative difference between the target and performance but AE is immune to canceling effects that may occur between positive and negative trials (because it is expressed as an absolute value). For this reason as well as the one that follows, AE was the dependent measure used when comparing one trial type to another (e.g. magnitude of error on trials with 1) post-performance feedback vs. those without or 2) trials with post-performance feedback (trial n) vs. the trial that follows (trial n+1)). AE was hypothesized to best represent the information used by self-control participants as the basis for switching tasks (Wu, 2007) and to guide the trial by trial changes in performance as observed during acquisition. The basis for this hypothesis stemmed from the type of feedback information that was provided at the end of certain trials either upon request (self-regulation) or assignment (yoked). Feedback information consisted of the movement time for trial *i* as well as the target time. In order to be aware of their absolute constant error or variable error, participants would have to keep a tally of performance direction and spread over a series of trials and then analyze them comprehensively. Based on this, absolute error $(x_i - T)$ is likely the most salient and direct measure available to the participant for processing on a trial by trial basis.

During the first session, the chronological order of feedback requests/dismissals and task switches as well as the number of task switches were also recorded for the respective self-regulation groups. A task switch occurred whenever two different sequences were performed on consecutive trials. This measure was used to help place the practice schedules appropriately on the blocked to random practice structure continuum with random practice consisting of the greatest number of task switches possible and blocked practice consisting of the fewest.

At the beginning of the retention session, subjects were scored on their ability to verbally recall the sequences and corresponding target times learned during acquisition. A score based on the level of correctness that sequences and target times were remembered as well as the correct matching between sequences and target times was calculated.

Data obtained from questionnaires was used to help identify the extent and manor that individuals in the self-regulation groups used the available opportunities to self-regulate their learning. Likewise it was also used to identify the extent that all individuals were prevented from the use of desired movement strategies that are dependent on timely task switching and/or feedback presentation. Questions were adapted from Wu (2007) and Chiviacowsky and Wulf (2002) for the purposes of this experiment.

Data Analysis

In the data analysis all ANOVA significant effects and interactions were examined using Tukey's post hoc procedure with α set at $p<.05$. Significance levels for other test types (student's T-test, chi-square, Pearson's Product Coefficient) were also set at $p<.05$. To standardize performance on the four sequences each assigned a different target time, the MT of each trial was divided by its target time. Thus the MT values used to calculate |CE|, VE and E were all expressed as a unit-less fraction (or proportion) of their goal target time. Reported MT values were left as a raw true value and expressed in ms. Trials for which the observed MT was over two standard deviations away from a subject's mean MT for that given task type, were identified as outliers and not included in the analysis. Of all trials, 3.8% were deleted as outliers.

Acquisition. Acquisition data for MT, | CE | , VE and, E were analyzed using a 2 Feedback Control (Self-Controlled vs. Yoked) by 2 Task Order Control (Self-Controlled vs. Yoked) by 4 Pattern (A, B, C, D) by 8 Block (16 trials; 4 trials of each pattern) mixed ANOVA where pattern and block were treated as repeated measures.

The number of task switches made by both the Self-Self and Yoked-FB groups was analyzed using an independent measures student's t-test to determine if the control of the feedback variable in addition to the task order variable was linked to an increase or decrease of task switching in the Self-Self group relative to the Yoked-FB group. Furthermore, to indicate if similar processes regarding the nature of task switching were shared by Self-Self participants and their corresponding Yoked-FB participant, a Pearson's Product Moment Correlation Coefficient was calculated between the number of task switches made by each Self-Self participant and the number of task switches made by the matched Yoked-FB participant.

A chi-square analysis was used to determine if participants preferred to request feedback following certain sequences more than others. Trials were divided into categories based on task type (A, B, C, or D) and FB selection (yes – FB was requested or no – FB was not requested) (Table 1). The null hypothesis was that feedback requests would be evenly distributed across all sequences for both the Self-Self and yoked-TO groups. Another chi-square analysis was used to determine if participants practiced certain sequences in a more random fashion than others. Here, the frequency of trials preceding a task switch, was recorded for sequences A, B, C and D. The null hypothesis for this analyses being that task switches would be preceded by trials of sequences A, B, C and D in equal proportions (Table 2).

In order to examine if self-regulation participants requested feedback after good trials, the mean AE of trials that directly preceded a feedback request was compared to the mean AE of trials that were not followed by a feedback request. This was analyzed in a 2 Feedback Control (Self-Controlled vs. Yoked) 2 Task Order Control (Self-Controlled vs. Yoked) by Trial Type (Feedback vs. No Feedback) ANOVA with repeated measures on Trial Type.

The immediate effects of feedback provision were analyzed by comparing the AE of trials that preceded a feedback request (trial n) with the previous (trial n - 1) and following (trial n + 1) trials of the same pattern. This was done using a 2 Feedback Control (Self-Controlled vs. Yoked) 2 Task Order Control (Self-Controlled vs. Yoked) by 3 Trial (n - 1 vs. n vs. n + 1) ANOVA with repeated measures on Trial.

Retention. Declarative recall scores were calculated for each individual by the assignment of points for recalling each of the following: correct sequence (1 point x 4 sequences = 4 potential points), incorrect sequence with only one mistake (.5 points x 4 sequences = 2 potential points), correct target times (.25 x 4 target times = 1 potential point), target time correctly matched to sequence (.25 x 4 matches = 1 potential point). The maximum declarative recall score was 6 points.

Retention data for dependent measures MT, |CE|, VE and, E were analyzed using a 2 Feedback Control (Self-Controlled vs. Yoked) by 2 Task Order Control (Self-Controlled vs. Yoked) by 4 Pattern (A, B, C, D) by 2 Block (Last Acquisition Block, Retention Block) mixed ANOVA where pattern and block were treated as repeated measures.

A Pearson's Product Moment Correlation Coefficient's was calculated to identify a possible relationship between the number of task switches during acquisition and the performance variable of E shown during retention. All groups were included in this analysis.

Transfer. Transfer data for |CE|, VE and E were analyzed using a 2 Feedback Control (Self-Controlled vs. Yoked) by 2 Task Order Control (Self-Controlled vs. Yoked) ANOVA.

Questionnaire. Responses to the multiple-choice questions were tallied and expressed as categorical frequencies. Worded responses to open ended responses were recorded and grouped to identify common self-regulation and/or learning strategies.

Across Measures Analysis. The top and bottom three participants from the Self-Self group were identified and compared in terms of number of task switches used during acquisition, their average E across all blocks of acquisition and their average E during transfer. The top three participants were defined as those with the lowest total error during retention while the bottom three had the greatest. Questionnaire responses were used to identify the possible strategies, or perhaps the lack of strategy used by these participants during acquisition. The purpose of this analysis was to find behaviors expressed by participants during acquisition that are associated with either strong or poor retention.

CHAPTER 4: RESULTS

Two subjects were not included in the final analysis. One of these was from the Yoked-TO group and the other was from the Yoked-Yoked group. Data from both subjects were removed from the final analysis for failure to follow instructions (they completed each task with the goal of making the MTs as fast as possible).

Acquisition

Task Switching. Task switches were made following the performance of sequences A, B, C, and D equally for both the Self-Self and Yoked-FB groups. There was no difference in the number of task switches made by the Self-Self group and the Yoked-FB group. The mean number of switches was 23.0 for the Self-Self group (min: 3, max: 102, SD: 30.96) and 20.9 for the Yoked-FB group (min: 3, max: 89, SD: 26.39) (Table 3). There was an insignificant negative correlation of $r = -0.3$ between Self-Self individuals and their matched Yoked-FB counterparts. Given the identification of the Self-Self and Yoked-FB data sets for number of task switches as positively skewed, the data were further analyzed using non-parametric methods. A Mann-Whitney U test was used in place of the T-test and Spearman's Rho was used in place of Pearson's R coefficient for correlation. The results of both non-parametric tests were non-significant.

Feedback. When deciding which trials to request feedback after, participants from neither the Self-Self or Yoked-TO groups demonstrated a sequence bias. Feedback was requested equally often after the performance of sequences A, B, C and D. The trial type analysis revealed no significant effects or interactions. Trials followed by feedback were no better in terms of performance as indicated by AE than trials that were not followed by feedback. This indifference between trial types did not vary by the group factors of trial order (Self-Controlled vs. Yoked) or feedback (Self-Controlled vs. Yoked).

There was a significant main effect for trial type F (2, 68) = 13.73, p<.001 when trials that were augmented by feedback (trial n) were compared to the immediately preceding (n-1) and following trials (n+1). Post Hoc analysis revealed that the mean AE (expressed as a proportion of the target MT) of the trial n+1 group of trials (for all subjects) ($\bar{X}$ AE = .116) was lower than that of both the n-1 group of trials ($\bar{X}$ AE = .126) and n group or trials ($\bar{X}$ AE = .124). Additionally, a significant interaction of feedback condition by trial type F (2, 68) = 3.91, p<.05 was found. For this interaction, Post Hoc Analysis revealed that the self-regulated feedback groups performed similarly on trials n-1 ($\bar{X}$ AE = .1250) and n ($\bar{X}$ AE = .1206) while performance improved significantly on trials that were performed after a trial where feedback had been requested (trials n+1, $\bar{X}$ AE = .1098). Meanwhile the yoked feedback groups performed equally on all three trial types (Figure 2). No other main effects or interactions regarding trial type were found.

Movement Time. Main effects were found for feedback condition F (1, 34) = 10.02, $p < .05$ and sequence F (2, 102) = 904.21, $p < .000000$. Significant interactions were found for sequence by feedback condition F = (3, 102) = 3.1074, $p < .05$, feedback by block F (7, 238) = 2.6298, $p < .05$ and sequence by block F (21, 714) = 3.0046, $p < .0001$. Participants from the self-regulated feedback conditions had significantly greater MTs than participants from the yoked feedback conditions (1775.85ms vs. 1706.54ms). Post Hoc analysis revealed the mean MT of each sequence type to be different from the others (A = 1106.43ms, B = 1498.81ms, C = 1967.62ms, D = 2389.49ms). Post Hoc analysis revealed no same sequence differences between the self-regulated and yoked feedback conditions, rather the differences that caused the significant sequence by feedback condition interaction were found to exist between sequences of different types which was deemed theoretically insignificant. For the feedback condition by block interaction, the self-regulated participants had greater movement times than the yoked participants at blocks 3 (MT: self-regulated = 1808.27ms, yoked = 1659.41ms) and 4 ((MT: self-regulated = 1818.73ms, yoked = 1707.99ms) (Fig. 3). For summary of means, see Table 4.

Absolute Constant Error. Main effects were found for sequence $F(3, 102) = 9.42$, $p < .00001$and block $F(7, 238) = 15.72, p < .00001$. A single significant interaction was found for feedback condition by block $F(7, 238) = 2.15, p < .05$. Post Hoc analysis revealed that despite raw |CE| values having already been divided by their target MT and expressed as a proportion, the fastest sequence (1000ms) still had a greater |CE| than the other 3 sequences. The other three sequences were not significantly different from each other (Fig. 4). For the main effect of block, |CE| decreased across blocks. This decrease was significant between blocks 1 and 2. By blocks 4-7, |CE| was significantly lower than it had been during blocks 1 & 2. By block 8, |CE| was lower than blocks 1, 2 and, 3. For the feedback by block interaction, at no given block did groups who self-regulated their feedback outperform or become outperformed by groups from the yoked feedback condition. However the yoked and self-regulated feedback did improve their |CE| across acquisition at different chronological time points. The two groups from the self-regulated feedback condition performed significantly better during blocks 3 through 8 than they did in block 1. Meanwhile the two groups from the yoked feedback condition had a |CE| that was lower than their block 1 |CE| during block 4. By block 5, the |CE| was lower than that of blocks 1, 2 & 3. Block 6 was lower than blocks 1 & 2. Block 7 was lower than Block 1. and Block 8 was lower than blocks 1, 2 & 3 (Fig. 5). For summary of means see table 5 and graph 6.

Variable Error. A main effect was found for block F (7, 238) = 18.9657, $p <$ .0000001. There was a significant increase in performance (lower VE) from block 1 to block 2. This performance increase was maintained across all subsequent following blocks (3-8). Blocks 4-8 had VE scores that in addition to being lower to block 1, were also lower than block 2. An almost interaction was found for Task Order condition by Feedback Condition by Block F (7, 238) = 1.9632, $p < .06$. The most obvious difference between means in this interaction was the high VE of the Yoked-TO group in block 1 ($\bar{X}\ VE = .1764$ while $\bar{X}\ VE$ for the Self-Self, Yoked-FB and Yoked-Yoked groups were .1353, .1503 and, .1357 respectively). No other main effects or interactions were found. For summary of means see table 5 and graph 7.

Total Error. Main effects were found for sequence F (3, 102) = 5.7308, $p < .001$ and block F (7, 238) = 25.0668, $p < .0000001$. Interactions that failed to reach statistical significance were found for feedback condition by block F (7, 238) = 1.7641, $p < .09$, sequence by block F (21, 714) = 1.5611, $p < .06$ and, task order condition by feedback condition by block F (7, 238) = 1.8973, $p < .08$. A post Hoc analysis of the sequence main effect found that sequence 1 had significantly greater error than sequences 2 and 3. A post Hoc analysis for Block found that a decrease in E occurred from block 1 to block

2. This improvement was maintained as block 3 also had lower E than block 1, blocks 4 to 6 had E lower than blocks 1 and 2 and block 8 had lower E than blocks 1, 2 and 3. For summary of means see table 5 and graph 8.

Retention

Declarative Recall. Analysis of variance revealed no significant main effects or interactions. As a whole, subjects recalled the target times very well, with 34 of 38 subjects recalling the four target times perfectly. In contrast, declarative recall of sequence button order was relatively poor. Of 38 subjects, 7 correctly recalled sequence A, 3 correctly recalled B, 6 correctly recalled C, and only one correctly recalled D. Subjects were given 1 point for each time they were able to correctly match a sequence to its target time. This accumulated to a maximum total of 4 points. On average, subjects scored .8816/4 on this task (Table 6).

Movement Time. Main effects were found for feedback type F (1, 34) = 5.4552, $p < .05$, and sequence F (3, 102) = 755.547, $p < .0000001$. An interaction was found for sequence by block F (3, 102) = 5.84, $p < .001$. As in acquisition, participants in the self-regulated feedback condition had an overall greater movement times than those who were yoked ($\bar{X}$ MT = 1792.71ms vs. $\bar{X}$ MT = 1701.62ms). As would be expected, each sequence had a mean MT that was similar to their target time and all sequences had MTs that were significantly different from each other. The MT for sequence A was significantly greater in retention (1160.74ms) than at the end of acquisition (1064.51ms) while the MT for sequence D was significantly less in retention (2343.34ms) than in the end of acquisition (2455.71ms). The MTs for sequence B were 1514.60ms and 1525.09ms while the MTs for sequence C were 1979.59ms and 1933.70ms at the end of acquisition and in retention respectively (Table 4).

Absolute Constant Error. Main effects were found for sequence F (3, 102) = 5.21, p < .05 and block F (1, 34) = 45.77, $p < .001$. Similar to in acquisition sequence A ($\bar{X}$ |CE| = .1287) had significantly greater |CE| than sequences B ($\bar{X}$ |CE| = .0822) and C ($\bar{X}$ |CE| = .0767). Overall mean |CE| was higher in retention than during acquisition (from .0599 to .1306). For a summary of means, see table 5 and figure 6.

Variable Error. No main effects or interactions were found for VE. There was a trend showing that VE decreased from the end of acquisition to retention (from .0961 to .0880). For a summary of means, see table 5 and figure 7.

Total Error. Main effects were found for sequence and block. Sequence A ($\bar{X}$ E = .1612) had a greater E than C ($\bar{X}$ E = .1262) and an almost greater E than B (($\bar{X}$ E = .1295). Sequence D had an intermediate E ($\bar{X}$ E = .1336). E was greater during retention (.1732) than at the end of acquisition (.1023). No correlation was found between the number of task switches made during acquisition and E during retention (R^2 = .0638). For a summary of means, see table 5 and figure 8.

Transfer

No significant main effects or interactions were found for MT (Table 4), |CE|, VE, E or AE (Table 5). The Yoked-TO group had the lowest overall error.

Questionnaire

Tables 7, 8, 9, and 10 reconstruct the questionnaires and the corresponding results for the Self-Self, Yoked FB, Yoked TO and Yoked-Yoked groups respectively. In regards to the practice phase, 80% of Self-Self, 62% of Yoked TO, 90% of Yoked FB and 80% of Yoked-Yoked participants reported that they were able to try as many mental movement strategies as they wanted. Of the participants who self-regulated their feedback presentation, 40% from the Self-Self group and 25% from the Yoked-TO group reported to ask for feedback after they thought they had a good trial. When asked why they chose to request feedback on the trials that they did, some participants (approximately n = 6 of a total of 20) wrote very obvious responses such as "To see how close or far I was to the trial time". A second category of answer type was identified by the experimenter and described as 'answers that indicate the existence of cognitive processes related to the patterning of feedback requests that do not fit into the conventional options provided by the previous multiple choice question'. Examples of answers that fall into this category include: "My goal was to use the feedback on 4 consecutive trials, with each trial being closer to the target time than the previous" and "I wanted to see how I was progressing across the entire block so I decided to select feedback mainly on every other trial..." Approximately 7 out of 20 participants who self-regulated their feedback provided written answers that were representative of this category. The remaining participants provided answers to this question that were either in line with their responses from the multiple choice question that was of a similar nature, not very informative or too unique to be grouped with other responses into a category. Of the participants that did not self-regulate their feedback, 70 % from the Yoked-FB group and 78% from the Yoked-Yoked group reported that they did not receive feedback after the preferred trials. Four of the seven participants from the Yoked-FB group who reported to receive feedback after the wrong trials, indicated that they would have preferred to receive feedback after good trials. Meanwhile two others would have preferred it after bad trials and the last participant, good and bad trials equally. In the Yoked-Yoked groups, 3 participants indicated that they would rather receive feedback after good trials, while the other remaining 6 participants reported that they would rather to have received feedback after good and bad trials equally.

For the groups that self-regulated the task order variable, 60 % of Self-Self and 40% of Yoked-FB participants reported that they did not choose to practice a different task after good trials, bad trials, good or bad trials equally or randomly. Rather the most popular response for this question was "none of the above". When asked why they chose to practice a different task, participants who had chosen "none of the above," in the previous multiple choice questions provided answers such as: "I did one task after another, completed all of a task type and then switched," and "One task was practiced until all feedback was used, then remaining four were random." Of participants who did not self-regulate the task order variable 44.44% from the Yoked-TO and 40.00% from the Yoked-Yoked groups reported that there was a point in practice where they would have liked to practice a task more but were unable to because the schedule told them to practice another task.

In the Self-Self group, 80% of individuals reported that they did not request feedback because they were considering a task switch for the following trial. In this same group, 80% of participants also reported that the displayed results after a feedback request did not influence their subsequent task selection. In the Yoked-FB group, 40% of the participants reported that the provided feedback influenced their subsequent task selection while 50% of them said that it did not.

Across-Measures Analysis

Interestingly, the three Self-Self subjects that scored as the top three subjects within their group for having low E during retention, also had the lowest average E in acquisition. Two of these three top scoring subjects requested feedback after good trials while a third requested feedback on every other trial throughout the block. Of the three Self-Self participants who had the worst error scores during retention, one requested feedback after bad trials while the other two requested it mostly during the first four trials of a block to "learn the target time" or to "develop a model of the target time" and then completed the last four trials of a block with a general absence of feedback. No clear differences in task switching behavior differences appeared to exist between the best and worst Self-Self performers. The best three of these participants switched tasks 9, 15, and 3 times while the worst three switched tasks 9, 5, and 3 times. For summary, see table 8.

Did Measurable Learning Occur?

Given the absent of group differences during retention for each of the measured performance variables as well as the significant increase in |CE| and E scores from the end of acquisition to retention, and the insignificant change in VE, the experimenter decided to run an ANOVA on the |CE|, VE, and E practice variables comparing the beginning of acquisition to retention. This was done using a 2 (trial order condition: Self-Controlled vs. Yoked) by 2 (feedback condition: Self-Controlled vs. Yoked) by 2 (Block: 1st block of acquisition vs. retention) ANOVA with repeated measures on block. No main effects on interactions were found for |CE| or E. For VE, a main effect was found for block $F = (1, 34) = 93.671$, $p < .0000001$ and an interaction was found for trial order condition by feedback condition by block. The overall average VE for all participants in the study was greater at the beginning of acquisition ($\bar{X} = .1494$) than during retention ($\bar{X} = .0989$). The significant interaction of for trial order condition by feedback condition by block was due to the Yoked-TO group having a significantly greater VE than the other three groups during the first block of acquisition but not during retention.

CHAPTER 5: DISCUSSION

The purpose of the current experiment was to examine the effects of self-controlling two practice variables on motor learning. A Self-Self group that controlled two practice variables was compared to three control groups that were all yoked to either one or both of the Self-Self group's practice structure. It was in this way that the main effects of self-regulating the task order and feedback scheduling variables were intended to be isolated as well as any interactions between them. A second purpose of the study was to describe the patterns of behaviors exhibited by self-regulators under each of these conditions as well as to identify commonly used self-regulation strategies in terms of their effectiveness. The research extended the work that has been done on the self-regulation of task order (Keetch & Lee, 2007; Titzer et al., 1993; Wu, 2007) and feedback presentation practice variables (Chiviacowsky and Wulf, 2002, 2005; Jannelle et al., 1995, 1997) individually. Based on prior research, it was hypothesized that self-regulation of single practice variables would have benefits over non self-regulated learning. Drawing from the concept that increased cognitive processing during acquisition leads to increased retention as well as better performance during transfer (Lee & Magill, 1985; Lee, Swinnen, & Serrien, 1994; Shea & Morgan, 1979), it was predicted that increased self-regulation opportunity would result in an increased processing of information during acquisition. This increased processing would in turn display itself during retention and transfer in terms of a stronger performance relative to the other groups. An alternative hypothesis proposed that increased self-regulation opportunity that was greater than the self-regulation of just one practice variable would be too cognitively demanding. This would be reflected by the Self-Self group demonstrating the poorest performance on measures of long-term retention or a performance that was no greater than that of the Yoked-Yoked group who had no self-regulation opportunities.

The Effects of Self-Control on Learning

The first hypothesis - that the Self-Self group would show higher levels of learning than the other groups, was not supported. The second hypothesis - that the self-regulation of one practice variable would be beneficial to learning but that the self-regulation of two would be too demanding on the individual was also not supported. The literature to date has been convincing that giving individuals control over single practice variables during acquisition is beneficial to the learning of a motor task (Wulf, 2007). The results of the current study do not support this argument. Although performance did improve over acquisition and some of this learning was retained over time (as was seen in the decrease of VE from the first block of acquisition to the end of acquisition and the retention of this decrease 24hrs later) there were no significant between-group performance differences that were retained over time. The results did not even demonstrate a trend in support of self-regulation. In terms of total error during retention, the Yoked-FB group had the strongest performance ($\bar{X}$ = .1663, SD = .0645) followed by the Yoked-Yoked ($\bar{X}$ = .1615, SD = .0628), Self-Self ($\bar{X}$ = .1774, SD = .0619) and Yoked-TO ($\bar{X}$ = .1882, SD = .0535) groups respectively. In terms of total error during transfer, the Yoked-TO ($\bar{X}$ = .1671, SD = .0479) group had the strongest performance followed by the Self-Self ($\bar{X}$ = .2043, SD = .1144), Yoked-Yoked ($\bar{X}$ = .2069, SD = .1551) and Yoked-FB ($\bar{X}$ = .2100, SD = .0982) groups.

As we know, changes in motor behavior and performance are not direct measures of learning, one cannot completely rule out the possibility that long-term differences between groups did exist. The measurement of these variables is a tool used by behavioral scientists to make inferences about the processes of learning that take place within the central nervous system at the molecular, cellular and neuronal networking levels. Performance is not a perfect index of learning. Although motor learning should produce reliable performance changes, these changes may not always lead to performance improvements. In some instances where a skill is practiced improperly, the improper version of the skill will be learned and hinder later performance (Rose & Christina, 2006). There are other instances where learning is not exhibited by behavior. This can be due to the time lag between the non-observable changes in the CNS that precede changes in behavior. If acquisition is stopped before the internal changes become apparent, learning will not be observed. Learning is sometimes a trial and error process. Should a learner try several different attempts to perform a skill correctly, none of which are successful, they will still not be able to exhibit improvements in performance. They have however come closer to knowing the correct movement as they have eliminated several of the incorrect options for achieving correct performance and therefore are more likely to find the correct one on subsequent attempts (Rose & Christina, 2006). As was seen in the permanent decrease of VE, the participants in this study did become more reliable at performing the skill. They did not however learn to perform it accurately relative to the assigned target times as was seen in the very high |CE| exhibited on the second day.

Effects of Self-Control of Trial Order on Acquisition

Condition of trial (self controlled vs. yoked) order did not affect performance over the acquisition period. The manner in which participants who self-controlled their trial order, chose task switches was unaffected by the assigned level of the second feedback variable; feedback schedule (self-controlled vs. yoked). This contradicts previous literature reported by (Keetch & Lee, 2007; Titzer et al., 1993; Wu, 2007) where subjects who self-controlled their trial order performed better on measures of learning than those who did not. In the current study, only three of twenty self-controlled trial order participants reported that they chose to switch tasks mostly after good trials. This is contradictory to the results of Wu (2007) who found that subjects reported a preference to switch tasks after good trials as opposed to poor ones. Wu (2007) also found that subjects who chose their trial order on a trial-by-trial basis throughout acquisition tended to choose a more random practice schedule than those who chose their entire trial order prior to beginning acquisition. Although the current study did not include a group that chose trial order prior to beginning acquisition, it can be said that subjects predominantly preferred a blocked style of practice (Table 3).

Effects of Self-Control of Feedback on Acquisition

It appears that feedback had the greatest effect on performance during acquisition. These effects were dependent on whether or not the individual self-regulated the feedback schedule or was assigned the feedback schedule. The effects of feedback condition on acquisition were unaffected by the assigned level of the second factor; trial order condition (self vs. yoked). The effects of feedback condition on acquisition were made apparent on analysis of trial type (AE on trial n vs. trial n +1), MT, and |CE|. A quantitative analysis was done to compare the AE of trials where feedback was requested to the AE of trials where feedback was not requested, showed no significant difference between the trial types. This analysis did not support the previous work done by Chiviacowsky and Wulf (2002, 2005) who found that trials followed by feedback requests had lower average AE than trials that were not. From these results Chiviacowsky and Wulf concluded that learners who self-regulate their feedback tend to prefer feedback after good trial performances as this is when the information contained within the feedback is most tailored to the learners' needs. The participants in the Chiviacowsky and Wulf (2002) study not only had a lower average absolute error on trials where they requested feedback, they also seemed to by cognitively aware of their strategy or requesting feedback after good trials as 10 participants reported to have done so on a questionnaire while none reported to have requested feedback after bad trials. The results from the current study do not refute the effectiveness of a strategy to request feedback after a 'good' trial. Quantitatively, the participants who self-regulated feedback in the current study performed no better on the set of trials where feedback was requested than on the set of trials where it wasn't. Qualitatively, only 6 of the 20 self-regulators of feedback reported to have requested feedback after good trials. The current study does not support the notion that self-regulators will inherently request feedback after good trials without being informed of the effectiveness of this strategy.

A second analysis of trial type was performed. This analysis compared each trial that was followed by a feedback request (trial n) with the trial that preceded it (trial n -1) and the subsequent trial that was performed immediately after trial n (trial n + 1). Subjects who self-controlled their feedback were able to perform stronger on trial n + 1 (trial following the trial with AF) than trial n (trial with AF). According to Guadagnoli and Lee (2004), in order for feedback to be effective, not only does the learner have to be skilled enough at the task (low functional difficulty) to be able to efficiently process the augmented performance information in addition to the intrinsic performance information, the amount of feedback information has to be great enough or sensitive enough for the learner to notice a significant difference between their expected and actual outcome of performance. They can then compare these two things and alter their movement plan on following trials such that the expected and the actual become more similar. It does not appear that participants in the current study requested feedback based on previously reported performance based strategies. It is plausible that participants in the current study planned whether or not to request feedback on a given trial, before even performing the trial. If this is to be true, it is possible that in addition to their intent to request feedback, they were also more aware of their expected outcome of performance than were participants who were yoked to the feedback variable. Developing a more resolute and clear expected outcome of performance prior to beginning a trial, could aid in a more sensitive and unambiguous comparison of expected outcome and actual outcome, making the estimated difference between the two more accurate. A more accurate estimated difference is likely better at guiding future performance than an inaccurate one. This interpretation of the trial n, trial n + 1 effect in terms of the guidance hypothesis could possibly explain the differences in acquisition performance between participants that self-controlled their feedback and those that didn't.

When movement time was analyzed as a dependent variable, there was a main effect for feedback condition as well as an interaction between feedback condition and block. Participants from the self-regulated feedback condition had a significantly greater average movement time (1775.85ms) than those who were yoked (1706.54ms). Given that the average of the target times for each sequence (A = 1000ms, B = 1500, C = 2000, and D = 2500) was 1750ms, it can be seen that the self-regulated groups were closer to the average TT value than were the yoked groups (Fig. 3). This difference between groups was apparent during the third and fourth blocks. It is possible that different processes of learning went on between the yoked and self-controlled feedback groups that caused them to learn the TTs at different rates of progress. However as the |CE| was greater during retention than in acquisition, it can be argued that neither feedback condition learned the TTs, but merely demonstrated temporary changes in their abilities to produce MTs close to the TTs across acquisition.

Lastly when |CE| was analyzed as a dependent variable a main effect was found for block and a significant interaction was found for feedback condition by block. Although there were not significant decreases in |CE| between each block and the subsequent following one, there was such a decrease between some of them. Also, the overall trend was that of |CE| decreasing across the acquisition period. Groups from the two feedback conditions experienced improvements in the |CE| performance relative to their initial performance in block 1 at different chronological time points in acquisition. Much like MT, the feedback condition by block interaction indicated that the self-controlled and yoked feedback groups progressed through different processes of learning or progressed through the same processes of learning at a different rate. It is difficult to say what exactly these processes of learning are, although they could have something to do with the way that groups from the self-regulated feedback condition used the information from feedback to improve performance on the following trial while groups from the yoked feedback condition did not.

CHAPTER 6: GENERAL DISCUSSION

When Will Learners Choose the Most Effective Practice Schedules?

Much is known about the most effective experimenter imposed practice structures for the task order and feedback schedule task variables. It is not entirely known if the best self-regulation strategy is to choose a schedule that best matches that of what would be the ideal schedule under experimenter imposed condition. Keetch and Lee (2007) found that task order self-regulators used a variety of different strategies and task switch patterns all of which were found to be effective for learning. They interpreted this to mean that it may be self-regulation in general and not the control of a certain aspect of the learning context or the selection of a task that is beneficial. Their results could also mean that is self-regulation in general that is beneficial for learning and not necessarily a certain self-regulation strategy that learners may use instead of others. The current study did not find such general benefits of self-regulation. This could be because self-control individuals, despite being given control over aspects of the practice schedule and the opportunity to self-regulate throughout the entire time span of practice, did not take advantage of the opportunity and neglected to partake in self-regulatory processes. Just because an experimental structure has built in room for self-regulatory processes to occur, does not necessarily mean that the learner will engage in them. A possible indicator that the groups who were given self control over their trial did not engage in self-regulation of the trial order variable is the extremely blocked nature of their chosen practice schedules. The experiment had 128 practice trials with the opportunity to switch tasks up to 127 times. Ten of twenty participants in the self-controlled task order condition chose to switch tasks fewer than ten times and only one participant chose to switch tasks more than 100 times (Table 3). Many of these self-control participants chose to switch tasks in a patterned manner that was dissociated from performance. They chose their practice schedule according to non-performance associated reasons such e.g. "what was most orderly" or according to mislead beliefs about what is most effective for practice e.g. "blocked is better for performance." It is even possible that they planned out the chronological order of their task switching prior to even beginning practice.

If self-regulation benefits are dependent upon choosing a practice structure that is in resemblance to a specific ideal prototype, the inability of learners to identify this prototype or unwillingness to structure one's own practice in resemblance of it, could have dangerous implications for the use of self-regulation in motor learning. Baddely and Longman (1978) trained postal workers to use a typewriter that was intended to be incorporated into the letter sorting process. They compared massed verses distributed work/rest ratios and found the expected results of distributed practice being better for long term retention. Interestingly, when workers were asked to rate their subjective experience; they rated the massed schedule as the most preferable and the distributed schedule as the least. When they were informed of the benefits of the distributed schedule: that it would lead to better long-term learning, and then asked which schedule they would prefer, a majority of the workers indicated that they would still prefer the massed schedule. If there is a general benefit of self-regulation that occurs regardless of chosen practice structure, the ability of learners to utilize certain self-regulation strategies over others is not of a concern. If however as Chiviacowsky and Wulf (2002, 2005) suggest, that self-regulation is performance and strategy dependent; the inability of individuals to be aware of such strategies and even more so to follow them, is of concern. It seems that many individuals in the current study were unaware of the effectiveness of requesting feedback after good trials.

Limitations

Conditions of the current study enforced subjects in the self-controlled feedback conditions on exactly 50% of the trials, a rate that was determined by the experimenter. The number of feedback requests per block also had to remain equal between blocks with feedback being requested after 4 of the 8 trials within a block. Similar feedback schedule enforcements were used in another self-regulation of feedback scheduling study where the study consisted of 60 practice trials to be practiced in blocks of ten. For every ten trials practiced, participants were required to request feedback on three of them (Chiviacowsky & Wulf, 2005). This mandatory percentage of trials to be followed by feedback requests was determined based on a previous study were participants were allow to requests feedback in an unrestrained manner (as much or as little as they wished to). These participants chose to request feedback on 35% of the trials. Given that the work done by Chiviacowsky and Wulf used a sequence timing task similar to the one used in the current study, it is possible that the mandatory average feedback frequency (50%) was too high and instead of catalyzing learning, prevented it from occurring by developing a learner dependence on feedback. The restrictions of feedback request rate and mandatory distribution across blocks that were imposed by the experimenter on the subjects also prevented the learner from choosing, fading feedback schedules that have been shown to be beneficial to learning under experimenter imposed conditions. Whether or not fading would also be beneficial to learning under self-regulation conditions is unknown but one cannot rule out the possibility that preventing it could also prevent learning.

Applications of the Findings and Future Directions

More research is needed to determine the effectiveness of self-control and regulation in practice schedules. The current study does not support the common held belief that the availability of self-regulation opportunity will enhance motor learning. Despite differences in performance during acquisition between feedback conditions, the experimental group (Self-Self) and the three control groups performed the same during retention. It is possible that performance incentives meant to increase motivation could have yielded much different results. It is suggested that similar experiments be conducted under conditions that increase subject motivation.

CONCLUSION

In summary, self-control groups performed equally to the non-self-control group during retention and transfer regardless of the amount of self-control assigned to the group. It is possible that effective practice structures and schedules are more important to learning than the opportunity to choose the practice structure oneself. Group differences dependent upon feedback condition existed during acquisition. The groups that self-controlled their feedback schedule exhibited greater movement times that were closer to the target times. These self-control groups were also influenced by the information provided to them by feedback in that they were able to perform the following trial with a reliably lower absolute error. Coaches and teachers of motor skill should be cautious of incorporating self-control into the practice schedule as the effects of such may not be as robust as is commonly assumed. They should be especially cautious of incorporating high levels of self-regulation as the current study provided no support for the effectiveness of such practice conditions.

REFERENCES

Alberet, J. M., & Thon, B. (1998). Differential effects of task complexity on contextual interference in a drawing task. *Acta Psychologica*, 100, 9-24.

Baddely, A. D., & Longman, D. J. A. (1978). The influence of length and frequency of training session on the rate of learning to type. *Ergonomics*, 21, 627-635.

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist*, 28, 117-148.

Baumeister, R. F., & Vohs, K. D. (Eds.). (2004). *Handbook of self-regulation: Research, theory and applications.* New York, NY: The Guilford Press.

Brady, F. (2004). Contextual interference: A meta-analytic study. *Perceptual and Motor Skills,* 99, 116-126.

Cauraugh, J. H., Chen, D., & Radlo, S. J. (1993). Effects of traditional and reversed bandwidth knowledge of results on motor learning. *Research Quarterly for Exercise and Sport,* 64, 413-417.

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.

Ferrari, M. (1996). Observing the observer: Self-regulation in the observational learning of motor skills. *Developmental Review*, 16, 203-240.

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.

Hartman, J. M. (2007). Self-controlled use of a perceived physical assistance device during a balancing task. *Perceptual and Motor Skills,* 104, 1005-1016.

Huet, M., Camachon, C., Fernandez, L., Jacobs, D. M., & Montagne, G. (2009). Self-controlled concurrent feedback and the education of attention towards perceptual invariants. *Human Movement Science,* 28, 450-467.

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., & Cauraugh, J. H. (1997). Maximizing performance feedback effectiveness through videotape replay and a 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 and learning of a closed motor skill. *Perceptual and Motor Skills*, *81*, 627-634.

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

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

Rose, D. J., & Christina, R. W. (2006). *A multilevel approach to the study of motor control and learning (2nd ed.).* San Francisco: Benjamin Cummings.

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

Schea, 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.

Schea, 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. 245-266). Amsterdamn: Elsevier.

Schea, J.B., & Zimny, S.T. (1988). Knowledge incorporation in motor representation. In O.G. Meijer & K. Roth (Eds.), *Complex movement behavior: 'The' motor-action controversy* (pp. 289-314). Amsterdamn: Elsevier.

Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: A behavioral emphasis (3rd ed.).* Champaign: Human Kinetics.

Schmidt, R. A., Young, D. E., Swinnen, S., & Shapiro, D. C. (1989). Summary knowledge of results for skill acquisition: Support for the guidance hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 15, 352-359.

Sherwood, D. E. (1988). Effect of bandwidth knowledge of results on movement consistency. *Perceptual and Motor Skills*, 66, 335-342.

Schunk, D. H., & Zimmerman, B. J. (1994). *Self-regulation of learning and performance: Issues and educational applications*. Hilldale, N.J.: Erlbaum.

Swinnen, S. P., Schmidt, R. A., Nicholson, D. E., & Shapiro, D. C. (1990). Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 706-716.

Titzer, R., Shea, J. B., & Romack, J. (1993). The effect of learner control on the acquisition and retention of a motor task. Paper presented at the annual conference of the North American Society of Sport and Physical Activity, Brainerd, MN (abstract published in *Journal of Sport and Exercise Psychology,* 13, S84).

Viitasalo, J. T., Era, P., Konttinen, N., Mononen, H., Mononen, K., & Norvapalo, K. (2001). Effects of 12-week shooting training and mode of feedback on shooting scores among novice shooters. *Scandinavian Journal of Medicine and Science in Sports,* 11, 362-368.

Weinstein, 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.

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. 792-794.

Wu, W. F. W. (2007). *Self-control of multiple motor skills.* Louisiana State University, http://etd.lsu.edu/docs/available/etd- 06142007-121955/.

Wuld, G. (2007). Self-controlled practice enhances motor learning: Implications for physiotherapy. *Physiotherapy*, 94, 96-101.

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

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

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.

Zimmerman, B. J., & Schunk, D. H. (1989). *Self-regulated learning and academic achievement: theory, research, and practice* (p. 3). New York: Springer-Verlag.

Table 1.
Trials performed by groups who self-controlled their feedback requests were divided into categories defined by task type and whether or not feedback was requested at the end of the trial.

	Task				
FB	1000	1500	2000	2500	sum
Yes	328	323	313	315	1279
No	312	317	327	320	1276
sum	640	640	640	635	2555

Table 2.
For groups who self-controlled their trial order, the trials that preceded a task switch were divided into categories defined by their task type.

Task				
1000	1500	2000	2500	sum
111	115	108	105	439

Table3.
Number of task switches made by Self-Self and Yoked-FB groups in acquisition.

	Acquisition Block								
	1	2	3	4	5	6	7	8	Total
Self-Self	2	1	2	2	2	2	3	1	15
	15	15	15	14	12	8	14	9	102
	0	1	3	1	1	2	0	1	9
	0	0	1	0	1	0	1	0	3
	0	0	1	0	1	0	1	0	3
	1	2	2	2	4	2	1	5	19
	4	2	2	2	4	8	16	12	50
	9	3	0	1	1	0	1	0	15
	3	2	1	1	1	0	1	0	9
	0	0	1	0	3	0	1	0	5
Yoked-FB	3	2	2	1	1	1	1	0	11
	4	0	1	0	1	0	1	0	7
	0	0	1	0	1	0	1	0	3
	10	7	11	8	12	14	14	13	89
	4	0	2	0	1	0	1	0	8
	5	2	1	1	1	1	1	3	15
	1	0	1	0	1	0	1	0	4
	15	16	2	0	1	0	1	0	35
	6	7	3	2	3	3	5	2	31
	0	0	1	0	3	1	1	0	6

Table 4.
MT (ms) in acquisition, retention (Ret.) and transfer (Trans.) as a function of block and group

		Acquisition Block								Ret.
		1	2	3	4	5	6	7	8	
A	Self-Self	1172	1097	1098	1123	1115	1108	1081	1059	1187
1000	Yoked-FB	1224	1107	1148	1084	1060	1072	1097	1078	1108
ms	Yoked-TO	1190	1136	1118	1109	1124	1098	1111	1057	1242
	Yoked-Yoked	1145	1102	1061	1047	1071	1072	1076	1059	1118
B	Self-Self	1415	1458	1501	1556	1457	1493	1514	1528	1660
1500	Yoked-FB	1508	1485	1436	1491	1483	1499	1554	1488	1420
ms	Yoked-TO	1457	1506	1555	1520	1488	1456	1448	1478	1539
	Yoked-Yoked	1434	1429	1402	1422	1426	1471	1426	1455	1505
C	Self-Self	2039	2036	2076	2066	1972	2027	1968	1994	2020
2000	Yoked-FB	1844	1866	1919	1920	1993	1970	1914	1946	1756
ms	Yoked-TO	1830	1911	2016	1960	1941	1970	1918	1920	2001
	Yoked-Yoked	1823	1871	1777	1908	1918	1919	1943	1983	1947
D	Self-Self	2306	2451	2415	2399	2358	2398	2454	2415	2461
2500	Yoked-FB	2090	2132	2239	2308	2378	2380	2436	2405	2108
ms	Yoked-TO	2399	2455	2475	2592	2380	2426	2381	2462	2417
	Yoked-Yoked	2211	2151	2039	2226	2225	2270	2355	2417	2319
Trans.	Self-Self									1832
1750	Yoked-FB									1640
ms	Yoked-TO									1792
	Yoked-Yoked									1685

Table 5.
Performance variables |CE|, VE, & E in acquisition, retention (Ret.) and transfer (Trans.) as a function of group and block.

		Acquisition Block								Ret.	Trans.
		1	2	3	4	5	6	7	8		
|CE|	Self-Self	0.11	0.07	0.06	0.08	0.08	0.08	0.06	0.06	0.13	0.19
	Yoked-FB	0.15	0.11	0.11	0.08	0.06	0.08	0.09	0.07	0.13	0.18
	Yoked-TO	0.12	0.09	0.07	0.07	0.07	0.06	0.06	0.05	0.13	0.11
	Yoked-Yoked	0.13	0.14	0.12	0.10	0.08	0.08	0.08	0.06	0.12	0.19
VE	Self-Self	0.14	0.11	0.10	0.10	0.11	0.10	0.09	0.09	0.09	0.07
	Yoked-FB	0.15	0.13	0.11	0.09	0.10	0.10	0.11	0.09	0.09	0.07
	Yoked-TO	0.18	0.13	0.11	0.10	0.11	0.11	0.10	0.09	0.09	0.09
	Yoked-Yoked	0.13	0.13	0.12	0.10	0.10	0.12	0.12	0.12	0.08	0.08
E	Self-Self	0.16	0.13	0.11	0.12	0.13	0.12	0.11	0.10	0.18	0.20
	Yoked-FB	0.19	0.16	0.15	0.12	0.11	0.12	0.13	0.11	0.17	0.21
	Yoked-TO	0.21	0.15	0.12	0.12	0.12	0.12	0.11	0.10	0.19	0.17
	Yoked-Yoked	0.18	0.17	0.16	0.13	0.13	0.14	0.13	0.11	0.17	0.21

Table 6.
Average Declarative Recall Score For Each Group. TTs = Target Movement Times

	Sequence Score / 1						
	1000ms	1500ms	2000ms	2500ms	TTs/1	Matching/1	Total
Self-Self	0.35	0.40	0.50	0.25	0.925	0.25	2.68
Yoked-FB	0.30	0.10	0.15	0.30	1	0.14	1.99
Yoked-TO	0.39	0.11	0.28	0.28	0.94	0.19	2.19
Yoked-Yoked	0.39	0.28	0.39	0.22	0.70	0.31	2.28
Max Score	1	1	1	1	1	1	6

Table 7.
Frequency of Self-Self group's questionaire responses to multiple choice questions.

Did you feel you were able to try as many mental movement strategies as you wanted?	
Yes	8
No	2
When did you ask for feedback?	
Mostly after you thought you had a good trial	4
Mostly after you thought you had a bad trial	2
After good or bad trials equally	1
Randomly	1
None of the above	2
When did you choose to practice a different task?	
Mostly after you thought you had a good trial	1
Mostly after you thought you had a bad trial	0
After good or bad trials equally	1
Randomly	2
None of the above	6
Did you request feedback because you were considering selection of a different task on the following trial?	
Yes	1
No	8
Sometimes	1
Did the displayed results after feedback requests influence your subsequent task selection?	
Yes	1
No	8
Sometimes	1

Table 8.
Frequency of Yoked-FB group's questionaire responses to multiple choice questions.

Did you feel you were able to try as many mental movement strategies as you wanted?		
	Yes	9
	No	1
Do you think you received feedback after the right trials?		
	Yes	3
	No	7
If the answer was "No," when would you have preferred to receive feedback?		
	After good trials	4
	After bad trials	2
	Equally	1
	Randomly	0
	Doesn't matter	0
When did you choose to practice a different task?		
	Mostly after you thought you had a good trial	2
	Mostly after you thought you had a bad trial	2
	After good or bad trials equally	1
	Randomly	1
	None of the above	4
Did the provided feedback influence your subsequent task selection?		
	Yes	4
	No	5
	Sometimes	1

Table 9.
Frequency of Yoked-TO group's questionaire responses to multiple choice questions.

Did you feel you were able to try as many mental movement strategies as you wanted?	
Yes	5
No	3
When did you ask for feedback?	
Mostly after you thought you had a good trial	2.5
Mostly after you thought you had a bad trial	1
After good or bad trials equally	2
Randomly	2.5
None of the above	2
Was there a point in practice where you wish you could have practiced a task more but was unable because the schedule told you to do another task?	
Yes	4
No	5
If the answer was yes, when would you have preffered to start practicing another task?	
After good trials	1
After bad trials	1
Equally	2
Randomly	0
Doesn't matter	0

Table 10.
Frequency of Yoked-Yoked group's questionaire responses to multiple choice questions.

Did you feel you were able to try as many mental movement strategies as you wanted?	
Yes	8
No	2
Do you think you received feedback after the right trials?	
Yes	2
No	7
If the answer was "No," when would you have preferred to receive feedback?	
After good trials	3
After bad trials	0
Equally	6
Randomly	0
Doesn't matter	0
Was there a point in practice where you wish you could have practiced a task more but was unable because the schedule told you to do another task?	
Yes	4
No	6
If the answer was yes, when would you have preffered to start practicing another task?	
After good trials	3
After bad trials	1
Equally	0
Randomly	0
Doesn't matter	0

Table 11.
Summary of across measures data for the top three and bottom three participants in the Self-Self group. Participants within the group were ranked on their total error (E) during retention relative to the other participants (n=10) in the Self-Self group. This placement was then compared to other measures to identify commonalities within the top three Self-Self regulators as well as the bottom three Self-Self regulators.

Rank out of 10			# Task	Notable Questionnaire Answers
Ret E	Acq E	Trans E	Switches	
1	2	4	9	Requested FB after good trials. Switched tasks when perceivable improvements ceased. Sometimes requested FB to help make task switch decision.
2	3	1	15	FB request decisions not based on performance. Requested FB on odd numbered trials. Prefered block practice for its orderliness.
3	1	7	3	Requested FB after good trials.
8	10	5	9	Requested FB after bad trials. Thought repetition gave better results. Requested FB at beginning of block to learn target MT Praticed without FB during 2nd half of block
9	6	2	5	Requested FB mostly at the beginning of a block to learn a "model"
10	7	9	3	Requested FB at the start of practicing a certain sequence to learn good strategies

Figure 1.
Sequential lay out of screens for the Self-Self group. a) Screen presented at the beginning of each trial after the sequence had been chosen. b) Screen presented while participants performed the trial. c) FB prompt screen. Groups who did not self-control FB saw a variant of this screen that informed them either: you will receive FB or you will not receive FB. d) FB screen only given on requested/assigned trials. E) Summary screen indicating the number of trials that remained for each sequence. Participants who did not self-control TO were not presented with the option of choose a sequence

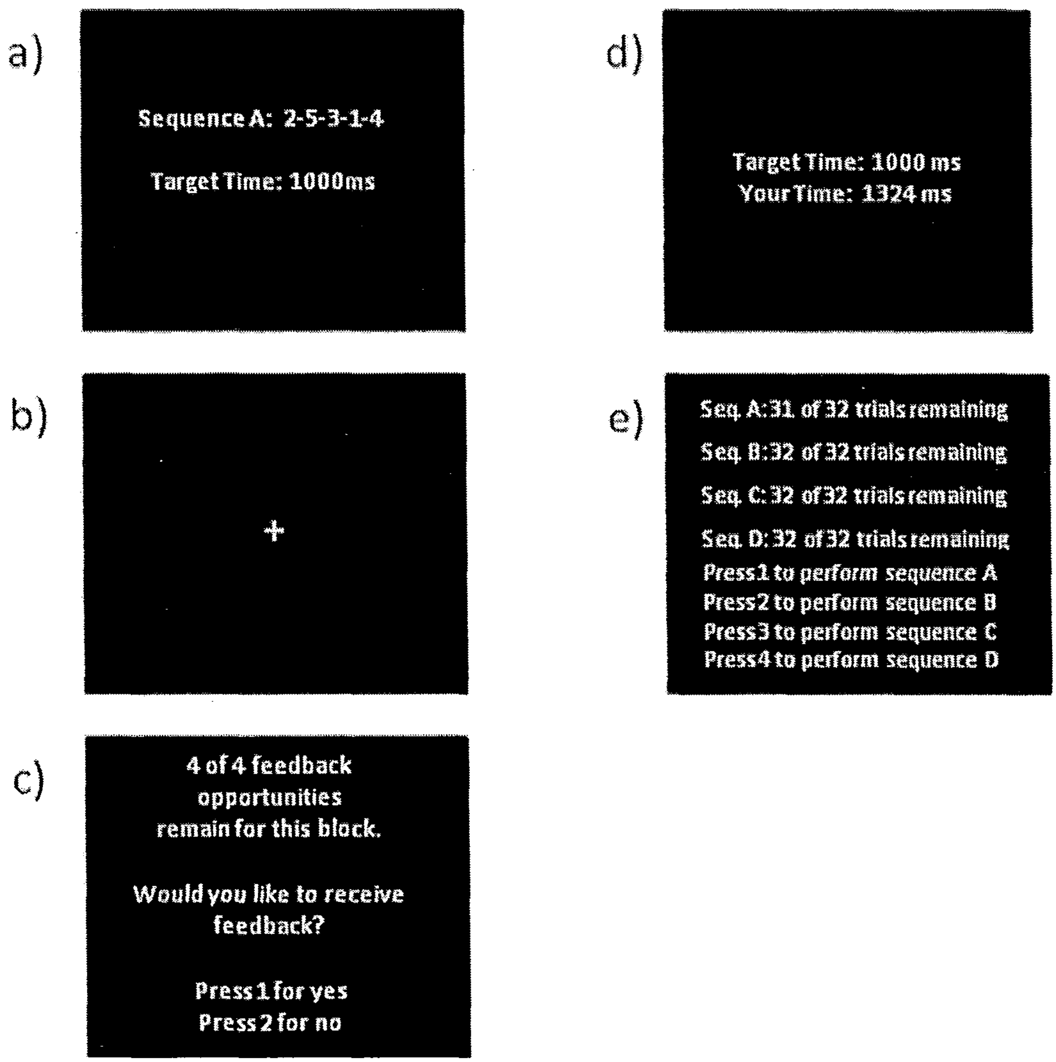


Figure 2.
AE plot of means for trial n-1 (trial preceding the feedback request trial), trial n (feedback request trial), and trial n-1 (trial following feedback request trial) for self-regulated and yoked feedback conditions. Significant differences between trial n-1 and n+1 as well as n and n+1 for the self-regulated feedback group.

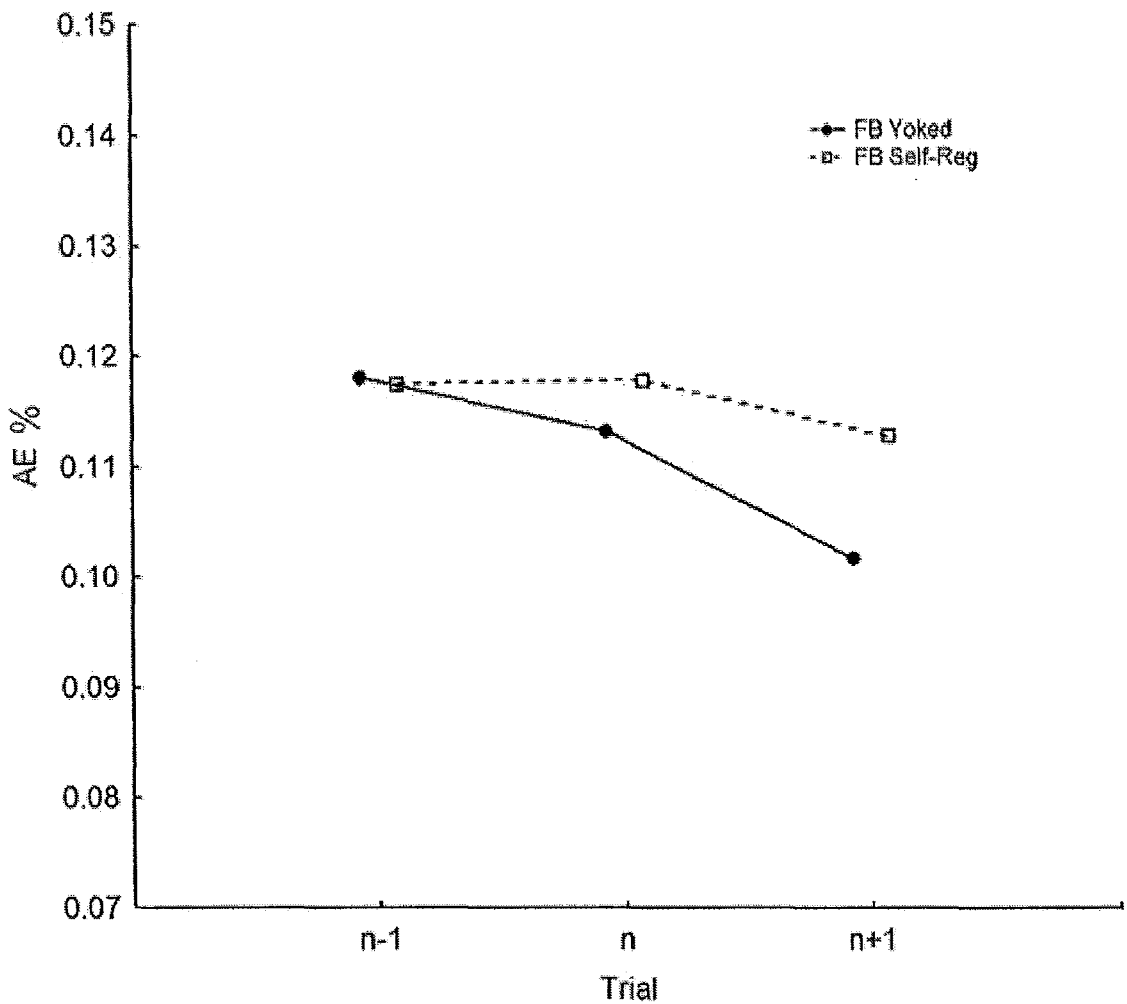


Figure 3.
MT plot of means for self-regulated and yoked feedback conditions across block.
Significant differences between feedback groups at blocks 3 & 4.

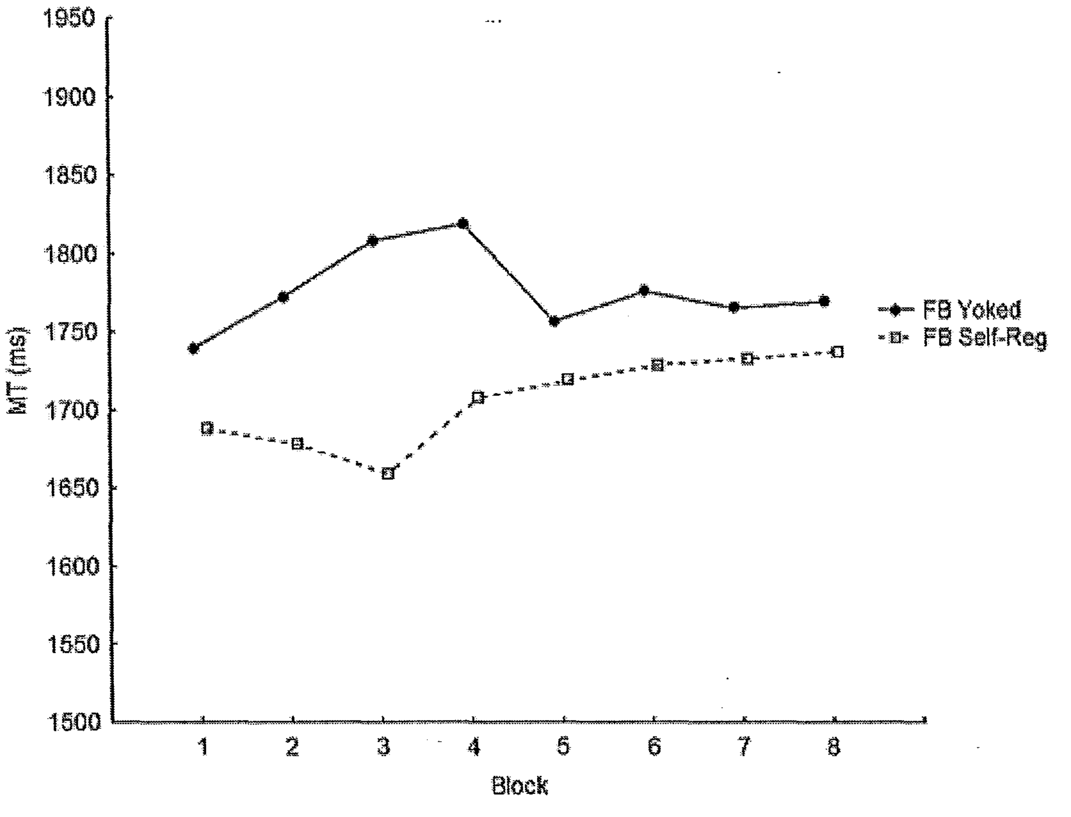


Figure 4.
Mean Proportional |CE| for each sequence during acquisition. Significance difference between 1000 ms and 1500ms, 2000ms, and 2500ms.

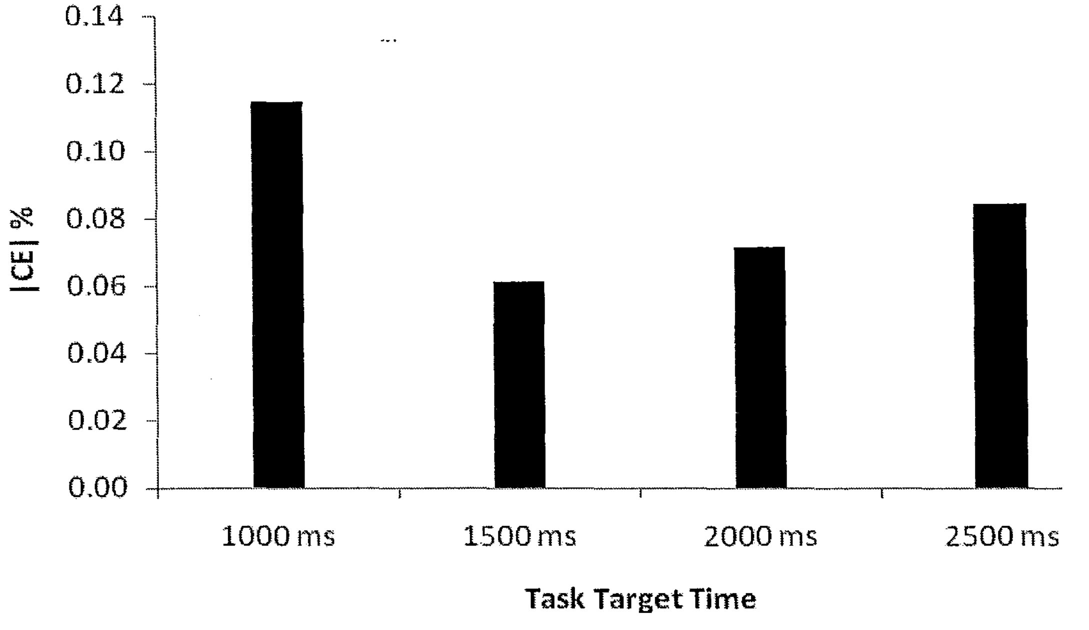


Figure 5.
Mean |CE| in acquisition for self-regulated and yoked feedback conditions as a function of block. Significant differences between conditions at blocks 2 and 3.

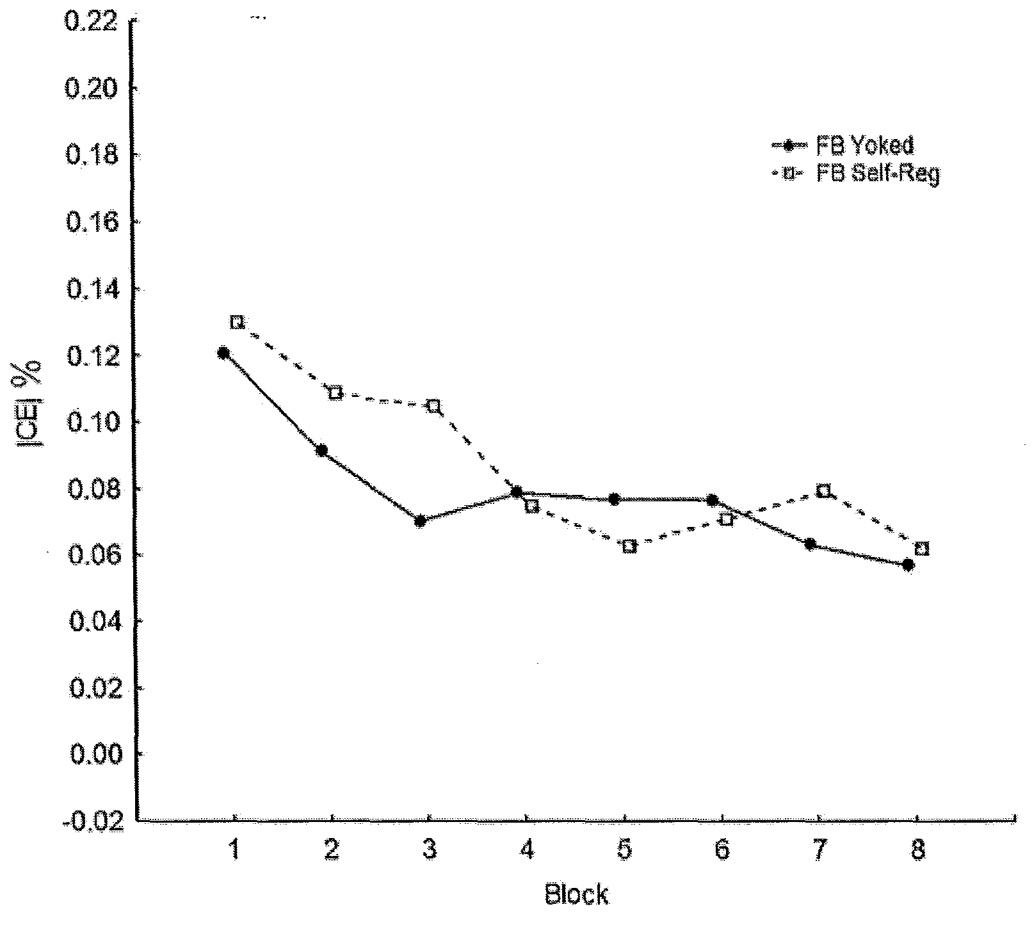


Figure 6.
Overall summary graph of |CE| in acquisition and retention for all groups as a function of block.

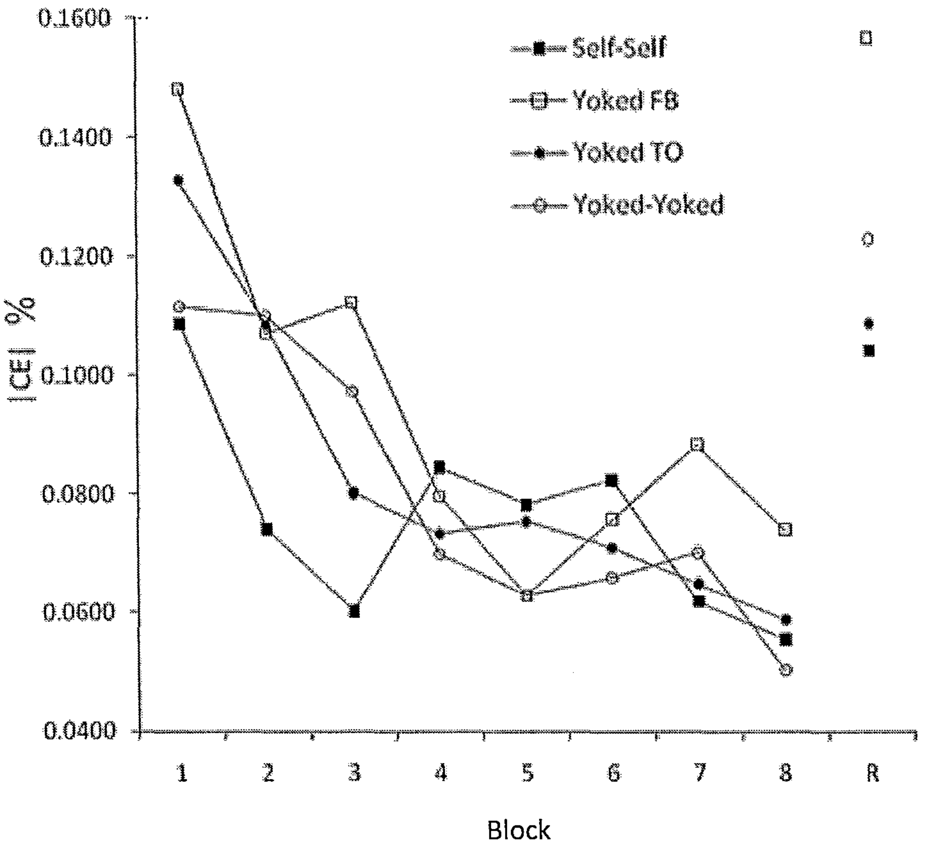


Figure 7.
Overall summary graph of VE in acquisition and retention for all groups as a function of block.

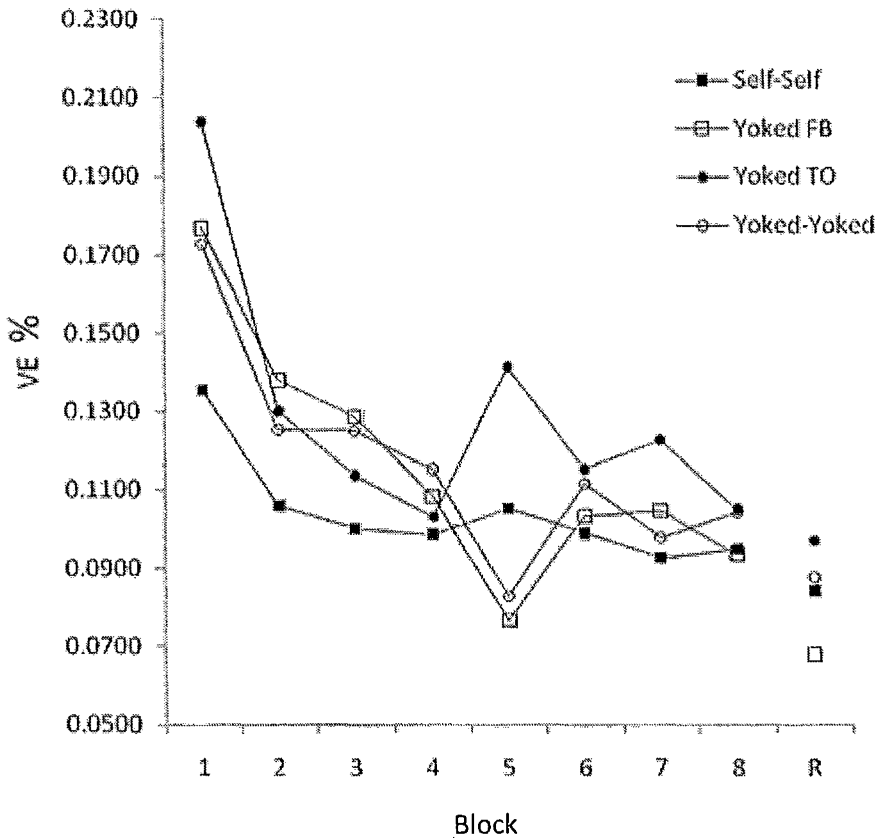
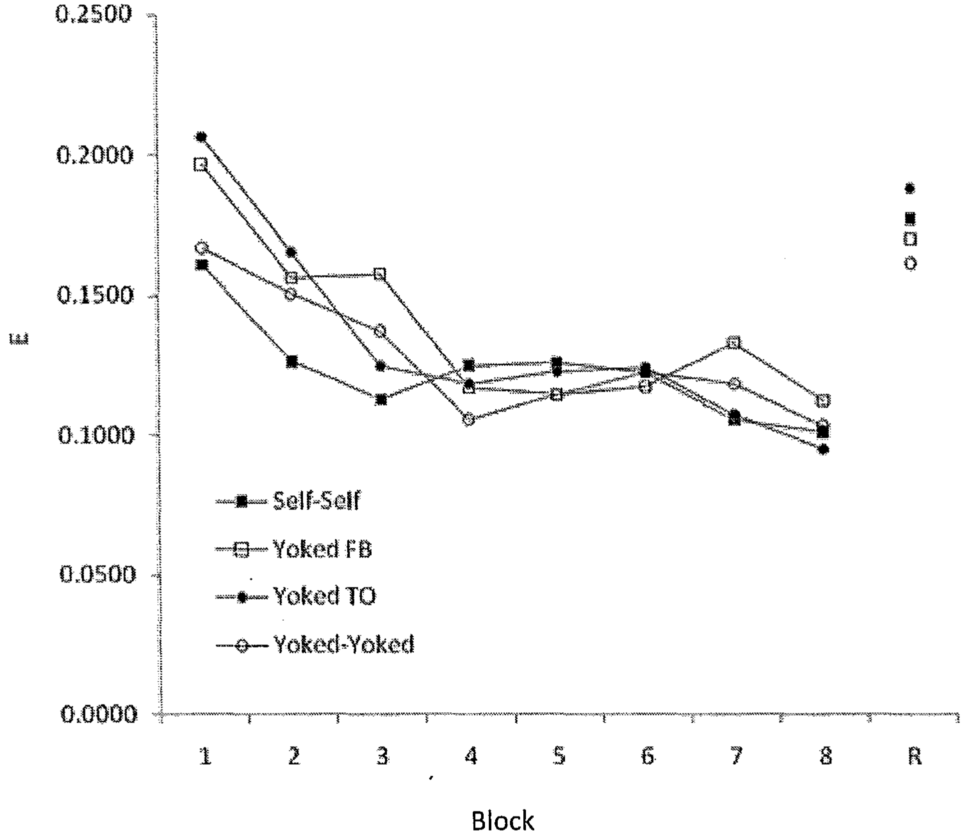


Figure 8.
Overall summary graph of E in acquisition and retention for all groups as a function of block.



APPENDIX

Declarative recall test.

Please write out the four sequences and their target times:

Target Time: ________

Target Time: ________

Target Time: ________

Target Time: ________

Questionnaire for Self/Self Group

Did you feel you were able to try as many mental movement strategies as you wanted?

______ Yes

______ No

When did you ask for feedback?

______ Mostly after you thought you had a good trial

______ Mostly after you thought you had a bad trial

______ After good or bad trials equally

______ Randomly

______ None of the above

When did you choose to practice a different task?

______ Mostly after you thought you had a good trial

______ Mostly after you thought you had a bad trial

______ After good or bad trials equally

______ Randomly

______ None of the above

When practicing, why did you stop practicing one task and start practicing another? Briefly explain.

When practicing, why did you request feedback on the trials that you did? Briefly explain.

Questionnaire for Self/Self Group Cont'd

Did you request feedback because you were considering selection of a different task on the following trial?

______ Yes

______ No

______ Sometimes

Did the displayed results after feedback requests influence your subsequent task selection?

______ Yes

______ No

______ Sometimes

Questionnaire for Yoked/Yoked Group

Did you feel you were able to try as many mental movement strategies as you wanted?

______ Yes

______ No

Do you think you received feedback after the right trials?

______ Yes

______ No

If the answer was "No," when would you have preferred to receive feedback:

______ After good trials

______ After bad trials

______ Equally

______ Randomly

______ Doesn't matter

Was there a point in practice where you wish you could have practiced a task more but was unable because the schedule told you to do another task?

______ Yes

______ No

If the answer was yes, when would you have preferred to start practicing another task?

______ After good trials

______ After bad trials

______ Equally

______ Randomly

______ Doesn't matter

Questionnaire for Self-FB/Yoked-Order Group

Did you feel you were able to try as many mental movement strategies as you wanted?

______ Yes

______ No

When did you ask for feedback?

______ Mostly after you thought you had a good trial

______ Mostly after you thought you had a bad trial

______ After good or bad trials equally

______ Randomly

______ None of the above

Was there a point in practice where you wish you could have practiced a task more but was unable because the schedule told you to do another task?

______ Yes

______ No

If the answer was yes, when would you have preferred to start practicing another task?

______ After good trials

______ After bad trials

______ Equally

______ Randomly

______ Doesn't matter

When practicing, why did you request feedback on the trials that you did? Briefly explain.

Questionnaire for Yoked-FB/Self-Order Group

Did you feel you were able to try as many mental movement strategies as you wanted?

______ Yes

______ No

Do you think you received feedback after the right trials?

______ Yes

______ No

If the answer was "No," when would you have preferred to receive feedback:

______ After good trials

______ After bad trials

______ Equally

______ Randomly

______ Doesn't matter

When did you choose to practice a different task?

______ Mostly after you thought you had a good trial

______ Mostly after you thought you had a bad trial

______ After good or bad trials equally

______ Randomly

______ None of the above

When practicing, why did you stop practicing one task and start practicing another? Briefly explain.

Did the provided feedback influence your subsequent task selection?

______ Yes

______ No

______ Sometimes