THE ROLE OF MINIMIZATION AND FACILITATION OF LEARNER INVOLVEMENT DURING ACQUISITION IN THE LEARNING OF A MOTOR TASK

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Abstract

When learning a new motor skill, how we choose to go about the learning process can influence how quickly and how well we learn the task. In particular, the role of learner involvement during the acquisition period can be manipulated through how practice is scheduled. Two separate sets of literature (progression of task difficulty and self-controlled practice) which discuss learner involvement during acquisition were reviewed. The motivation behind this thesis is to examine the effects of progressive and self-controlled practice on measures of retention, transfer and dual-task performance as well as to attempt to determine the underlying factors responsible for any benefits of each of these schedules. We examined the influence of practice scheduling during acquisition of a fine-motor skill within the context of the minimization and facilitation of learner involvement through a series of four experiments and one review paper.

The findings of the four experiments suggest that an easy-to difficult progression through versions of a task, whether prescribed or chosen, does not always induce implicit learning processes and is also not always beneficial to performance under a secondary task load. The only manipulation that was found to have an effect on dual-task performance was, not the minimization of learner involvement but the proximity of the version of the task first practiced in acquisition to the tested version of the task. Participants that began practice using versions of the task most similar to the test version performed a novel task well under dual-task conditions and maintained this performance over time.

The overall difficulty of versions of a task practiced in acquisition appears to have an influence on participants' ability to perform well on immediate transfer tests and to maintain that performance on delayed transfer tests. These results suggest that learner involvement can be beneficial to performance on transfer tests.

The possible benefit of cognitive involvement for learning of motor tasks found in the studies that examined the progression of task difficulty is consistent with one of the main explanations of the benefits of self-controlled learning summarized in the review paper. Interesting motivational implications found in study four, where motivational factors may have overridden the cognitive effort involved are also consistent with the findings summarized in the review paper from the perspective of the self-determination theory.

The results and information presented in this thesis present implications for anyone responsible for organizing a practice of motor skills. The most beneficial organization of versions of a practiced task is dependent upon the goals of the testing context.

Preface

This body of doctoral work has been prepared as a sandwich thesis. The thesis includes four experiments organized into two separate manuscripts. A theoretical interpretation of motor learning, self-controlled, practice contexts through the tenets of the self-determination theory (Deci and Ryan, 2000) is also presented as a review paper. The three manuscripts contained in this thesis present original work by the author except for the contributions of the thesis supervisor, Dr. Tim Lee, and the specified contributions of co-authors. Dr. Jae Patterson and Dr. Tim Lee contributed the editing of the paper presented in chapter four. Dr. Steve Bray contributed to the general conceptual layout of the paper and played an advisorial role on the presentation and revisions of the introductory and discussion sections pertaining to the self–determination theory perspective. Jim Burkitt assisted with data processing for the data presented in chapters two and three. As primary author I was involved in every aspect of the research including the study design, data collection and analysis and the writing of the papers. Each of the three manuscripts is presented as a separate chapter within the thesis.

The first chapter in this thesis provides background information about the classification of motor skills, models of motor learning processes and brief discussions of several motor learning and related theories and frameworks. Chapter one also presents the overall research question upon which the thesis work is based and articulates specific objectives to be addressed.

Chapters two through four contain an author-generated version of the appropriate manuscript. The figures and tables throughout the thesis document are labeled first according to chapter and second with the figure number for the given manuscript.

The last chapter contains a discussion of the work presented in chapters two through four within the context of the objectives presented in chapter one. The results will also be discussed in terms of the theories and frameworks presented in chapter one. References for each chapter are included at the end of the respective chapter in APA 5th edition format.

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List of Abbreviations

2D	two-dimensional
3D RE	three dimensional radial error
3D	three-dimensional
A	acquisition
AE	absolute error
ANOVA	analysis of variance
BVE	bivariate radial error
CE	constant error
(CE)	centroid error
|CE|	absolute constant error
CL	The procedural checklist
cm	centimeter
D	delayed
DR	delayed retention
DT	delayed transfer
E	total variability
e.g.	for example
F	Fishers statistic
FB	feedback
GRS	Global Rating Scale
I	immediate
IPPI	Integrated Procedural Performance Instrument
IPT	immediate post test
IR	immediate retention
IRED	infrared emitting diode
IT	immediate transfer
KP	knowledge of performance
KR	knowledge of results
LC	learner controlled
M	mean
MRE	mean radial error
MT	movement time
n	sample size
NM	never model
PT	post test
RE	radial error
RTE	relative timing error
SD	standard deviation
SDT	Self-determination Theory
SRE	subject-centroid radial error

T	target
Tukey's HSD	Tukey's honestly significant difference
VE	variable error
X^2	Mauchly's Statistic
ε	Greenhouse-Geisser correction

Chapter 1: General Introduction

Chapter 1: General Introduction

Motivation for Thesis

In day-to-day life we encounter the opportunity to learn new motor skills. How we choose to go about this learning process can influence how quickly and how well we learn the task. Our goals for learning a task may also differ depending upon the context in which we would like to best perform. For a specialized, closed skill such as throwing a bull’s-eye in a game of darts, consistency in performing the exact same task over and over might be the main goal of learning. However, in a wrestling match, where an opponent, the timing, and the positioning on the mat can be unpredictable, the ability to adapt to ever-changing conditions may take precedence. In the case of operating a helicopter, the ability to perform well at many aspects of the task concurrently is of utmost importance. Many researchers have examined the organization of practice schedules in order to determine the most appropriate schedule to facilitate one or more of 1) retention of a practiced task, 2) the ability to transfer learned skills to a novel version of the practiced task or 3) the ability to perform the task under dual-task or stressful conditions. As we can see from the examples discussed earlier, each of these measures of learning plays an important role in our understanding of how people learn a variety of motor tasks. Effective means of facilitating transfer of motor skills, such as providing control over the scheduling of practice to the learner (e.g., Wu & Magill, 2011) have been discussed using both cognitive and motivational factors as an explanation for their success. Effective means of facilitating performance of a motor skill while engaging in a secondary task such as a progressive or errorless practice schedule (e.g., Maxwell, Masters, Kerr &

Weedon, 2001) have also been discussed in terms of cognitive and motivational factors as possible reasons for success. The theoretical backgrounds which support these very different approaches to the scheduling of practice seem to contradict each other and raise questions as to which may be most appropriate for learning. The motivation behind this thesis is to examine the effects of progressive and self-controlled practice on all three of these measures as well as to attempt to determine the underlying factors responsible for the benefits of each.

Performance and Learning of Motor Skills.

Motor skills.

The examination of motor learning is rooted in attempts to understand the effects of experience and practice on the acquisition of motor skills (Schmidt & Lee, 2011 p.327). Gallahue, Ozmun and Goodway (2012) define motor skills as the processes that are involved in the execution using one or more body parts, of a voluntary, goal-oriented action or task that has been learned (p.14). Motor skills, whether executing a complicated dance move, performing lengths of back stroke in the pool or suturing a wound in the ER, can be classified in several ways. One important classification is the distinction between *open* and *closed* motor skills. Closed motor skills take place in an environment that is predictable, where it is possible for performers to plan actions ahead of time. For example, when ten-pin bowling, a bowler can reasonably expect that he or she can plan the bowling movement and execute it without needing to adapt the movement in the middle of execution. This is true because the location of the pins, the distance and width of lane, and the equipment used remain constant and are not expected to change.

Successful performances of closed skills require performances that are stable and consistent, but adaptability is less important than for an open motor skill (Schmidt & Lee, 2011 p.24). Open motor skills take place in a changing environment, often with unpredictable elements. For example, the actions of an opponent, the weather, or terrain may be unpredictable in a beach volleyball game. Adaptability is important for successful performances of open skills (Schmidt & Lee, 2011 p.23). Each motor skill to be learned or performed will fall somewhere along a continuum from an open to a closed skill classification. While catching the Frisbee in a game of ultimate Frisbee is an open skill and typing your name at the end of an e-mail is a closed skill, carrying a mug of coffee to a friend would most likely fall somewhere in the middle. Carrying a mug of coffee involves both predictable aspects such as the route to take and the amount of coffee as well as unpredictable elements such as manoeuvring around obstacles. The open verses closed motor skill distinction is based upon the environment or conditions within which the skill is executed. Another factor that can be used to distinguish types of motor skills is the extent or size of the movement and the muscles used to perform the skill. Motor skills that require the use of many large muscles and produce large movements such as jumping and running are classified as gross motor skills. Motor skills that require the use of small muscles and produce precise movements such as typing or sewing are classified as fine motor skills (Gallahue, Ozmun and Goodway, 2012, p. 16). Another way to classify motor skills is on a continuum in terms of the temporal aspects of the task. Discrete skills have a definite beginning and end defined by the skill itself (Schmidt & Lee, 2011 p.21). An example of a discrete skill is pitching a baseball. Serial skills string a number of discrete skills together into a whole task (Schmidt & Lee, 2011 p.22). An example of a serial task would be a dance routine that includes several discrete steps, leaps and movements, where the flow between them and the timing are important parts of the whole. A continuous task does not have a recognizable beginning or end and thus the end occurs arbitrarily (Schmidt & Lee, 2011 p.22). An example of a continuous task is the back stroke in swimming where the end of the task depends on the length of the race, or how much time you have to exercise.

One and two-dimensional models for movement classification, which take into account the functional aspects of a movement (stability, locomotor, or manipulative), have been developed by Gallahue (2012) and Gentile (2000) in motor development and rehabilitation contexts respectively. These models are particularly useful for the classification of movements in rehabilitation and teaching settings, for example, but are not often referred to when skills are classified in the research involving the organization of practice schedules in a laboratory setting.

Performance and learning.

Motor *performance* is defined as the act of performing a movement skill where the movement can be directly observed and the outcome can be measured in some way (Gallahue, Ozmun and Goodway, 2012, p. 15). In contrast, motor *learning* is defined as a set of processes resulting in a relatively permanent change in performance of a skilled movement due to practice or experience (Schmidt & Lee, 2011 p.327). Several important distinctions between motor performance and motor learning can be highlighted. While motor performance is directly observable and can be measured, motor learning is a set of internal processes which cannot be directly observed. In order to discuss motor learning, inferences about these internal processes must be made through observations of motor performance under specific conditions. In particular, motor learning can be inferred from a relatively permanent change in motor performance which can be measured using experimental designs that include tests of retention and transfer.

In a typical motor learning experiment, measures of performance as well as tests for learning are reported. However, scores on one of these is not always indicative of the scores on the other. For example, a classic study by Shea and Morgan (1979) found that the participants who followed an easier schedule (blocked) performed significantly faster in practice than those who followed a more difficult schedule (random). However, the results were reversed on immediate and delayed retention tests, with participants that followed the more difficult schedule performing faster.

Keeping this distinction in mind, motor learning studies usually discuss experiments in two different phases; 1) the acquisition phase, where differences in *performance* due to experimental manipulations are measured and 2) the testing phase where *learning* can be inferred through *relatively permanent changes in performance*. Because the testing phase occurs after some time of non-practice (often 24 hours), changes in performance can be considered relatively permanent and not due directly to the condition in which the participant was performing the task.

In this thesis measures of performance in acquisition as well as measures of learning through retention and transfer will be reported. A retention test measures performance on a task that was used in acquisition after a period of non-practice. A transfer test measures performance on a novel version of the task after a period of non practice. Each of these tests can tell us about a different aspect of learning. A retention test allows us to comment on how well performance of a task is maintained over some time of non-practice and is typically what is referred to as learning. A transfer test allows us to comment on how well rules, strategies and motor components for performance, developed during practice, influence performance of a new task.

Stages of learning.

Many changes must be undergone in order to bring a learner from a novice to a skilled performer in the process of learning a new motor skill. Several researchers have described a series of stages through which a learner progresses in the acquisition of a motor skill. Fitts and Posner (1967) described, by using a computer analogy, three stages that the learner passes through while learning a motor skill. They described an executive program which provides a decision framework which allows for adaptability within the overall system. Small subroutines, which can be very automatic, consisting of sets of instructions or operations, can be recruited into play by the executive program in any number of combinations or configurations. Likewise, Fitts and Posner (1967) described the learning of human movements in terms of fixed sequences of actions that can be called into play in numerous orders and configurations to perform activities.

Fitts and Posner (1967) described the early, cognitive stage as a start to the development of a decision framework or an executive program, allowing for the ability of the system to adapt to new situations. In this stage, previously learned subunits of movement are gathered together in order to be integrated and ordered into a new overall movement. In this stage instructions and demonstrations play a large role in the problem-solving processes needed in order to organize and add to the subunits (Fitts & Posner, 1967).

In the second, associative stage of motor learning described by Fitts and Posner (1967) the learner has already figured out what subunits of movement are required for the task and improvements are now based upon how the task is performed. In this stage, errors gradually decrease over time, with the total time spent in this stage dependent upon task complexity (Fitts & Posner, 1967).

In the final, autonomous stage described by Fitts and Posner (1967), movements become more automatic. Movements are also less influenced by cognitive control and less affected by external factors such as the environment or other concurrent tasks.

Anderson (1982) used Fitts and Posner's (1967) three-stage model of learning as a point of reference when describing his theory of skill acquisition. The first stage of Anderson's theory is the declarative stage, in which the learner encodes instructions and information as a set of information points about the skill (Anderson, 1982). These information points are then used to generate behaviour through interpretive procedures (Anderson, 1982). This stage is similar to Fitts and Posner's (1967) cognitive stage.

The second stage of Anderson's theory, similar to Fitts and Posner's (1967) autonomous stage is the procedural stage. In the procedural stage knowledge is fine-tuned in order to apply more appropriately to the task.

Rather than a third stage in between the declarative and procedural stages, Anderson (1982) describes the transitional process where declarative knowledge is converted to procedural knowledge as knowledge compilation. Anderson (1982) states that the time over which knowledge compilation takes place is similar to Fitts and Posner's (1967) associative stage.

Gentile (1972) developed a two-stage model for the acquisition of skills with a particular emphasis on the application to teaching. Gentile's two stages are the "getting the idea of the movement" stage and the "fixation/ diversification" stage. Gentile's (1972) initial stages of learning have a goal of organizing a motor pattern to solve a problem arising from an interaction with the environment. This goal was borrowed from Bernstein (1967 as cited by Gentile, 1972). Gentile (1972) describes the problem as being clear to the learner whereas the plan of action needed to accomplish the goal is the aspect to be learned. This initial stage of learning is proposed by Gentile (1972) to be similar for open and closed skills. The organization of motor components is accompanied by the need to identify and process environmental conditions that play a part in the execution of movement.

After a number of attempts where the movement has been executed as planned and the goal has been accomplished, the learner enters into the second stage of learning. Gentile (1972) explained that the number of these successful attempts required before a shift from the first to the second stage of learning is dependent upon personality characteristics and the general experience of acquiring motor skills of the learner. The fixation/ diversification stage takes the seemingly effective motor pattern developed in the getting the idea of the movement stage and attempts to refine characteristics and increase consistency. Whether the pattern is refined or noticeably altered is dependent upon the environmental control under which the skill is performed (Gentile, 1972). This is where the fixation/ diversification distinction comes into play. Fixation refers to the variability of movements becoming more restricted, honing in on the most effective movements for a relatively fixed set of performance conditions for a closed skill. Diversification refers to the development of a repertoire of motor patterns for each temporal and spatial organization of movement dictated by changing conditions for an open skill. The likelihood of each of the options in the repertoire occurring must also be determined and included. For closed skills, fixation of the same or a similar pattern as in the first stage of learning takes place. For open skills, diversification of the skill from the first stage is undergone during the second stage of learning.

Adams (1971) also described a two-stage model of motor skill acquisition with the verbal-motor stage at the beginning of learning followed by the motor stage. In the verbal-motor stage, knowledge of the results of a movement is used to adjust the next attempt. Adams (1971) also described verbal aspects of the learning process, such as saying out loud what will be changed on the next attempt, as playing a large role in this stage. By this view, a learner moves on to the motor stage once the error has been acceptably minimal for a long time, and the knowledge of the results of the movement is no longer important. Adams (1971) explains that this is in agreement with the concept of conscious behaviour becoming automatic (James, 1890).

Snoddy (1926) was perhaps the first to describe motor learning as a two-stage process and described the early portion of learning, which he termed adaptation, as the growth of a new pattern and the latter portion, termed facilitation, as the extending of the pattern developed in the adaptation stage. Snoddy (1926) also stated that the adaptation stage was influenced by additional factors beyond repetition where as the facilitation stage was not affected by these additional factors. These concepts remain a part of later two-stage models such as Adams (1971). Gallahue developed a model that not only takes into account the internal processes of the learner, but also to role of the environment and teachers (Gallahue et al., 2012, p. 319). Gallahue's (2012) model (p. 320) describes three levels of learning (Beginning/ Novice level, Intermediate/ Practice level and Advanced/ Fine-tuning level) as well seven stages of learning (awareness, exploratory, discovery, combination, application, performance and individualized). For each of these levels and stages Gallahue (2012) describes the cognitive state of the learner, the goals of the learner and the role of the instructor.

Regardless of the differences in number of stages and what they are called, there are some key commonalities amongst these concepts and theories that are important to discussions in this thesis. The first of these is that learning involves a hierarchy of habits which was first described by Bryan and Harter (1899) in a study of telegraphic language. Bryan and Harter (1899) explained that higher-order habits are made up of a number of lower-order habits as they are learned, and that proficiency involves the mastery of these habits in a hierarchical way. This concept of hierarchical organization of skills was further elaborated upon by Fitts and Posner (1967) who stated that the hierarchical organization of skills implies: 1) that movements can be grouped into categories and 2) that a restrictive order or relationship amongst the categories can be specified. It was upon this basic concept that the discussion of stages of learning has been based.

Another important common characteristic amongst the stages of learning models and theories discussed is that learners start off requiring a relatively large amount of cognition in comparison to later stages of learning. Also important is that early stages of learning require the development of general rules or strategies. Both the amount of cognition needed and verbal rules at the forefront of the learners' minds decrease as the process of learning progresses in each of the models and theories.

Theories and frameworks of motor learning.

Reviews describing motor learning research from 1945-1959 (Bilodeau & Bilodeau, 1960) and 1960-1963 (Adams, 1964) describe series of experiments in the domains of human-factors engineering, skills learning, general experimental psychology and basic research. While these reviews provide a collection of examinations of motor learning for a number of tasks and the effects of a number of independent variables on learning, the measures used were quite global in nature (Schmidt, 1976, p. 41). Many of these experiments examined aspects of Hull's (1943) learning theory, which was considered to be global in nature (Schmidt, 1975). Measures in this body of work were focused on overall learning and performance of motor tasks and did not focus on changes that took place within individuals in order for learning to take place (Schmidt, 1975).

This focus changed after 1960 with the influence of the information processing approach, which posited specific intermediary processes between perception and action. An important change was also due to the emergence detailed theories of motor performance and learning, which provided many testable hypotheses and constructs. The most influential of these was Adams' (1971) closed-loop theory of motor learning.

Adams' closed-loop theory of motor learning.

Adams (1971) identified three key elements for a closed-loop system; feedback, error detection and error correction. Adams (1971) discussed feedback in terms of knowledge of results (KR), which he described as a type of reinforcement for movement. He described KR as the most important source of information for making corrections which lead to the correct response. Adams (1971) stated that learners will use the KR to solve the movement problem at hand by forming strategies and hypotheses, which can be modulated by the precision and type of KR that is provided to the learner. Adams (1971) also explained that KR is the starting point for covertly-guided motor behaviour through verbal responses, such as self-talk to correct movement on the next trial.

The element of KR is important for the first of two traces that form Adams' (1971) closed-loop theory of motor learning. The perceptual trace provides reference about past movements and moment to moment guidance during movement. The moment by moment guidance is achieved through immediate feedback about the current position of the limb in comparison to memory of past movement (termed the perceptual trace). This comparison uses the perceptual trace as a reference to adjust the next movement in order to make it more correct. The strength of the perceptual trace increases with experience with the task and with feedback. Feedback can be in the form of proprioceptive, tactile, pressure, visual or auditory information.

In the verbal-motor stage, at the start of a movement, there is an anticipatory arousal of the perceptual trace and learners can recognize it as a previously made response. However, learners need to use the perceptual trace in relation to the KR that is being provided in order to make adjustments.

In the motor stage, where the perceptual trace is very strong, due to practice (with KR), the movement attempt is compared to the perceptual trace in order to assess error. If there is no difference between the perceptual trace and the ongoing movement, then the learner knows that no error has been made. In this stage, there is no longer a reliance on KR.

Adams (1971) stated three reasons why a second trace, termed the memory trace, was essential to his theory. The first of these reasons is that a second trace must initiate the original movement in order to provide an independent mechanism for the detection of errors. Adams (1971) explained that if a single trace is responsible for the initiation and the checking of a response, then a signal, checked against itself will always be considered to be correct. The second reason is that the perceptual trace is closely tied with the use of feedback, which can only be provided once the movement has started. Therefore another (open-loop) mechanism for the initiation of movement is required. The final reason provided by Adams (1971) is that while the perceptual trace deals with the recognition of movement (e.g., knowing if the movement is proceeding correctly), the recall of movement must also be dealt with. Adams (1971) explains that recall and recognition are based on separate memory states in the verbal learning literature (Adams & Bray, 1970; Kintsch, 1970, as cited by Adams, 1971).

With these reasons in mind, the purpose of the memory trace is to select and initiate the response prior to the engagement of the perceptual trace. The strength of the memory trace is increased through practice trials and is a function of the proximity of the stimulus and response (Adams 1971).

Schmidt's schema theory of learning for discrete motor skills.

In Schmidt's (1975) paper, which described a schema theory of learning for discrete motor skills, a number of strengths and criticisms of Adams' (1971) theory were discussed. Some aspects of Adams' (1971) theory are retained in one form or another in Schmidt's (1975) theory; however Schmidt also addressed a number of the shortcomings identified. One major shortcoming is that while Adams' (1971) theory provided a basis for the discussion of retention of a motor task, it did not provide a framework for the discussion of transfer to a novel task. In fact, the theory does not account for novel movement production at all. Other challenges to Adams' (1971) theory include the application to a very narrow class of movements (slow, positioning movements), the inability to create a perceptual trace without reaching the correct location, and the degradation of the perceptual trace with each trial without KR, weakening the argument that Adams' (1971) closed-loop theory can account for learning without KR. Adams' (1971) closed loop theory also presents a challenge to the central nervous system in terms of storing an infinite number stored states (Schmidt, 1975).

Schmidt's (1975) schema theory of discrete motor learning borrowed a number of ideas from previous work and identified these ideas at the outset. The ideas of a schema and a motor program were borrowed from Bartlett (1932) and Lashley (1917) respectively (as cited by Schmidt, 1975). The applications of the concepts of a closed-loop theory and a schema to motor skills were attributed to Adams (1971) and Pew (1974) respectively (as cited by Schmidt 1975).

Important to Schmidt's (1975) theory is the concept of a generalized motor program, which deals with the storage issue identified earlier. A generalized motor program exists for a certain class of movements and presents pre-structured commands in the presence of specific details (Schmidt, 1975). Movement parameters, such as force or time can be varied prior to movement initiation. The opinion as to what constitutes a class of movement differs, but in general refers to a group of movements that share common invariant characteristics. An example of a class of movements might be an overhand throw general motor program that is inclusive of any overhand throw, regardless of the force direction or release angle (Schmidt, 1975).

The motor response schema relies on the storage of four bits of information (initial conditions, response specification for the motor program, sensory consequences of the response and the outcome) when a person makes a movement in an attempt to satisfy a specific goal. The state of the body (muscles) and environment, additional details above and beyond the general motor program (e.g., speed or force), an exact copy of the afferent information sent as well as KR and subjective reinforcement after the movement are stored after each movement (Schmidt, 1975). The schema is formed when a number of movements have been made and the relationships between these variables can begin to be abstracted into a schema. The strength of these relationships, and therefore the schema increases with the number of similar movements and the accuracy of the feedback received (Schmidt, 1975).

Schmidt (1975) described what happens, according to the theory, when a movement is produced. The first step is the specification of the desired outcome along with the initial conditions. This information, along with the knowledge of past relationships between response specifications and outcomes allow for the selection of response specifications for the present movement. This set of relationships is called the recall schema (Schmidt, 1975). Concurrently, the information about desired outcome and initial conditions along with the knowledge of past relationships between sensory consequences and outcomes allow for the selection of expected feedback for the present movement. This set of relationships is called the recognition schema (Schmidt, 1975). Following this, the movement can be initiated by running the now-parameterized motor program. During the movement the expected sensory consequences are compared with sensory feedback. If these do not match, an error is sent back to the schema as both raw information and as subjective reinforcement through the error labelling system. This process also occurs at the end of the movement using terminal information. Learning takes place as the schema is updated and can change the response specifications and expected sensory consequences estimates for subsequent trials (Schmidt, 1975).

These two theories have provided useful motor learning frameworks from which to formulate testable hypotheses about how motor skills are learned and the optimal organization of practice. These summaries also illustrate a transition in view from errors during practice being viewed as a way that the perceptual trace is degraded during learning (Adams, 1971) to being viewed as equally helpful as correct responses in the formation of a schema (Schmidt, 1975). While both theories address errors during acquisition, albeit in different ways, neither address practice conditions such as the scheduling of variable practice. The role of cognitive effort of the learner or task difficulty and its influence on learning is also not discussed in either framework. These aspects of practice organization can be examined within a more recent framework; the challenge point framework (Guadagnoli & Lee, 2004).

The challenge point framework (Guadagnoli & Lee, 2004).

The challenge point framework (Guadagnoli & Lee, 2004) focuses on two variables in the learning of motor skills; task difficulty and the skill level of the learner. Two types of task difficulty are identified by Guadagnoli and Lee (2004); nominal task difficulty and functional task difficulty. Nominal task difficulty refers to task difficulty within constraints of the task protocol and does not change based upon the conditions in which the skill is practiced, or with the person performing the task. Functional task difficulty refers to the challenge presented relative to the conditions in which the task is performed and the skill level of the learner (Guadagnoli & Lee, 2004).

Guadagnoli and Lee (2004) describe both an action plan and feedback (inherent and/or augmented) as essential to learning. They describe learning as a process of problem solving, in which the action goal serves as the problem to be solved and the movement itself as the attempt to solve it (Guadagnoli & Lee, 2004). Learning occurs when the problem-solving process becomes more efficient and assured. This framework provides room for errors to be useful in the problem-solving process.

One major premise of the challenge point framework is that when information is present, so is the potential to learn from it as information represents a challenge to the learner (Guadagnoli & Lee, 2004). With this in mind the challenge point framework states that successful learning occurs when the optimal amount of information is presented to the learner in relation to the functional difficulty of the task. No learning can occur if information (e.g., feedback) is absent and conversely too much information can also be detrimental to learning. In the case of too much information, though there may be a lot of information, much of it may not be interpretable by the learner (Guadagnoli & Lee, 2004). Information can only be transmitted to the learner when some sort of uncertainty is reduced (as is the case when feedback indicates the quality of the performance or the outcome of a movement). This information can be transmitted at the conscious or unconscious level (Guadagnoli & Lee, 2004). Through functional task difficulty, conditions of practice, such as practice scheduling can influence the amount of information available to the learner during acquisition of a task (Guadagnoli & Lee, 2004). An optimal challenge point (where the amount of information and thus task difficulty is optimal for learning) can change with practice and the expertise of the learner, and thus the optimal organization of practice in order to facilitate learning can also change.

Thus far, the three frameworks discussed have allowed for theory-based hypotheses to be made about how the practice context can influence the learning process of motor skills. Once a skill is learned to the point of automaticity under a certain practice context, Masters and Maxwell (2008) propose that the context that was employed during learning can later influence performance under secondary task conditions.

The theory of reinvestment (Masters and Maxwell, 2008).

While Adam's closed-loop theory (1971), Schmidt's schema theory (1975) and the challenge point framework (Guadagnoli & Lee, 2004) originate in the same line of research, the theory of reinvestment takes a different line of approach. Masters (1992) explains that while Adam's and Schmidt's models rely on the assumption that skill acquisition follows through a series of stages ending with an automatic stage (e.g., Fitts & Posner 1967), learning can occur without the accumulation of explicit, and easily verbalized knowledge early in practice. The challenge point framework (Guadagnoli & Lee, 2004) acknowledges implicit and explicit knowledge but in terms of learning benefit, does not distinguish between them.

The theory of reinvestment is reviewed extensively by Masters and Maxwell (2008); however this thesis will focus on the aspects most relevant to the acquisition of motor skills which have been reviewed in Masters and Maxwell (2004). The theory of reinvestment for motor learning is presented as an addition to the models of stages of learning presented by Fitts and Posner (1967) and Anderson (1983). The theory is based on two premises; 1) motor skills can be acquired without being dependent on working memory early in learning and 2) the efficient control of automatic movements can experience interference when working memory resources are recruited for explicitly learned motor skills (Masters & Maxwell, 2004).

Reinvestment is defined as a tendency to manipulate conscious, explicit, rule-based knowledge through working memory to control the mechanics of movement (Masters & Maxwell, 2004). Reinvestment can also be thought of in terms of moving from implicit processing to explicit processing (Masters & Maxwell, 2004). Explicit processes rely on working memory for the manipulation and storage of information. Working memory is also the source of verbal mediation and knowledge as well as the control of attention and is the overseer of cognition. When using explicit processing, learners are consciously aware of information and are able to share that information with others (Masters & Maxwell, 2004). Implicit processes cannot be subjected to conscious examination and implicit information is difficult to share with others (Masters & Maxwell, 2004).

Masters and Maxwell (2004) provide five criteria for implicit processes. The first criterion is the lack of verbal knowledge about the task collected by the learner. The second and third are a resistance to interference in the movement from stress and a characteristic of being less prone to forgetting over time. The fourth criterion is that the processes do not place a demand on working memory or attention. The final criterion is that the processes are age- and IQ-independent (Masters & Maxwell, 2004).

Masters and Maxwell (2004) add implicit and explicit processing to existing models of stages of motor learning by indicating; 1) during the unskilled, early, declarative stages of learning motor output results from explicit processes, and 2) during the highly skilled, autonomous stages of learning motor output results from implicit processes. Masters and Maxwell (2004) also state that the reinvestment of task-relevant information into movements (or the return to controlled processing) under predominately implicit processes results in a breakdown of performance. Another addition to the previous models of the stages of learning that Masters and Maxwell (2004) made was that the early processes of learning could occur implicitly as well as through the traditional explicit learning route.

The three theories and one framework discussed so far can be used to make predictions about changes in behaviour (e.g., performance on retention, transfer and dual-task tests) due to the organization of a practice context. The final theory discussed in this section comes from the psychology literature and can be used to make predictions about changes in behaviour and motivation.

The self-determination theory (Deci & Ryan, 2000).

The self-determination theory is a macro-theory made up of several micro-theories, three of which are discussed in chapter four. The basic psychological needs micro-theory predicts that supports for autonomy, competence and relatedness result in improved behavioural outcomes, such as learning as well as improved quality of motivation (Ryan and Deci, 2007, p. 7). The role of errors during acquisition can be examined within the context of supports for autonomy and competence. The occurrence of some errors during practice may be indicative of the provision of an optimal amount of challenge to the learner which in turn can be supportive of feelings of autonomy. However, errors may also limit the support of feelings of competence. The amount of cognitive effort may likewise influence support of autonomy through optimal challenge and feelings of competence based upon the difficulty of the task.

The cognitive evaluation micro-theory addresses the contextual elements that can lead to differentially motivated behaviour. Behaviour that is intrinsically motivated is undertaken out of interest or enjoyment without external or internal influence of consequences or threats (Deci, Ryan & Williams, 1996). Behaviour that is extrinsically motivated is undertaken in order to avoid guilt or punishment, obtain approval or a reward or to support personally held values (Deci, Ryan & Williams, 1996). The type of practice discussed in this thesis is almost always extrinsically motivated. The Organismic Integration micro-theory further divides extrinsic motivation into four subtypes of behavioural regulation which can be influenced by the practice context, for example through the satisfaction of psychological needs.

Each of the theories and frameworks discussed in this section provide unique points of view from which to form, test and interpret hypotheses about the role of the practice context during acquisition.

Learner Involvement in Acquisition

A definition.

In this thesis, learner involvement refers to the degree to which hypothesis or strategy formation and testing by the learner is facilitated by the organization of the practice schedule during acquisition. The minimization of learner involvement is examined in the context of "errorless" or progressive learning protocols, specifically designed to minimize hypothesis and strategy formation and testing by preventing errors, particularly at the beginning of acquisition. The facilitation of learner involvement is examined in the context of self-controlled practice schedules, where participants are provided control over how they choose to organize practice, allowing for strategy formation and testing.

Minimization of learner involvement.

The errorless learning protocol

The errorless learning protocol is one of a series of paradigms that have been designed to test predictions of reinvestment theory. The series also includes the use of a secondary task, removal or manipulation of outcome feedback and analogy learning (see Masters & Maxwell, 2004, for review).

The goal of an errorless learning protocol, such as the one used by Maxwell et al. (2001) is to minimize errors, especially at the start of practice. An errorless learning protocol consists of a progression through increasingly more difficult versions of a task. In Maxwell et al.'s (2001) study, participants learning a golf putting task began at a starting point quite close to the hole and after every fifty trials, moved 25 cm further away from the hole, gradually increasing the task difficulty as acquisition progressed. In reality, this type of practice is not truly errorless but does attempt to minimize the occurrence of errors (Poolton & Zachry, 2007). Maxwell et al. (2001) suggested that when no errors are present in acquisition, hypothesis creation and testing are unnecessary.

Practice under an errorless learning protocol has been shown to be advantageous to task performance under secondary task conditions when compared to a reverse (errorful) protocol or a protocol where the starting points were randomized for a golf putting task (Maxwell et al., 2001). No advantage was revealed for any of the three protocols for novel-distance transfer test.

In a more recent study, Poolton, Masters, and Maxwell (2005) found that errorless learning protocols had the greatest effect during early acquisition. They also found that if explicit instructions were later introduced, they did not decrease the benefit of early errorless learning.

The design of this errorless protocol was based upon a suggestion by Baddeley and Wilson (1994, as cited by Maxwell et al. 2001) that the identification and elimination of errors, which are examples of hypothesis and strategy formation and testing, are important factors in the process of explicit learning, whereas these processes cannot occur in implicit learning. Maxwell et al. (2001) hypothesized that implicit learning would occur as a default when an errorless learning protocol is used.

Implicit and explicit learning.

In this section several iterations of the stages of motor learning were discussed. One commonality amongst the various versions was that the early stages of learning involve a great deal of cognition, strategizing and hypothesis formation and testing in order to get the idea of the movement. In other words, the amount of learner involvement is highest at the start of practice and diminishes as learners progress through the stages of learning until it is virtually non-existent in the end stages. Explicit learning refers to learning where these early processes result in deliberate hypothesis formation and testing and the production a set of rules, which can be easily verbalized (Bright & Freedman, 1998). Attempts have been made to bypass the early, explicit stages of learning, because when explicit learning takes place, the rules and strategies developed in the earliest stages can come back to the learner under stressful or secondary task conditions interfering with the automaticity of the task. Masters (1992) explained that this reinvestment of rules or strategies into a process that has become automatic can lead to a failure of skill under pressure. Through implicit learning, however, the learner does not collect explicit knowledge about how to perform the skill, but rather task-relevant information that is difficult to verbalize (Masters, 1992; Maxwell et al., 2001). If a learner has undergone implicit learning processes, he or she will have less rules and strategies to reinvest at inappropriate times, such as under a secondary task condition.

Comparing and contrasting theoretical predictions.

Based upon Maxwell et al.'s (2001) description of an errorless learning protocol, Adams' (1971) theory would predict that a progressive protocol would be more beneficial to learning than the corresponding reverse protocol. According to Adams (1971) errors during acquisition would degrade the strength of the perceptual trace, leading to poorer learning outcomes.

One prediction that can be made using Schmidt's schema theory (1975) is that a typical progressive and the corresponding reverse protocol should produce an equally strong schema. This prediction is based upon the tenet of the schema theory indicating that the schema is strengthened by the number of trials and the accuracy of feedback, which are equated between the protocols. The schema theory also predicts that equated variability of practice should produce equal benefit to production of a novel movement because participants following each protocol encountered the same spread of experiences in order to form the schema.

A prediction to account for differences in learning between progressive and reverse ordering of practice cannot be made using Schmidt's (1975) schema theory.

The theory of reinvestment would predict that learners that followed a progressive protocol should be unaffected by a secondary task in comparison to learners who followed a reverse protocol, but only if the progressions were successful in manipulating the amount of error experienced in acquisition. The theory of reinvestment predicts that if no errors are made then, no opportunity to create and test hypotheses arises.

Though the challenge point framework is not a theory, it can guide us in making some predictions about errorful and errorless protocols. The challenge point framework point of view would predict that for a complex task with a high level of nominal task difficulty, such as golf putting, used in the study by Masters and Maxwell (2001) an easier functional task difficulty at the beginning of practice, when learners are least experienced (such as an errorless learning protocol) would be more beneficial to learning than a more difficult functional task difficulty at the start of practice. However, this prediction would reverse with a task of low nominal difficulty. The challenge point framework acknowledges both implicit and explicit knowledge but does not distinguish between them in terms of benefit to learning. While the challenge point framework may assist us in predictions about how a dual task may affect performance during acquisition through changes in functional task difficulty in relation to the experience of the performer, it does not assist in predictions specific for immediate or delayed dual-task tests.

From a self-determination theory perspective, the influence of progressive and reverse protocols on learning would be dependent upon the characteristics of the practice environment as a whole, and on the particular learner. While error experienced using a reverse protocol may indicate and optimal challenge for one learner, in may have a negative effect on feelings of competence for another. Both protocols can be equally influenced by factors such as controlling instructions or the provision of a meaningful rationale.

Facilitation of learner involvement

The self-controlled practice schedule.

Learners have been provided the opportunity to control the schedule of practice during the acquisition of motor tasks. Researchers such as Keetch and Lee (2007) and Wu and Magill (2011) have compared groups of participants under self-controlled and yoked order of practice conditions. Participants in the self-controlled conditions were able to choose the order in which they practiced trials during the acquisition of multiple versions of a motor task, while participants in the yoked conditions followed a schedule identical to a self-controlled counterpart, but without the choice. Self-controlled studies indicate that those provided with choice over the organization of the practice schedule perform equally, or more often, better on retention, transfer or both tests of learning than those not provided with choice (e.g., Keetch & Lee, 2007; Wu & Magill, 2011).

The contributions of learner involvement to a self-controlled practice schedule.

One of the major explanations for the benefits of a self-controlled practice schedule is the cognitive involvement of the learner during acquisition. Bund and Wiemeyer (2004) explained that self-control creates more strain on cognition, requiring decision making, monitoring, evaluating and correction in comparison to yoked conditions. Chiviacowsky and Wulf (2005) also suggested that spontaneous error estimations might contribute to the learning advantages of self-control.

Janelle, Barba, Frehlich, Tennant and Cauraugh (1997) suggested that the development of better learning strategies could be a possible reason for the benefits of self-control. Other explanations for the benefits of a self controlled practice context (e.g., schedule or receipt of feedback) include more efficient, deeper or independent information processing (Hartman, 2007; Janelle, Kim & Singer, 1995; Patterson, Carter & Sanli, 2011; Wulf, Clauss, Shea & Whitacre, 2001; Wulf, Raupach & Pfeiffer, 2005). Several other researchers have discussed the formation and use of strategies as having been influential for self-controlled learning benefits (Chen, Hendrick & Lidor, 2002; Patterson & Carter 2010; Wu & Magill, 2011).

In terms of acquiring a set of rules, Huet, Camachon, Fernandez, Jacobs and Montagne (2009) stated that learners extracted perceptual information as well as information that might also guide learning from a self-controlled practice context. The information that might also guide learning could include rules for how to execute the task. Though not all these explanations have been specific to self-control of the practice schedule, it is clear that hypothesis testing and strategy formation are thought to play a role in the beneficial effects of self-controlled practice.

Theoretical predictions for the comparison of self-controlled and yoked motor learning protocols.

Adams' (1971) theory would predict no differences between self-controlled and yoked practice schedules unless the number of errors committed under each differed. In the case where there was a difference, Adams' (1971) theory would predict that the learner who committed fewer errors during acquisition would perform better on tests of learning.

Similar to progressive verses reverse protocols, one prediction that can be made using Schmidt's schema theory (1975) is that a self-controlled and a yoked protocol should produce an equally strong schema, based upon equated number of trials and accuracy of feedback. The schema theory also predicts that equated variability of practice should produce equal benefit to production of a novel movement because participants following each protocol encountered the same spread of experiences in order to form the schema.

A prediction to account for differences in learning between self-controlled and yoked practice is not discussed in Schmidt's (1975) schema theory. However, a prediction that would be consistent with the schema theory point of view would be that no differences between the groups would occur, based upon the equal variability, number of trials and feedback provided to both groups.

The theory of reinvestment would predict that learners in a yoked schedule condition should be unaffected by a secondary task in comparison to learners who followed self-controlled schedule based upon two possible tenets. In a case where learners who followed a self-controlled practice schedule performed with more errors during acquisition, the theory of reinvestment would predict that a self-controlled schedule would result in more hypothesis testing and thus more explicit learning processes. The second reason for predicting that participants in a yoked condition would be more successful under dual-task conditions is that participants in the self-controlled condition are specifically being asked to use cognition, and possibly outcome feedback, necessitating the use of explicit learning processes.

The challenge point framework (Guadagnoli & Lee, 2004) can assist us in making some predictions in relation to the comparison of self-controlled and yoked acquisition protocols. One reason for the benefit of self-controlled practice is that a learner can better design practice to meet their individual needs. Perhaps those able to choose a practice schedule can adjust the functional task difficulty of the task (e.g., through increasing contextual interference) to reach and maintain optimal challenge points throughout the acquisition session. The application of this thought to a prediction is limited though, as this would assume that a learner understands and can identify optimal challenge points. Learners under a self-controlled practice schedule could have more information (interpretable or not) provided to them through the opportunity to strategize, form and test hypotheses. The challenge point framework view would predict that the differing amounts of information received by the self-controlled and yoked schedule groups would influence learning differently under most nominal and functional task difficulties. Whether the additional information is beneficial, detrimental or neither is dependent upon the nominal task difficulty and other aspects of the functional task difficulty.

Chapter four includes a detailed discussion of the predictions that can be made from the self-determination theory in respect to self-controlled versus yoked practice schedules. The most straightforward prediction is that the provision of choice for those in the self-controlled condition would provide support for feelings of autonomy leading to changes in behaviour, namely learning. The self-determination theory point of view would predict that those in the yoked condition, without the provision of choice would not experience the same benefit to learning. Many other characteristics within the learning environment would be predicted to influence learning and motivation.

Research Question and Objectives

Research question.

In the previous sections of this chapter, the stages of learning as described by several authors have been outlined along with some theories and frameworks which describe the processes of motor learning. Two separate sets of literature discussing learner involvement during the acquisition of a motor task have been briefly summarized. A general research question of the present thesis, driven by the various predictions highlighted in the review of the literature is this:

> Can the theory-driven explanations of the consequences of both minimizing and facilitating learner involvement during acquisition of a motor task, through the scheduling of practice be reconciled into an overall framework of the influence of learner involvement on measures of learning?

Four specific objectives arise from this general research question.

1) To determine the influence of progressive and reverse practice scheduling protocols on delayed measures of learning (retention and transfer tests).

2) To determine the influence of self-controlled and yoked practice scheduling protocols on performance under a secondary task (dual-task test).
3) To examine the characteristics of progressive and reverse practice scheduling protocols in order to better understand the contributions of each characteristic to performance on tests of learning.
4) To examine the characteristics of self-controlled and yoked practice scheduling protocols in order to better understand the contributions of each to performance on tests of learning.

Thesis Overview

In this thesis the influence of practice scheduling during acquisition of a fine-motor skill was examined within the context of the minimization and facilitation of learner involvement. In chapter two the influence of progressive and reverse protocols and the contributions of specific characteristics of each protocol for immediate and delayed tests of learning were examined. In chapter three the influence of self-controlled and yoked practice schedules on performance under secondary task conditions (as well as on retention and transfer tests of learning) was examined. In chapter four the influence of cognitive and motivational factors in self-controlled and yoked practice contexts are reviewed and discussed. Chapter five discusses some conclusions derived from the body of work contained within this thesis.

Outline of Experiments

In this section the title of the paper featured in each chapter and a brief summary of its content will be provided. Chapter two contains the manuscript "The effects of progressive and reverse acquisition protocols on retention, transfer and dual task tests for a fine-motor disc propulsion task." This paper included three experiments which examined the role of easy-to-difficult and difficult-to-easy progressions through versions of a fine-motor disc propulsion task during acquisition for immediate and delayed tests of learning. The third experiment within this paper also examined the characteristics of progressive and reverse practice scheduling protocols in order to better understand the contributions of each characteristic to performance on tests of learning. Easy-to difficult progression through versions of a task does not always produce less error than a reverse progression. Thus, a progressive protocol is not always beneficial to performance under a secondary task load. This paper also determined that the overall difficulty of versions of a task practiced in acquisition has an influence on participants' ability to perform well on a novel version of the task and to maintain performance on the novel task over time. The proximity of the version of the task first practiced in acquisition to the tested version of the task had an effect on participants' ability to perform a novel task well under dual-task conditions and to maintain this performance over time.

Chapter three contains the manuscript "The effects of self-controlled and yoked practice schedules on retention, transfer and dual task tests for a fine-motor disc propulsion task." This paper examined the influence of self-controlled and yoked practice scheduling protocols on performance under a secondary task (dual-task test). No differences were found between participants who followed a self-controlled practice schedule and a yoked practice schedule on dual-task tests, however differences were also not found on retention and transfer tests. This indicated that perhaps both groups received enough self-control in acquisition to benefit learning.

Chapter four contains the manuscript "Understanding self-controlled motor learning protocols through the self determination theory." This paper provides an extensive review of the motor-learning self-controlled practice literature and examines the body of work from a self-determination theory perspective. This paper examined the characteristics of self-controlled and yoked practice scheduling protocols in order to better understand the contributions of each to performance on tests of learning.

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Chapter 2: The minimization of learner involvement: The effects of progressive and reverse acquisition protocols on retention, transfer and dual task tests for a fine-motor disc propulsion task

Chapter 2: The effects of progressive and reverse acquisition protocols on retention, transfer and dual task tests for a fine-motor disc propulsion task

Introduction

Descriptions of acquisition of a motor skill usually describe two or more "stages of learning" through which a learner progresses (e.g., Adams, 1971; Fitts & Posner, 1967.) At the beginning of learning (e.g., cognitive stage, Fitts & Posner, 1967) the learner is cognitively involved in formulating and testing many strategies. At this stage the learners are more than likely figuring out what to do rather than how to do it (Schmidt & Lee, 2011, p.431). In later stages (e.g., autonomous stage, Fitts & Posner, 1967) the learned skill becomes more automatic and can become unaffected by a secondary task (Schmidt & Lee, 2011, p. 431).

Some researchers (e.g., Masters, 1992) have made attempts to bypass the cognitive- intensive early stages of learning through what is termed implicit learning – a process through which the learner does not collect explicit knowledge about how to perform the skill, but rather task-relevant information that is difficult to verbalize (Masters, 1992; Maxwell, Masters, Kerr, & Weedon, 2001). In contrast, explicit learning takes place through the processes of hypothesis formation and testing and produces a set of "rules", which can be easily verbalized. The implementation of an implicit learning protocol was introduced in order to overcome performance breakdown in stressful situations, typically seen when learners have initially gone through an explicit learning protocol, achieved automaticity and then return to explicit processes when placed under stress (Masters 1992). According to Masters (1992), when initial explicit learning takes place, the collected set of rules and strategies can come back to the forefront of the learner's mind under stressful or secondary task conditions. The reinvestment or reappearance in conscious thought of these rules or strategies into a process that has become automatic can cause a breakdown of performance, often referred to as "choking" in sports contexts.

An effective protocol for minimizing the accrual of rules and strategies was first demonstrated in a motor task by Masters (1992) in a dual-task methodology. A secondary task of random letter generation was performed during the learning of a golf putting task. The addition of the secondary task was shown to minimize the number of rules or strategies reported by learners, arguably because working memory was already occupied by the letter-generation task. The putting performance of the participants who practiced under dual-task conditions improved across performance, which was reported as indicative of learning by the authors. The ability of a dual-task protocol to induce implicit learning was replicated by Hardy, Mullen and Jones (1996) as well as Bright and Freedman (1998). Two issues arose from the use of dual-task acquisition protocols; 1) despite the benefit to performance on tests under stressful conditions, during acquisition, a dual task protocol was detrimental to performance and 2) in an applied context such as sport, requiring learners to shout out letters at random (random letter generation) is impractical.

With the above limitations of a dual-task protocol for acquisition in mind, Maxwell et al. (2001) proposed an alternative practice protocol termed "errorless learning." Despite the term, Poolton and Zachry (2007) explain that errorless learning refers to the *minimization* of errors, especially at the start of practice, rather than actually *preventing* any from occurring. The design of this errorless protocol was based upon a suggestion by Baddeley and Wilson (1994, as cited by Maxwell et al. 2001) that the identification and elimination of errors are essential to the process of explicit learning, whereas these processes cannot occur in implicit learning. Maxwell et al. (2001) suggest that hypothesis creation and testing needs to occur when errors are present, however if there are no errors, hypothesis creation and testing are unnecessary. Maxwell et al. (2001) hypothesized that learners who followed an errorless protocol would adopt an implicit learning style by default because the need for explicit learning through hypothesis creation and testing would be removed.

Maxwell et al. (2001) conducted two experiments to test this hypothesis using a golf-putting skill. The errorless condition in each experiment consisted of trials that moved from distances closer to the hole to distances further from the hole, which was presumed to minimize errors early on but progressed in difficulty. Learners in the errorful conditions completed the putts in the opposite order, which induced many more errors early on but decreased in difficulty as practice progressed. As predicted, learners in the errorless conditions were unaffected by a secondary task in a transfer test whereas performance by those in the errorful condition as well as those in a random control condition was degraded when a secondary task was introduced. Participants who followed the errorless schedule also performed better on a retention test than those who followed an errorful schedule. No differences in performance were found between participants in the three groups when a novel distance transfer test was conducted. Unfortunately the amount of time between the acquisition phase and the retention/ transfer phases of these experiments was not indicated.

Though the benefits of an errorless practice continue to be examined in differing types of stressful conditions, examination of the effects of errorless learning on retention and transfer of tasks has not been frequently examined. Poolton and Zachry (2007) acknowledge this limitation and explain that though immediate retention has been examined; delayed retention which is an indication of a relatively permanent change in performance (learning) has not been widely tested. The importance of carrying out experiments to test the effects of an errorless learning protocol on delayed retention and transfer tests is highlighted when we review experiments where random practice has been shown to be beneficial to learning (Poolton & Zachry, 2007).

The danger of not including delayed tests of retention and transfer is that in some cases the condition that is beneficial to performance during acquisition can actually be detrimental to learning. An example of such a case is illustrated by an examination of the research that has addressed the "contextual interference effect". For example, Shea and Morgan (1979) examined the influence of blocked versus random practice schedules on performance during acquisition, retention and transfer of a motor task. Blocked practice occurs when all the trials for a task are practiced at once, with no intermingling of the tasks, whereas random practice occurs when the tasks are interleaved, with repetition of any individual task on consecutive trials minimized (Schmidt & Lee, 2011, p. 373). The results of Shea and Morgan's (1979) experiment during acquisition are in line with the early implicit learning experiments (e.g., Masters 1992) in that those performing the more difficult practice condition (random, and dual-task respectively) performed worse than those practicing under an easier condition (blocked and without the dual-task respectively). However, Shea and Morgan found that this decrement in performance was reversed on retention and transfer tests, indicating that while blocked practice is beneficial to performance, it is detrimental to learning in comparison to random practice (Shea & Morgan, 1979). Perhaps, like random practice, errorful practice will provide a benefit for performance on delayed tests.

The overarching purpose of the experiments presented in this paper is to compare protocols similar to Maxwell et al. (2001)'s errorless and errorful protocols (referred to as progressive and reverse protocols, respectively, in the following studies to better reflect the manipulations by the experimenters) on both immediate and delayed retention, dual-task and transfer tests for a fine-motor disc propulsion task. To our knowledge, thus far errorless versus errorful practice protocols have been compared only for gross-motor tasks such as golf putting or rugby throws (see Poolton & Zachry, 2007 for review). We chose to use a fine motor task in a laboratory setting in order to allow for more precise measurement of performance, such as the magnitude and variability of error.

Experiment 1

Experiment one was designed to examine whether an easy-to-difficult progression and a difficult-to-easy progression during acquisition would lead to differential performances on retention, transfer and dual-task tests of learning for a fine motor task. Similar to Maxwell et al. (2001), the progressions through versions of the task were manipulated in order for errors to occur at different rates during acquisition. However, there are several important differences between the present study and the one conducted by Maxwell et al. (2001). The present study used a fine-motor, disc-propulsion task and manipulated the target-size progression, whereas Maxwell et al. (2001) used a gross-motor, golf-putting task and manipulated the distance from the start position to the target (hole). Consistent with the findings of Maxwell et al. (2001), we predicted that learners who followed an easy-to-difficult, target-size progression in acquisition would perform with less error in acquisition overall due to decreased hypothesis-formation and testing compared to learners who followed a difficult-to-easy target-size progression.

Immediate and delayed retention tests measured the relatively permanent influence of acquisition practice schedules on learning for the most difficult target size used in acquisition. It was hypothesized that those who followed an easy-to-difficult progression of target size in acquisition would perform better on retention tests, consistent with performance in acquisition.

Immediate and delayed dual-task tests measured the role of working memory in acquisition and the subsequent effects on performance when the working memory was engaged in a secondary task. Following the work of Maxwell et al. (2001), we hypothesized that those who followed an easy-to-hard progression in acquisition would use less working memory while learning the task (characteristic of more implicit rather than explicit learning) and therefore would require less working memory when later performing the task under secondary-task conditions. This decreased use of working memory for the execution of the motor task would allow more working memory resources to be allocated to the secondary task allowing for more accurate performance compared to those who learned using a greater amount of working memory (difficult-to-easy progression). Robust performance on a dual-task test is considered a reliable test for implicit processing in comparison to explicit processing (Berry & Dienes, 1993 as cited by Maxwell et al. 2001.)

The transfer tests assessed the ability of participants to transfer knowledge and skill of the practiced task to a novel version of the task. It was predicted that, based upon Maxwell et al. (2001) no differences in performance would be found between groups.

Method

Participants

Nineteen young adults (7 females and 12 males, *M* age = 25.6 years, *SD* = 3.2 years) participated in this study. Three participants self-reported preferring to use his or her left hand for the task, while the remainder of participants reported preferring to use their right hand. This research was approved by the institutional review board and participants were unaware of the purposes of the experiment. Informed consent was obtained from all participants. Participants were randomly assigned to one of two experimental groups; progressive (n=9) and reverse (n=10).

Task

The participants were required to propel a small disc along a smooth table top, with the purpose of stopping it in a specified target area (a lighted circle projected onto the surface of the table). Participants could choose to propel the disc using any strategy they chose, using their preferred hand, as long as the disc slid along the table top (e.g., did not become airborne or break contact with the table surface)..

Apparatus

Participants were seated at a table, 69.5 cm high, with a smooth table top measuring 76.5 cm x 92 cm. The home position was in the center of the table-top, 9 cm from the edge closest to the participant and was indicated with a small red x. White tape was placed 2.5 cm from either side of the small x to further encourage proper positioning of a 3 cm diameter, brown, plastic disc at the start of each trial. An 11mm infrared emitting diode (IRED) was glued to the center of the disc, which was attached to an Optotrak 3020 that collected three-dimensional position data. The weight of the combined disc and IRED was 12.5 grams. Sampling rate was 500 Hz, collected for 1 s. An Epson PowerLite 50 c projector was suspended 109 cm above the table top and connected to a computer. Microsoft Power Point was used to project a white circle onto the table top. See figure 1 for a diagram of the apparatus set up. The target was displayed as a white circle with a surrounding black background. Nine target sizes were used in the experiment with the center of each target located 22cm from the home position. The diameters of each of the eight targets used during acquisition were; 6.5, 10, 13.5, 17, 20.5, 24, 27.5 and 31cm. The diameter of the target used for the transfer tests was 4.5 cm. The order in which the targets were presented during acquisition differed by experimental group (see figure 2.) For the dual-task tests, a customizable software program (E-prime version 1.2, Psychology Software Tools Inc., Pittsburgh, PA) randomly presented 500 Hz or 1000 Hz auditory tones at intervals of 1500 ms. The tones were delivered by two speakers placed 60 cm from the participant.

Procedure

Participants in both groups listened to a script describing the task, read by the experimenter. The two groups heard the same instructions as to how to perform the task.

The participants completed a total of 200 acquisition trials (25 to each of 8 target sizes), 50 retention trials (25 immediate and 25 delayed), 50 dual-task trials (25 immediate and 25 delayed), and 50 transfer trials (25 immediate and 25 delayed). Learners in the progressive group began acquisition with the largest target size and progressed through the remainder of target sizes in sequential order so that the last acquisition target practiced was the smallest target size (e.g., in order, 31cm, 27.5, 24, 20.5, 17, 13.5, 10, then 6.5). Learners in the reverse group progressed through the acquisition target sizes in the reverse order (e.g., 6.5cm, 10, 13.5, 17, 20.5, 24, 27.5 then 31).

Acquisition began with the instructions; the participants were then shown the first target that would be used in acquisition. When participants were ready to begin they placed the disc on the home position and propelled the disc towards the appropriately-lit target (the other targets were not visible). The experimenter then recorded the end location of the disc using Optotrak, and then raised her hand signaling to the participant to return the disc to the home position to begin the next trial. Participants completed 25 trials at each target before moving on to the next target. At the completion of acquisition participants were asked to work on a a "Hard Sodoku Puzzle" (from http://www.sudokupuzz.com) for 10 minutes.

Following the puzzle, participants completed the immediate retention test consisting of 25 trials at the 6.5cm target size (the smallest acquisition target size.) This was followed by the immediate dual-task test, consisting of 25 trials using the same target size as retention, with the added task of counting the total number of high tones (1000 Hz) that were presented in the random series of high and low (500 Hz) beeps throughout the entire block of trials. Participants were asked to report the total number of high beeps at the conclusion of the series. Participants then completed a further 25 trials to a 4.5 cm target size that had not been previously practiced (the immediate transfer test). Participants returned one day later for delayed retention, dual-task and transfer tests that were identical to the immediate tests.

Data Analyses

An error trial was defined as a final position where the disc did not land completely within the target area. The dependent variable, proportion of errors per block was used to examine performance during acquisition, retention, dual-task and transfer tests. For acquisition, the ANOVA was run in two different manners: 1) the dependent variable was analyzed using a 2 (group: progressive, reverse) x 8 (acquisition blocks) analysis of variance (ANOVA) with repeated measures on block, and 2) as a 2 (group: progressive, reverse) x 8 (target size) analysis of variance (ANOVA) with repeated measures on target size. The two different analyses were run on the same data because target size was nested within trial blocks as a function of the practice schedule [e.g., block 1 represented the largest target (31 cm) for the progressive group but the smallest target (4.5 cm) for the reverse group]. Therefore one analyses contrasted between-group acquisition performance as a function of practice block whereas the other analysis contrasted the groups on their performance with the 8 target sizes.

For immediate and delayed retention, dual-task and transfer tests, the dependent variable was analyzed using a 2 (group: progressive, reverse) x 2(sessions: immediate, delayed) x 3 (tests: retention, dual-task, transfer) ANOVA with repeated measures on both session and test. To examine performance on the counting portion of the dual-task test a 2 (group; progressive, reverse) x 2(session; immediate, delayed) ANOVA with repeated measures on session was conducted. Tukey's HSD tests were used to contrast mean differences where appropriate. Alpha was set at 0.05 for all statistical analyses.

Results

Acquisition

A 2 (group; progressive, reverse) x 8 (block) ANOVA with repeated measures on block revealed a significant main effect for block [$F(7, 119) = 36.35$, $p < .001$] as well as a significant interaction between block and group [$F(7, 119) = 135.56$, $p < .001$]. No significant main effect was revealed for group [$F(1,17) = .64$, $p = .44$]. In block one the disc landed outside of the target for a greater proportion of trials than in blocks two through eight. In block two the disc landed outside of the target for a greater proportion of trials than in blocks four through six. In block seven the disc landed outside of the target for a greater proportion of trials than in blocks three through six and in block eight the disc landed outside of the target for a greater proportion of trials than in blocks two through seven. In blocks one, two and three the participants in the reverse group produced significantly more error trials than those in the reverse group. In blocks five through eight the participants in the progressive group produced significantly more error trials than those in the reverse groups. No difference between groups was revealed for block four.

A 2 (group; progressive, reverse) x 8 (target size) ANOVA with repeated measures on target revealed a significant main effect for target size [$F(7,119) = 169.44$, $p < .001$] and a significant interaction between target size and group [$F(7, 119) = 2.47$, $p = .021$]. No significant main effect was revealed for group [$F(1,17) = .64$, $p = .44$]. For the 31cm target size (the largest target size) the disc landed outside of the target for a significantly smaller proportion of trials than for the 6.5, 10 and 13.5 cm target sizes. For the 27.5 cm target size (the disc landed outside of the target for a smaller proportion of trials than for the 17cm, 13.5cm, 10cm and 6.5cm target sizes. For the 24cm target size the disc landed outside of the target for a smaller proportion of trials than for the 13.5cm, 10cm and 6,5cm target sizes. For the 20.5cm target size, the disc landed outside of the target for a smaller proportion of trials than for the 13.5cm, 10cm and 6.5cm target sizes. For the 17cm target size, the disc landed outside of the target for a smaller proportion of trials than for target the 10cm and 6.5cm sizes. For the 13.5cm target size the disc landed outside of the target for a smaller proportion of trials than for the 10cm and 6.5cm target sizes. For the 10cm target size, the disc landed outside of the target for a smaller proportion of trials than for the 6.5cm target size eight. For the 31cm and 10cm target sizes those in the reverse group performed with significantly less error trials than those in the progressive group. For all other target sizes the groups performed equally well (see the left side of figure 3.)

Retention, dual task and transfer tests

A 2 (group; progressive, reverse) x 2(session; immediate, delayed) x 3 (test; retention, dual-task, transfer) ANOVA with repeated measures on session and test revealed a significant main effect for test [$F(2,34) = 6.11$, $p = .005$]. Significantly more error trials occurred during transfer tests than during dual task tests (see the right side of figure 3.) All other main effects and interactions were non-significant ($p > .05$.)

A 2 (group; progressive, reverse) x 2(session; immediate, delayed) ANOVA with repeated measures on session revealed no significant difference in performance on the counting portion of the dual task test.

Discussion

In acquisition, the manipulation of task difficulty through the change in target size was effective as indicated by the smaller proportion of error trials for the larger (easier) targets and vice versa. However, contrary to our hypotheses, no differences in the total proportion of error trials during acquisition were found between the progressive and reverse groups. Furthermore, no differences in the proportion of error trials or counting accuracy between the progressive and reverse groups were found during the retention, dual-task and transfer tests. While the overall difficulty of the task was manipulated across the blocks of acquisition in opposite directions for each group, it is possible that the participants did not modulate their goals along with the size of the target. In terms of reinvestment theory this could result in both groups identifying and eliminating perceived errors at the same rate, most likely under explicit learning processes. For example, a participant may have always been aiming for the exact center of the target regardless of the target size and therefore did not follow any progression of difficulty at all, regardless of the group to which they were assigned. A second experiment was carried out in order to create progressive and reverse conditions where the goals needed to progress along with the targets in order to be successful.

Experiment 2

Progression of task difficulty was once again manipulated using easy-to-difficult versus difficult-to-easy progressions through versions of a disc-propulsion task. In experiment two the *distance* from the start position to the target was manipulated instead of the *size* of the target (the size of the target remained constant). This change from experiment one was made in order to more strongly encourage the participants to adopt a progression of goals along with the adjustment of task difficulty.

Again, based upon reinvestment theory and Maxwell et al. (2001), we predicted that learners who followed an easy-to-difficult progression in target distance from the start position in acquisition would perform with less error in acquisition overall due to decreased hypothesis formation and testing compared to those following a difficult-to-easy progression of target location. Learners who followed an easy-to-difficult progression of target location in acquisition were predicted to perform better on retention tests consistent with performance in acquisition.

We also hypothesized, based upon Maxwell et al. (2001) that those who followed an easy-to-hard progression in acquisition would use less working memory while learning the task (characteristic of more implicit rather than explicit learning) and therefore would perform better on the dual-task tests than those who followed a hard-to-easy progression.

Based upon Maxwell et al. (2001), no differences between groups were predicted for the transfer tests,

Method

Participants

Twenty young adults (12 females and 8 males, *M* age = 21.2 years, *SD* = 2.9 years) participated in this study. All participants self-reported preferring to use his or her right hand for the task. This research was approved by the institutional review board and participants were unaware of the purposes of the experiment. Informed consent was obtained from all participants. Participants were randomly assigned to one of two experimental groups; progressive (n=10) and reverse (n=10).

Task

The task was identical to the one used in experiment one.

Apparatus

The apparatus was identical to that used in experiment one with the exception of the projected targets. Nine target *locations* were used in the experiment with the front edge of the target located 3.5, 7.5, 11.5, 15.5, 18.5, 22.5, 26.5 and 30.5 cm from the home position in acquisition and 34.5 cm from the home position for the transfer test. The diameter of each of the targets was 6.5 cm. Target location differed in only one axis. The order in which the targets were presented during acquisition differed by experimental group (see figure 4.)

Procedure

A procedure identical to experiment 1 was followed with the exception of differences due to the change in target location rather than size. Those in the progressive group began acquisition with the target location closest to the home position and progressed through the remainder of target locations in sequential order so that the last acquisition target location practiced was the farthest from the home position. Those in the reverse group progressed through the acquisition target locations in the reverse order. For the transfer test, participants completed 25 trials to a 34.5 cm target location that had not been previously practiced. The targets are numerically labelled in figure 4.

Data Analyses

The dependent variables (proportion of errors per block, 2-dimension centroid error (CE) and variable error (VE) measures) were used to examine performance during acquisition, retention, dual-task and transfer tests. While the proportion of errors per block provides a global measure of task success, CE and VE measure the magnitude of errors observed and variability of end locations respectively. CE is a measure of the magnitude of bias from the target centre over a block of trials. VE is a measure of variability relative to the individual's centroid within each block. Both of these measures take into account the two-dimensional nature of the task and are independent of the axes chosen to record the raw data (Hancock, Butler & Fischman, 1995.) However, the measures of CE and VE did not provide additional information beyond that provided by the more global measure of proportion of errors per block and thus the analyses of the measures is not reported.

For acquisition and immediate and delayed tests all three dependent variables were analyzed using the same statistical tests as experiment one.

Results

Acquisition

A 2 (group; progressive, reverse) x 8 (block) ANOVA with repeated measures on block revealed a significant main effect for block [$F(7,126) = 3.54$, $p = .002$] as well as a significant interaction between block and group[$F(7, 126) = 71.45$, $p < .001$]. Significantly fewer error trials occurred on block eight than on blocks three through five. For blocks one and two the progressive group produced less error than the reverse group while for blocks three through five the groups performed with similar error and for blocks six through eight the reverse group performed with significantly fewer errors than the progressive group. A significant main effect was also revealed for group [$F(1, 18) = 5.32$, $p = .033$] with those in the progressive group performing with more errors during acquisition than the reverse group.

A 2 (group; progressive, reverse) x 8 (target location) ANOVA with repeated measures on target location revealed a significant main effect for target location [$F(7,126) = 73.49$, $p < .001$] with significantly fewer errors for targets1 and 2 than targets3-8, error for target 3 significantly less than for targets 4-8, error for target 4 significantly less than for targets 6-8 and error for target 5 significantly less than for targets 7 and 8. A main effect for group [$F(1, 18) = 5.32$, $p = .033$] was significant with those in the progressive group performing with more errors than those in the reverse group (see the left side of figure 5.)

Retention, dual-task and transfer tests

A 2 (group; progressive, reverse) x 2 (day; immediate, delayed) x 3 test ANOVA with repeated measures on day and test revealed a main effect for test [$F(2,36) = 4.02$, $p = .027$] with significantly more errors produced on the retention tests than the dual-task tests. A significant interaction between group and test was also found [$F(2,36) = 3.3$, $p = .048$] with the progressive group performing with significantly more error on transfer tests than the reverse group (see the right side of figure 5.) No other effects or interactions were significant ($p > .05$.)

A 2 (group; progressive, reverse) x 2 (session; immediate, delayed) ANOVA with repeated measures on session revealed no significant difference in performance on the counting portion of the dual task test.

Discussion

In acquisition, similar to experiment one, the manipulation of task difficulty was effective as indicated by the smaller proportion of error trials for the closer (easier) targets compared to the further (more difficult) targets and vice versa. However, unlike experiment one, a difference in the proportion of error trials in acquisition was found. This difference was opposite our prediction which was made based upon reinvestment theory and Maxwell et al. (2001). In the present study, the progressive group performed with *more* error than the reverse group. This finding suggests that an easy-to-difficult progression does not always represent an "errorless learning" protocol, and as such may not induce implicit learning either. This is further supported by the lack of differences between the performances of groups for the dual-task tests.

Participants in the progressive group performed with a significantly greater proportion of error trials compared to the reverse group on both transfer tests. A number of possible reasons for the benefit of the reverse progression protocol over the progressive protocol for transfer to a novel version of the task can be hypothesized. In terms of implicit versus explicit learning, it is possible that the smaller proportion of errors committed in acquisition by those in the reverse protocol, better approximated an "errorless learning" protocol and thus facilitated learning. It is also possible that since implicit learning is most important at the beginning of practice (Poolton, Masters & Maxwell, 2005) and those in the reverse protocol group began practice using the target closest in distance to the one used in the transfer test that the benefit may be due to implicit rather than explicit learning processes. However performance on a dual-task test is considered to be a reliable test for implicit versus explicit learning and no differences in performance between groups were found. Another possible reason that learners who followed the reverse protocol performed better on the transfer tests may be that the amount of challenge or cognitive effort experienced by those in the reverse protocol group was optimal for learning. A third experiment was carried out in order to dissociate the aspects of progressive and reverse protocols that most contribute to benefits in transfer (as well as any benefits found for retention or dual-task tests.)

Experiment 3

Experiment three compared four experimental groups with the purpose of dissociating the nature of progressive and reverse protocols that most contribute to differences in dual-task and transfer tests. The four conditions allowed for examination of the effects of overall task difficulty, progression in relation to the home position and progression in relation to the test target. Two sets of targets (near and far) were used in acquisition with two practice-order groups (progressive and reverse) using each set of targets.

We hypothesized, based upon the differences in performance between targets in experiment two, that those who practiced with the near targets (near-progressive, near-reverse) would perform with a smaller proportion of error trials during acquisition than those who practiced using the far targets (far-progressive, far-reverse.) Based upon the results of experiment two, it was also hypothesized that those who practiced using a reverse protocol would produce a smaller proportion of error trials during acquisition.

For the dual-task tests, we hypothesized that those that practiced using the near targets would perform better on the dual task tests than those that used the far targets. This prediction was based upon Maxwell et al.'s (2001) discussion of the minimization of hypothesis formation and testing and how it occurs when error is minimized, resulting in a more implicit form of learning. Furthermore also based upon Maxwell et al.'s (2001) prediction, it was predicted that those who practiced following a progressive protocol would outperform those following a reverse protocol with each respective set of targets.

For the transfer tests, it was hypothesized that those that practiced using the far targets would perform better on the transfer tests than those that used the near targets, based upon the provision of a more optimal amount of challenge or cognitive effort using the far targets. This is the same reason the opposite was predicted for the dual-task tests. It was also predicted that those who practiced following a progressive protocol would perform with more error trials than those following a reverse protocol with each respective set of targets, which was based upon the results of experiment 2.

Method

Participants

Forty young adults (23 females and 17 males, *M* age = 20.4 years, *SD* = 3.3 years) participated in this study. All participants self-reported preferring to use his or her right hand for the task. This research was approved by the institutional review board and participants were unaware of the purposes of the experiment. Informed consent was obtained from all participants. Participants were randomly assigned to one of four experimental groups; near-progressive (n=10), near-reverse (n=10), far-progressive (n=10) and far-reverse (n=10). Two participants (one from each of the far-reverse and close-progressive groups) failed to complete the delayed tests.

Task

The task was identical to the previous studies.

Apparatus

All apparatus was identical to that used in experiment one and two, with the exception of the projected targets. Nine target *locations* were used in the overall experiment with the distance from the home position to the front edge of the target differing. The front edges of the targets were located 7.5, 10.5, 13.5, 16.5, 22.5, 25.5, 28.5 and 31.5 cm from the home position in acquisition and 19.5 cm from the home position for the transfer test. The diameter of each of the targets was 6.5 cm. Target location differed in only one axis. The targets used and the order in which the targets were presented during acquisition differed by experimental group (see figure 6 where the targets have been numerically labeled.)

Procedure

The acquisition procedure was identical to experiments 1 and 2 with the exception of differences due to the change in the number of targets used in acquisition and their locations. The participants completed a total of 200 acquisition trials (50 to each of 4 target locations), 100 dual-task trials (50 immediate and 50 delayed), and 100 transfer trials (50 immediate and 50 delayed). Those in the near-progressive and near-reverse groups used the four target locations prior to the transfer target location, whereas those in the far-progressive and far-reverse groups used the four target locations after the transfer target. Those in the progressive groups began acquisition with the target location , within their respective sets of four locations closest to the home position and progressed through the remainder of target locations in sequential order so that the last acquisition target location practiced was the farthest from the home position. Those in the reverse group progressed through the acquisition target locations in the reverse order.

The immediate and delayed tests differed in that a retention test was not included and both the transfer test and the dual-task test used a target at a novel, central location.

Data Analyses

The dependent variables (proportion of errors per block, 2-dimension centroid error (CE) and variable error (VE) measures) were used to examine performance during acquisition, retention, dual-task and transfer tests. However, the measures of CE and VE did not provide additional information beyond that provided by the more global measure of proportion of errors per block and thus the analyses of the measures is not reported.

For acquisition, dependent variables were analyzed using separate 2 (overall distance; near, far) x 2 (progression; progressive, reverse) x 4 (block) ANOVA with repeated measures on block as well as separate 2 (groups: progressive, reverse) x 4 (target locations) analysis of variance (ANOVAs) with repeated measures on target location for each set of acquisition targets (near and far.)

For immediate and delayed dual-task and transfer tests, the dependent variables were analyzed using separate 2 (overall distance; near, far) x 2 (group: progressive, reverse) x 2(sessions: immediate, delayed) x 2 (tests: retention, dual-task, transfer) ANOVAs with repeated measures on both session and test.

To examine performance on the counting portion of the dual-task test a 2 (group; progressive, reverse) x 2(session; immediate, delayed) ANOVA with repeated measures on session was conducted.

Tukey's Honestly Significant Difference (HSD) tests were used to contrast mean differences where appropriate. Alpha was set at 0.05 for all statistical analyses.

Results

Acquisition

A 2 (overall distance; near, far) x 2 (progression; progressive, reverse) x 4 (block) ANOVA with repeated measures on block revealed a significant main effect for overall distance [$F(1,36) = 36.28$, $p = <.001$] with those who practiced using the far targets producing more error trials than those who practiced with the near targets. A significant main effect was also revealed for block [$F(3,108) = 24.93$, $p = < .001$] with significantly more error for block one than for blocks two to four. A significant interaction was revealed between progression and block [$F(3,108) = 23.37$, $p = < .001$], with the progressive groups performing with more error on block four than those in the reverse groups. A significant interaction between, overall distance, progression and block [$F(3,108) = 5.74$, $p = .001$] was revealed with the near-progressive group performing with less error than both far groups for block one and near-reverse and both far groups for block two. For block three, both near groups performed with less error than the far progressive group and the near-progressive group performed with significantly less error than the far-reverse group. For block four, the near-reverse group performed with significantly less error than all other groups.

Mauchly's test for a 2 (progression; progressive, reverse) x 4 (target) ANOVA for the near targets indicated that the assumption of sphericity had been violated for the main effect of target $\chi^2(5) = 19.18$, $p = .002$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .64$). A main effect for target [$F(1.93, 34.76) = 21.31$, $p < .001$] with fewer errors produced for target 1 than for targets 2-4, target 2 producing less error than 3 and 4 and target 3 producing less error than target 4 was revealed. A significant interaction between target and group was revealed [$F(1.93, 34.76) = 13.16$, $p < .001$] with the progressive group producing more error for targets 1 and 3 and equal error for targets 2 and 4 in comparison with the reverse group (see the far left of figure 7.)

A 2 (progression; progressive, reverse) x 4 (target) ANOVA for the far targets revealed a main effect for target [$F(2.19, 39.37) = 6.259$, $p < .001$] with less error produced for target 2 than for target 4. A significant interaction between target and group was revealed [$F(2.19, 39.37) = 11.59$, $p < .001$] with the progressive group producing more error for targets 1 and 2, equal error for target 3 and less error for target 4 in comparison with the reverse group (see the middle of figure 7.)

Dual-task and transfer tests

A 2 (overall distance; near, far) x 2 (progression; progressive, reverse) x 2 (day; immediate, delayed) x 2 (test; dual-task, transfer) ANOVA with repeated measures on day and test revealed a significant main effect for day [$F(1, 34) = 10.41$, $p=.003$] with delayed tests producing more error than immediate tests. A significant interaction was revealed between overall distance, progression, test and day [$F(1, 34) = 4.26$, $p=.047$]. For the transfer tests both groups that practiced using the near targets performed with more error on the delayed test than on the immediate one. For the dual-task tests the groups that started practice using the targets farthest from the test target (near-progressive & far-reverse) produced more error on the delayed test than the immediate test (see the right side of figure 7.) All other main effects and interactions were non-significant ($p > .05$.)

Discussion

In acquisition, as expected, those who practiced using the further targets performed with a greater proportion of error trials overall than those who practiced using the nearer targets, suggesting that the further targets provided a greater challenge to the learners than the closer targets. For the transfer test, those that practiced using the further targets did not experience a decrease in performance across testing sessions while those who practiced using the easier targets did experience a decline in performance from immediate to delayed tests. The transfer test results suggest that not only were the further targets more challenging, they were more optimally challenging to the performer than the closer targets. These results highlight two potential task characteristics that are important for relatively stable transfer performance; 1) the overall difficulty of the task practiced and 2) the direction of transfer from acquisition. However, the benefit of a more difficult practice condition for transfer, where the direction of transfer from acquisition was opposite from that seen here, was illustrated in experiment two. It appears that the optimal amount of difficulty, perhaps at the beginning of practice in particular is important for transfer to a novel version of a practiced task.

Unlike the previous two experiments, differences in performance for the dual task were seen between groups. For the dual-task tests, the groups that started practice using the targets farthest from the test target (near-progressive & far-reverse) experienced a decrease in performance across testing sessions while those that started practice at the targets closest to the test target (near-reverse & far-progressive) did not. Poolton et al. (2005) state that implicit learning processes are most important at the beginning of practice. Perhaps the participants experienced enough trials prior to any explicit processes taking place, at targets closest to the test target to provide an advantage over those who got to those targets closest to the test target after more explicit processing had occurred. It is also important to note that in previous studies the secondary task load was placed on a task that had been practiced in acquisition, rather than a novel version of the task. Perhaps proximity of the first target in acquisition to the test target is beneficial to performance of a *novel version* of the task under dual task conditions, rather than under dual-task conditions in general.

General Discussion

The studies reported here examined the influence of task progression during practice on subsequent performance on three tests of learning. It was predicted that participants who progressed from easier to more difficult versions of the disc-propulsion task would perform with less overall error in acquisition. It was also hypothesized that this minimization of errors, especially at the beginning of practice, would limit hypothesis formation and testing and thus be more characteristic of implicit learning as evidenced by maintained performance on dual-task tests.

None of these hypotheses were supported in any of the three studies, indicating that an easy-to-difficult progression of versions of a task during acquisition does not always limit errors. This, in turn suggests that easy-to-difficult progressions either do not always induce implicit learning or implicit learning does not always facilitate dual-task performance. In fact, in experiment two, an easy-to-difficult task progression produced *more* error in acquisition. Some differences between previous experiments (e.g., Maxwell et al. 2001) and the three presented here may help to account for the failure to replicate the errorless versus errorful practice distinction seen in previous work. The first of these differences is the task itself. The task used in the three experiments presented here was a fine-motor, unimanual task, whereas tasks used previously were gross-motor, bimanual or full body tasks (e.g., golf putting, Maxwell et al. 2001; table tennis shot, Masters et al. 2008; throwing task, Masters et al. 2008). Another difference was the total number of trials completed during acquisition. In the three experiments presented here, the total number of trials completed was about half of those used by Maxwell et al. (2001). While Maxwell et al. (2001) explained that the amount of practice during acquisition could affect implicit and explicit processing expression; the influence of fatigue during acquisition was also taken into account when designing the studies reported here. The implications of these findings for designing practice of a fine-motor skill, for example in a job training setting, are that simply progressing from a very easy version of a task to progressively harder versions does not ensure that implicit processes are undergone and thus stability under secondary task or stressful conditions will not necessarily be achieved.

Differences in performance on the dual-task tests were seen in experiment three which was designed in order to isolate the characteristics of progressive and reverse protocols and their relation to targets used for testing. However, it was not the minimization of error, as would be predicted by the previous errorless learning literature that was characteristic of the protocols that best maintained performance on dual-task tests. Participants who started their practice using targets closest to the test target, regardless of whether it was a slightly more difficult or a slightly easier target than the one used for the dual-task test, did not experience a decrement in performance from the immediate to the delayed dual-task tests; the other groups did. This suggests that perhaps some implicit learning did take place at the very beginning of practice despite the lack of error minimization. Poolton et al. (2005) found that implicit learning is most important at the beginning of practice, with a brief period of errorless learning at the beginning of practice remaining unaffected by subsequent errorful practice when tested under dual-task conditions. Our findings suggest that task specificity during this critical window at the beginning of practice may also play an important role.

We hypothesized that differential effects would be seen on dual task tests between groups in each of the three experiments, however only in study three was this hypothesis supported. Maxwell et al. (2001) indicate that the amount of practice trials in acquisition likely affect implicit and explicit learning processes. Perhaps the pace of progression, which differed from progressing after every 25 trials for studies one and two, to after every 50 trials for study three, also affected the expression of implicit and explicit learning processes. Previous studies where a distinction between errorless and errorful protocols on dual-task test performance were seen, also used blocks of 50 trials in acquisition for a golf putting task (Maxwell et al., 2001;Poolton et al., 2005). However blocks of less trials for throwing and tennis tasks still induced differences on dual task tests (Masters et al. 2008; Masters et al. 2008; Poolton et al. 2007).

Results on transfer tests have been mixed in the previous literature. Maxwell et al. (2001) initially found that those in the errorless group performed better on a novel distance transfer test, but once the higher performance level over all was accounted for, this difference was no longer seen. Most errorless learning studies have not included a novel transfer test absent of a secondary task (e.g.Bright & Freedman, 1998). It would seem that the very characteristics of acquisition considered detrimental to performance on dual task tests, would be most beneficial to performance on a novel version of the task (transfer tests.) Schema theory (Schmidt, 1975) explains that having a wide array of experiences; whether they are correct or incorrect, for a particular task can help to better form a schema (rule). A schema is formed by incorporating relationships between initial conditions, response specifications, sensory consequences, and response outcomes recorded for each experience of the task. A wider set of experiences with the task, including experiences with error, creates a schema that is better able to predict the parameters need to successfully complete the task (Schmidt, 1975). This suggests that errorless practice would be detrimental to the transfer of learning to a novel task.

We predicted that participants who followed a reverse protocol would perform better on immediate and delayed transfer tests than participants who followed a progressive protocol. Study number two supported this hypothesis. However, study three revealed that it was not the reverse progression protocol that was characteristic of practice beneficial to avoiding a decrement in performance from immediate to delayed transfer, but the overall difficulty of the acquisition tasks. Perhaps both the reverse progression in study two and the practice targets located further than the test target in study three allowed for the optimal amount of challenge for the learner during acquisition to benefit performance on transfer tests. According to the Challenge Point Framework (Guadagnoli & Lee, 2004), functional task difficulty refers to the challenge level of the task in relation to the skill of the learner and the conditions in which the task is performed. Perhaps a combination of skill level, which may have changed throughout practice, the difficulty of the targets practiced, as well as the pace of progression through the targets (25 vs. 50

trials before moving on) in each study equated to relatively the same functional task difficulty of the practice session, which in turn was beneficial for performance on transfer tests.

In conclusion, the findings of the three experiments reported here suggest that an easy-to difficult progression through versions of a task does not always induce implicit learning processes and thus is not always beneficial to performance under a secondary task load. The overall difficulty of versions of a task practiced in acquisition appears to have an influence on participants' ability to perform well on a novel version of the task and to maintain performance on the novel task over time. The proximity of the version of the task first practiced in acquisition to the tested version of the task appears to have an effect on participants' ability to perform a novel task well under dual-task conditions and to maintain this performance over time. It is evident that easy-to-difficult and difficult-to-easy progressions influence a number of aspects of learning and the ideal progression is dependent upon the end goal of performance.

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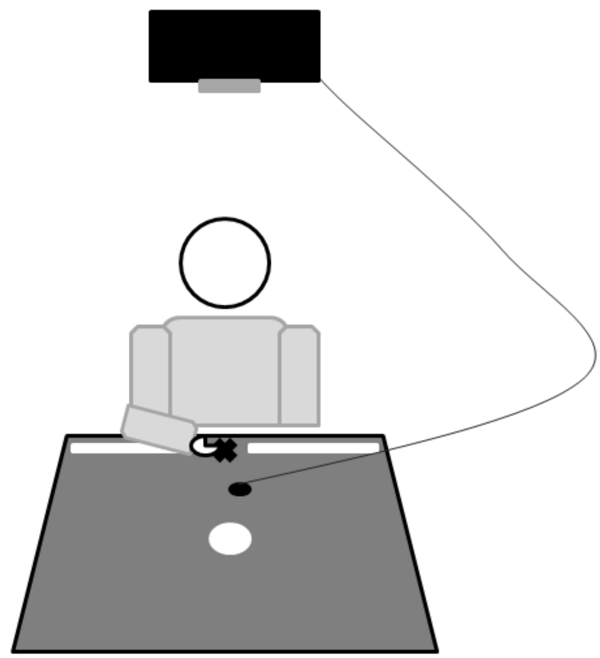

Figure 2.1. The apparatus and task set up for experiments one, two and three showing the position of the participant, the projected target, the home position, and the disc.

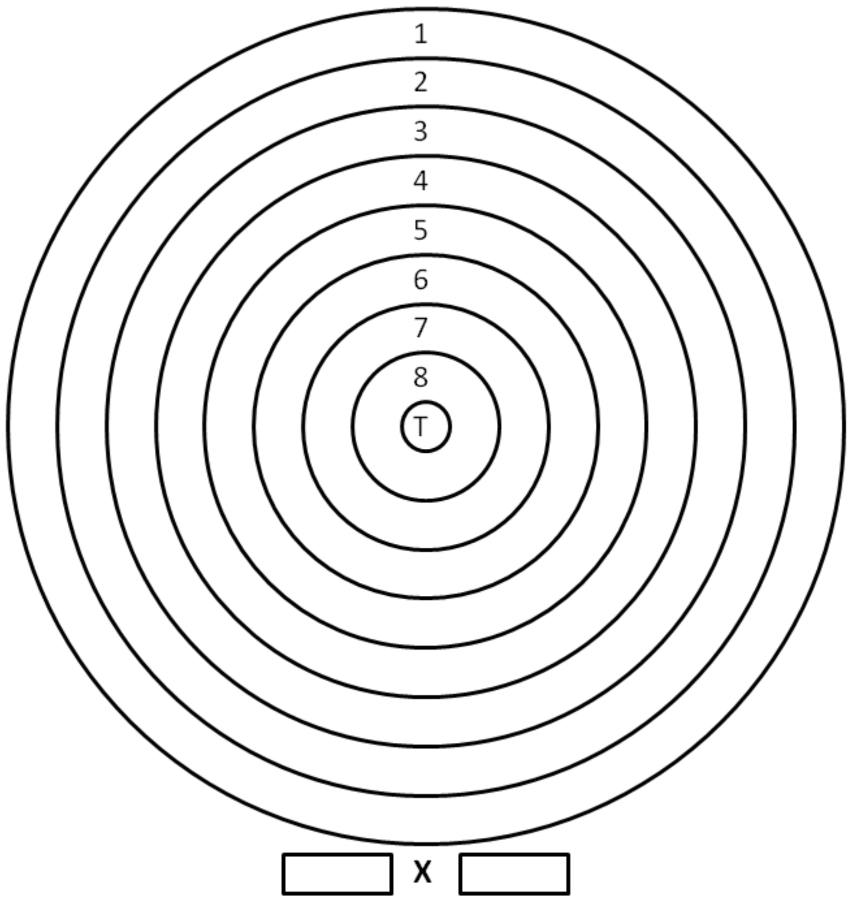

Figure 2.2. The relationships between the eight acquisition target sizes, the home position and the transfer target size for experiment 1. During the experiment only one target was displayed at a time.

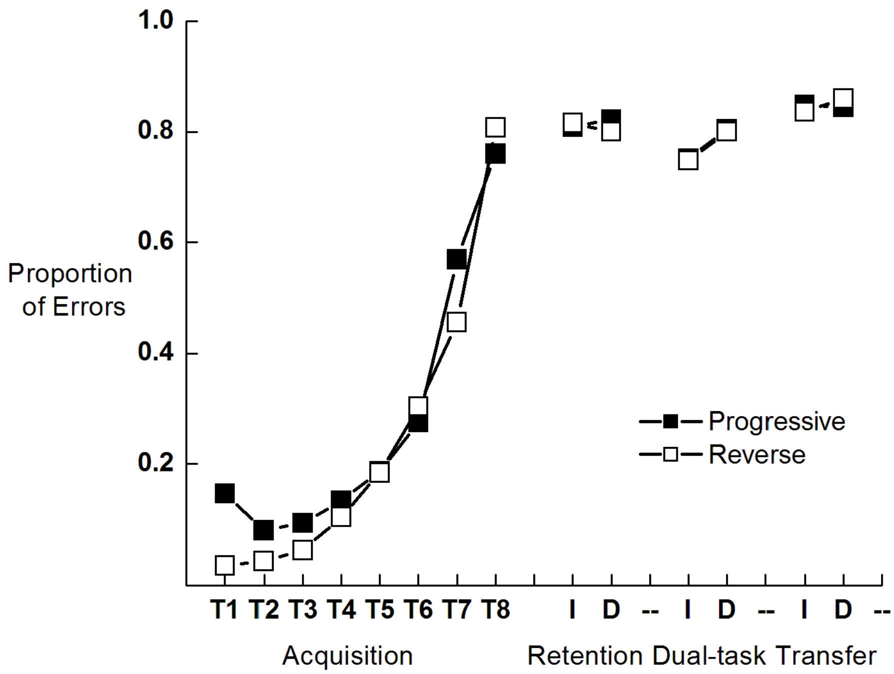

Figure 2.3. The proportion of error trials for each of 8 acquisition targets, retention, dual-task and transfer for experiment 1.

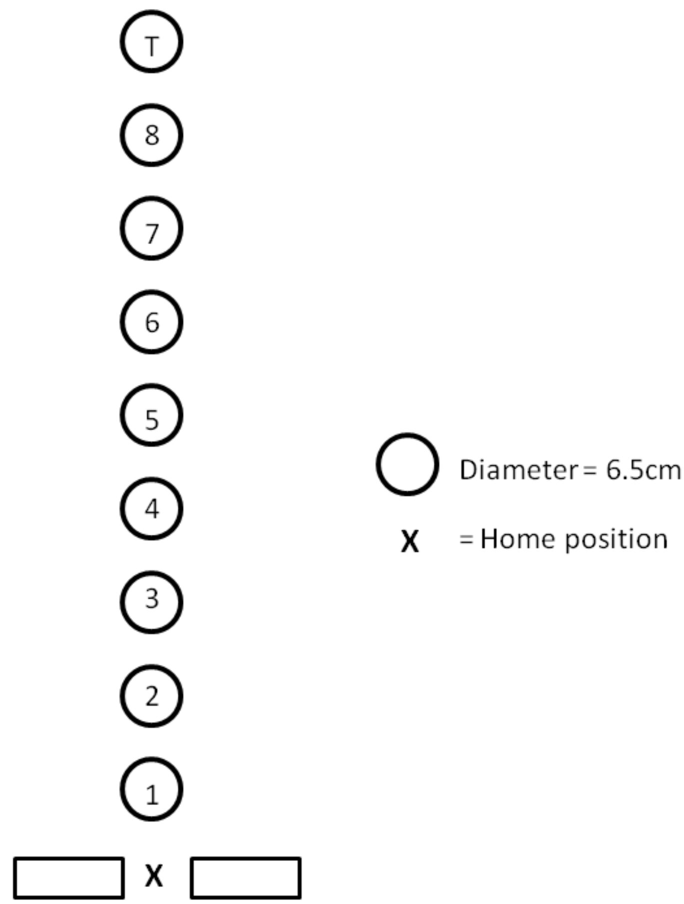

Figure 2.4. The relationships between the eight acquisition target locations, the home position and the transfer target location for experiment 2. During the experiment only one target was displayed at a time.

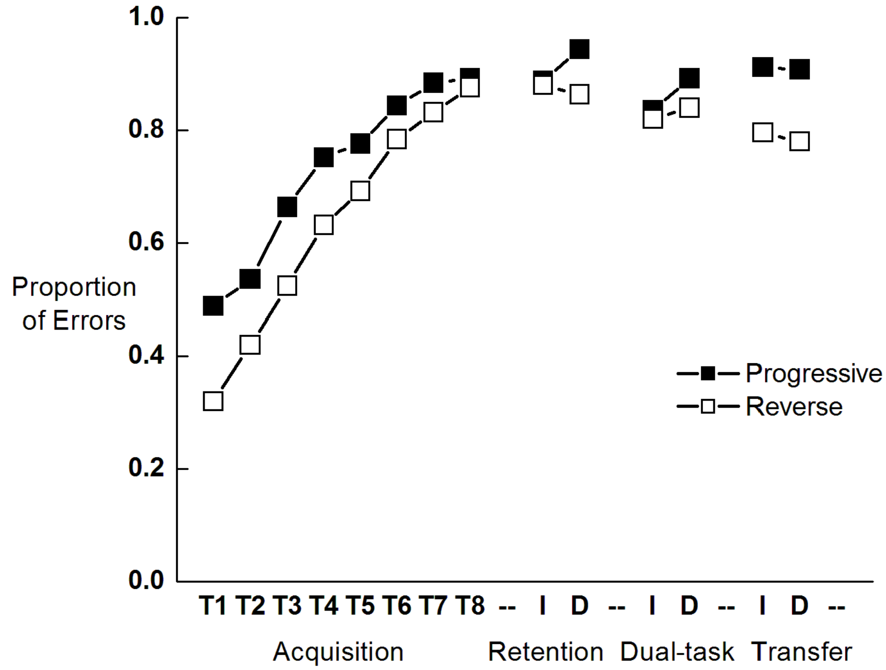

Figure 2.5. The proportion of error trials for each of 8 acquisition targets, retention, dual-task and transfer for experiment 2.

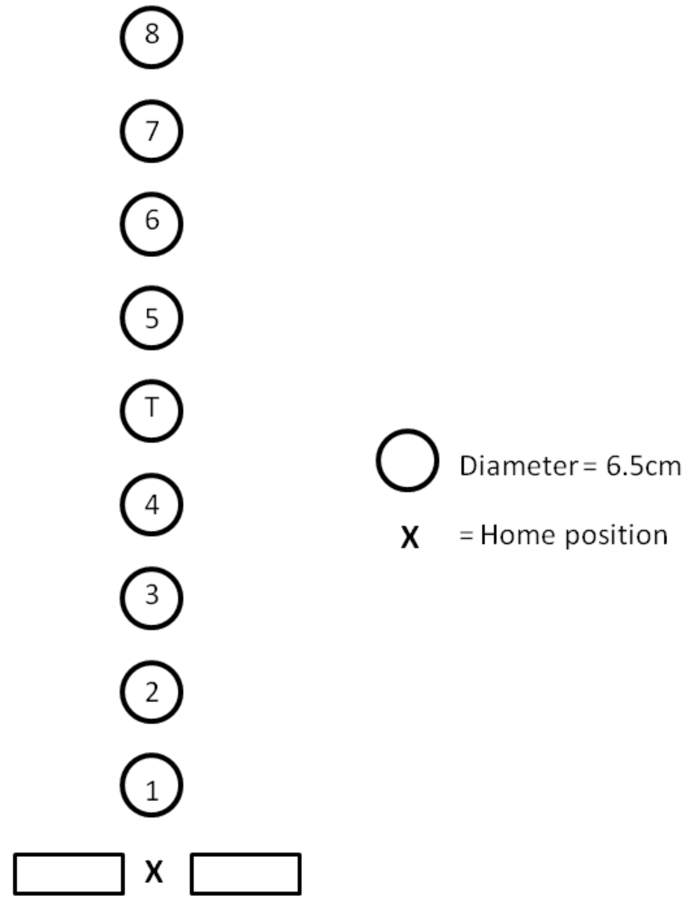

Figure 2.6. The relationships between the eight acquisition target locations, the home position and the transfer target location for experiment 3. During the experiment only one target was displayed at a time.

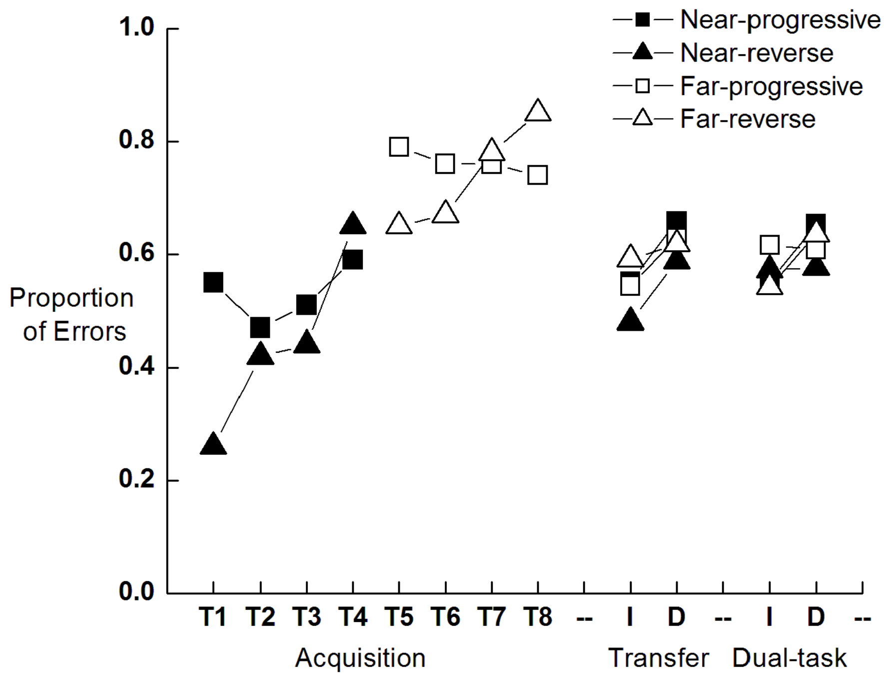

Figure 2.7. The proportion of error trials for each of 8 acquisition targets, dual-task and transfer for experiment 3.

Chapter 3: The facilitation of learner involvement: Yoked versus self-controlled practice schedules and performance on dual-task transfer tests

Abstract

The authors examined yoked versus self-controlled practice schedules to determine their influence in immediate and delayed dual-task performance. The task was to propel a small disc along a smooth table top, with the purpose of stopping it in a specified target area. Participants in the self-controlled schedule group chose the order in which eight acquisition targets, differing in distance from a home position, were practiced during acquisition. Members of a control group followed identical schedules to yoked-participants in the self-controlled group. The authors hypothesized that those in the self-controlled group would perform with less error on retention and transfer tests and with more error on dual-task transfer tests in comparison to those in the yoked group. No differences in performance on retention, transfer, or dual-task tests were found. Possible reasons for the similar performance between groups include the provision of choice over blocks of rather than individual trials and feelings of autonomy in both groups due to choice as to how to propel the disc.

Keywords: Implicit, Explicit, Cognitive Effort, Progression

Chapter 3: Yoked versus self-controlled practice schedules and performance on dual-task transfer tests

Introduction

The optimization of practice scheduling and organization for the acquisition and learning of motor skills can be of benefit in many contexts, such as teaching, coaching, and rehabilitation. Some recent studies (see Sanli, Patterson, Bray & Lee, 2013; Wulf, 2007, for reviews) have examined the utility of providing a learner with control over a portion of their practice context, including the scheduling of practice (e.g., Wu & Magill, 2011). One possible reason why a robust benefit of self control is seen in comparison to those not provided control over practice (yoked groups) is that those in a self-controlled condition engage in more cognitive effort than those in a yoked condition. In particular, it is hypothesized that those provided choice over a portion of practice, such as the scheduling of tasks, have greater demands placed on cognitive processes involved in decision making, monitoring, evaluating, correcting and strategizing (Bund & Wiemeyer 2004; Wu & Magill 2011).

Benefits to learning have been reported for the provision of self-control over a number of aspects of practice scheduling. For example, self-control of the order in which versions of a task are practiced (Keetch & Lee, 2007; Wu & Magill, 2011), the progression though increasingly difficult versions of a task (Brydges, Carnahan, Rose & Dubrowski, 2010), variability of practice (Bund & Wiemeyer, 2004), and when to cease practice (Hodges, Edwards, Luttin & Bowcock, 2011; Jowett, LeBlanc, Xeroulis, MacRae

& Dubrowski, 2007; Post, Fairbrother & Barros, 2011) have all been found to contribute beneficially to learning.

While in the self-controlled practice literature cognitive effort in acquisition is presented as beneficial, the implicit learning literature suggests a detrimental effect of cognitive effort during acquisition on later performance under dual-task conditions. Research indicates that, under specific conditions, the initial learning of a motor task can effectively bypass the earlier cognition-intensive stages of the learning process and in doing so minimize the amount of knowledge that can inappropriately reappear in later stages of learning, especially so when attention demands are put under pressure (Masters, 1992). This is referred to as implicit (Masters, 1992) or U-mode (Berry & Broadbent, 1988) learning. Implicit knowledge is described as knowing without awareness or the ability to articulate knowledge whereas explicit knowledge is made up of information (e.g., facts and rules) of which we are aware and thus can articulate.

Baddeley and Wilson (1994) proposed that explicit processes are required for error detection and elimination, whereas errors are unable to be corrected in situations without explicit knowledge such as in implicit learning. Because of these differences, the performance-supporting knowledge base of implicit learners contains a greater number of error experiences in comparison to explicit learners because the errors cannot be identified and filtered out. This provides a possible explanation for a benefit of the minimization of errors in implicit learning (Baddeley & Wilson, 1994; Maxwell et al., 2001). Maxwell et al. (2001) further suggested that a more implicit form of learning will occur when no (or little) hypothesis testing (involving explicit learning) is required during acquisition. One implication of this suggestion is that practice schedules that encourage cognitive effort, such as a self-controlled practice schedule, may be detrimental to later performance under dual-task transfer conditions, whereas a yoked schedule, with less cognitive effort may produce better performance when specifically tested under dual-task transfer.

The influence of self-controlled versus yoked practice on learning a novel task is typically measured using retention tests, transfer tests or both. Evidence is mixed as to whether implicit learning is beneficial for performance during acquisition, retention and transfer. However, the literature has consistently shown that those who learn a task under implicit practice conditions outperform those under an explicit condition when tested under attention-demanding, dual-task transfer conditions. Therefore, the purpose of the present experiment was to determine if self-controlled and yoked practice schedules would elicit differences in a dual-task transfer test – an experimental prediction that has previously not been tested The implicit learning literature suggests that the characteristics of cognitive effort, such as that which takes place in self-controlled learning contexts, hinder performance on dual-task tests, therefore we hypothesize that: 1) based upon previous comparisons of self-controlled and yoked scheduling of practice (e.g., Wu and Magill, 2011), no differences would be seen between groups during the acquisition session for any of the dependent variables, 2) that the self-controlled practice group would perform with less error, 2-dimensional centroid error (CE) and 2-dimensional variable error (VE) than the yoked practice group on retention and transfer tests and 3) based upon previous comparisons of greater and lesser amounts of cognitive effort in practice (e.g., Maxwell et al., 2001) that the yoked group would perform with less (CE) and (VE) than the self-controlled group on the dual-task tests.

Method

Participants

Twenty young adults participated in the study (10 females and 10 males, *M* age = 21.8 years, *SD = 4.2*). All but one female participant reported a preference to use their right hand. This research was approved by the institutional review board and participants were unaware of the purposes of the experiment. Informed consent was obtained from all participants. Participants were alternately assigned to the self-controlled or yoked group based on gender such that the first female participant was assigned to the self-controlled group while the second female participant was assigned to the yoked group and the first male to the self group and second male to the yoked group, etc. Self- and yoked-pairs were male to male and female to female.

Task

The participants were required to propel a small disc along a smooth table top, with the purpose of stopping the disc in a specified target area (a lighted circle projected onto the surface of the table). Participants could choose to propel the disc however they wished, using their preferred hand as long as the disc was released at the home position and slid along the table top (e.g., did not become airborne or break contact with the table surface).

Apparatus

Participants were seated at a table, 69.5cm high, with a smooth table top measuring 76.5cm x 92cm. The home position was in the center of the table-top, 9 cm from the edge closest to the participant and was indicated with a small red X. White tape was placed 2.5cm from either side of the X to further encourage proper positioning of a 3cm diameter, brown, plastic disc at the start of each trial. An 11mm infrared emitting diode (IRED) was glued to the center of the disc. The weight of the combined disc and IRED was 12.5g. The IRED was attached to an Optotrak 3020 that collected three-dimensional data, sampled at 500 Hz. An Epson PowerLite 50c projector was suspended 109cm from the table top and connected to a computer. Microsoft Power Point was used to project a 6.5cm diameter, white circle onto the table top. The target was displayed as a white circle with a surrounding black background. Nine targets were used in the experiment with the front edge of the target located 3.5, 7.5, 11.5, 15.5, 18.5, 22.5, 26.5, 30.5 or 34.5 cm from the home position (the red X – see figure 1 for a diagram of the targets used). The order in which the targets were presented during acquisition differed by experimental group. For the dual-task tests, a customizable software program (E-prime version 1.2, Psychology Software Tools Inc., Pittsburgh, PA) presented 500 Hz or 1000 Hz auditory tones at intervals of 1500ms. The tones were delivered by two speakers placed 60cm from the participant.

Procedure

An experimenter read a script that described the task to participants in both groups. The two groups were given similar instructions, with the exception that participants in the self-controlled group were told that they would choose the order in which the targets were practiced while the participants in the yoked group were told that the experimenter would choose the order. Both groups were shown the target that would be used for retention as well as a diagram of each of the acquisition targets prior to the beginning of acquisition. Those in the self-controlled group chose the target to which they aimed for each block of trials, with restrictions that each target was to be used for one block of trials and that all targets must be used during acquisition. Those in the yoked group were informed of the target that was to be used for the upcoming block of trials, that each target would only be used once and that all targets would be used during acquisition. The order of targets for the yoked participants followed a schedule chosen by a counterpart in the self-controlled group. In total, the participants completed 200 acquisition trials (25 to each of 8 targets), 50 retention trials (25 immediate and 25 delayed), 50 dual-task trials (25 immediate and 25 delayed), and 50 transfer trials (25 immediate and 25 delayed).

Acquisition began with the instructions; the participants then chose (or were told) which target would be used first on a diagram of all the possible targets. The target chosen then was filled in with the number 1 on the diagram to indicate that it was the first target chosen (or assigned). When participants were ready to begin they placed the disc on the home position and propelled the disc towards the appropriately-lit target (the other targets were not visible). The experimenter then recorded the end location of the disc using Optotrak. The experimenter then raised her hand indicating to return the disc to the home position and begin the next trial. Participants completed 25 trials at each target before choosing or being assigned the next target. At the completion of acquisition participants were asked to work on a “Hard Sodoku Puzzle” (from http://www.sudokupuzz.com) for 10 minutes.

Following the puzzle, participants completed a retention test consisting of 25 trials at target 8 (the farthest acquisition target.) This was followed by a dual-task test, consisting of 25 trials which also used target 8, with the added task of counting the total number of high tones (1000 Hz) that were presented in the random series of high and low (500 Hz) beeps throughout the entire block of trials. Participants were asked to report the total number of high beeps at the conclusion of the series. Participants then completed an additional 25 trials to target 9 which had not been previously practiced (the transfer test). Participants returned one day later for delayed retention, dual-task and transfer tests, which were identical to the immediate tests.

Data Analyses

The dependent variables, proportion of errors per block, two-dimensional centroid error (CE) and variable error (VE) were used to examine performance during acquisition, retention, dual-task and transfer tests. Proportion of errors was defined as the proportion of the total trials, within a block (of 25 trials) where the disc did not land completely within the lighted target. While the proportion of errors per block provides a global measure of task success, two-dimensional CE and VE provide measures of the average magnitude and variability of end-location. CE is a measure of the magnitude of bias from the target centre over a block of trials and VE is a measure of variability relative to the individual’s centroid within each block. Both of these measures take into account the two-dimensional nature of the task and are independent of the axes chosen to record the raw data (Hancock, Butler, & Fischman, 1995).

For acquisition, all three dependent variables were analyzed using separate 2 (groups: Self-controlled, Yoked) x 8 (targets) analysis of variance (ANOVAs) with repeated measures on target. We chose to analyze acquisition by comparing targets rather than blocks of trials as each pair of participants used the targets in a unique order. For example, for block one; every single target may have been used by one or more participants in each of the groups, making comparison between the groups on a block by block basis relatively meaningless. Comparing performance on the same target, regardless of the block in which it was practiced, provides a more meaningful comparison as the same number of participants in each group would have practiced that target at some point during acquisition.

In order to gain insight into pattern order strategy we examined the pattern of target choices made by those in the self-controlled group. Participants that chose to follow a progressive pattern starting at target 1 and ending at target 8, with one or less deviations were labeled with a progressive pattern (n=5). Participants that chose two or more deviations from a progressive pattern were labeled with a random pattern (n=5). In acquisition, all three dependent variables were analyzed using separate 2 (pattern order: progressive, random) x 2 (groups: Self-controlled, Yoked) x 8 (targets) analysis of variance (ANOVAs) with repeated measures on target.

For immediate and delayed retention, dual-task and transfer tests, the dependent variables were analyzed using separate 2 (group: Self-controlled, Yoked) x 2 (sessions:

immediate, delayed) x 3 (tests: retention, dual-task, transfer) ANOVAs with repeated measures on both session and test. To determine if differences in pattern strategy played a role in learning, the dependent variables were analyzed using separate 2 (pattern order: progressive, random) x 2 (group: Self-controlled, Yoked) x 2 (sessions: immediate, delayed) x 3 (tests: retention, dual-task, transfer) ANOVAs with repeated measures on both session and test. In order to determine if participants experienced a change in performance from acquisition to immediate and delayed tests, separate 2 (groups: Self-controlled, Yoked) x 3 (blocks: acquisition, immediate test, delayed test) ANOVAs were conducted for all three dependent variables for both retention and dual-tasks tests. This analysis was not performed for the transfer tests as the target for the tests was not used in acquisition. To examine performance on the counting portion of the dual-task test a 2 (group; self-controlled, yoked) x 2(session; immediate, delayed) ANOVA with repeated measures on session was conducted. Tukey's Honestly Significant Difference (HSD) tests were used to contrast mean differences where appropriate. Alpha was set at 0.05 for all statistical analyses.

Results

Acquisition

For the proportion of errors dependent measure, a main effect was revealed for Target [F (7, 126) = 23.79, p <.001], which generally showed that errors increased for targets located further from the home position. Specifically, the post-hoc tests revealed that target 8 elicited significantly more errors than targets 1-4; targets 5, 6 and 7 elicited significantly more errors than targets 1-3 and the target 4 elicited significantly more errors than targets1 and 2. Post-hoc analyses of a significant interaction between target and group [F (7, 126) = 2.57, p = .017] revealed that for targets 6 and 7, those in the yoked condition performed with significantly more errors than those in the self-controlled condition. There was no significant main effect revealed for group (see the left side of figure 2.)

For CE, a main effect was revealed for target [F (7, 126) =4.31, p <.001], with post-hoc test revealing that target 8 elicited significantly greater CE than targets 1-5. No significant main effect for group or interaction between target and group were revealed.

For VE, a main effect was revealed for target[F (7,126) = 28.63, p <.001], with post-hoc tests revealing that target 8 elicited significantly more variability than target 7 as well as targets 1-5. Targets 6 and 7 elicited significantly more variability than targets 1-4, target 5 elicited significantly more variability than targets 1-3, and target 4 elicited significantly more variability than targets 1 and 2. No significant main effect for group or interaction between target and group were revealed.

In the examination of pattern order strategy it was found that 3 participants chose a progressive schedule, 2 chose a schedule with one deviation from progressive and 5 chose a schedule with more than one deviation from progressive.

A main effect for pattern of order [F (1, 16) =5.00, p= .04] revealed that those who followed a random pattern of targets, regardless of group, performed with less proportion of error in acquisition (M = .54) than those who followed a progressive pattern of targets (M =.67).

Immediate and delayed tests

No significant main effects or interactions were found for retention, dual-task or transfer tests on any of the dependent variables. No significant differences on any of the dependent variables between performance in acquisition and immediate or delayed retention or dual-task tests were revealed (see the right side of figure 2). Also, there were no significant differences in dual-task counting performance between groups or testing sessions.

Discussion

Measures of performance

Using different distances from the home position to the target was effective in manipulating task difficulty, as revealed by the increase in error with increased distance from the home position. In general, participants in the self-controlled and yoked groups performed equally well at each target distance. The exceptions were targets 6 and 7 where those in the yoked group performed with a significantly greater frequency of error trials. The lack of differences between the self-controlled and yoked groups during acquisition was not unprecedented as several studies examining self-controlled versus yoked groups have not found benefits of self-controlled practice in acquisition (e.g., Chen, Hendrick & Lidor, 2002; Wulf, Raupach & Pfeiffer, 2005).

Measures of learning

The absence of differences between the self-controlled and yoked groups in both retention and transfer does not support our second hypothesis. Perhaps both groups experienced enough self-control in choosing how to propel the disc, that additional benefits were not seen for those that were also given the opportunity to choose the order of targets. Recent studies (e.g., Keetch & Lee, 2007) suggest that it is the overall experience of self-control that is the beneficial factor during acquisition rather than the specifics of type of control (Bund & Wiemeyer, 2004; Chen et al., 2002) or amount of control (Patterson, Carter, & Sanli, 2011). Neither group decreased in performance from acquisition to retention nor in dual-task tests on the same target, suggesting that the groups experienced a mutual benefit rather than detriment during acquisition. Bund and Wiemeyer (2004) explained that self-control can create more demands on cognition and requires decision making as well as monitoring, evaluating and correction processes. Although overt decision-making during acquisition occurred when those in the self-controlled group chose the target for the next block of trials, each of the processes discussed by Bund and Wiemeyer (2004) took place only at the *beginning* of each trial for both the self-controlled and yoked groups. Both groups had control over hand positioning and force production on every trial and had the opportunity to make adjustments as needed. Thus, the added seven decisions as to the target presentation order provided to the self-controlled group may not have provided a benefit above and beyond the control used throughout practice. Bund and Wiemeyer (2004) expanded the discussion of cognitive effort suggesting that strategies may make up a large portion of the cognitive effort taking place. In the case of the present experiment, though cognitive and informational strategies could be explored by choice of target presentation order, movement strategies could have been explored throughout acquisition. Wu and Magill (2011) described a pre-determined schedule as inhibitory to choice, evaluation and exploration of strategies. This may be the case when participants are able to choose the order of *individual trials*, such as in Wu and Magill (2011), however this may not hold true in the case of the present experiment where participants were only able to choose *blocks of trials.* In the present study participants may have made changes on a trial-by-trial basis to aspects of the task other than schedule, rather than on a block by block basis.

Another possible explanation for the lack of differences for the tests of learning is that the basic psychological needs of the learners in each group were met equally well (Sanli et al., 2013). Reeve (2009) explained that along with the provision of choice, the provision of solid rationales, use of non-controlling language, acknowledgement of negative feelings and a patient approach can also promote feelings of autonomy and in turn influence behaviour. Since the researcher read the same instructions from a script to each of the participants and both groups were shown the test target at the beginning of practice, each of these additional factors should have been equated and may have led to both groups feeling that the need for autonomy was met. A limitation of the present study is that subjective experience in relation to the task was not measured.

Measures of implicit vs. explicit learning

Regarding the third hypothesis, we predicted that the yoked group would experience decreased conscious processing of task information and decreased use of hypothesis testing strategies based on not being required to make decisions about target order. As discussed previously, participants from both groups may have in fact undertaken some type of cognitive effort. If this was the case, no differences in performance on the dual-task test would be expected.

Another way implicit learning, and therefore decreased conscious processing of task information and decreased hypothesis testing strategies, may have been introduced is through a pattern order strategy of targets that progressed from the easiest to the most difficult distance in order (or nearly so) (Maxwell et al., 2001). Since half the participants in the self-controlled condition chose such a progressive schedule, and accordingly half the yoked participants followed a progressive schedule, it is interesting that neither a yoked practice condition nor a progressive pattern order strategy provided a benefit for performance on dual-task transfer tests. It is possible that a more implicit form of learning was not induced through either manipulation; however it is also possible that implicit learning was induced but was not effective in providing a benefit to performance and dual-task transfer tests.

These surprising results highlight the intricacies of the effects of self-control and future studies should not only attempt to isolate the effects of self-control and yoked schedules when conducting dual task tests but should also explore the effects of layering self-control opportunities throughout practice. Measures of subjective experience in relation to the task would also be of benefit.

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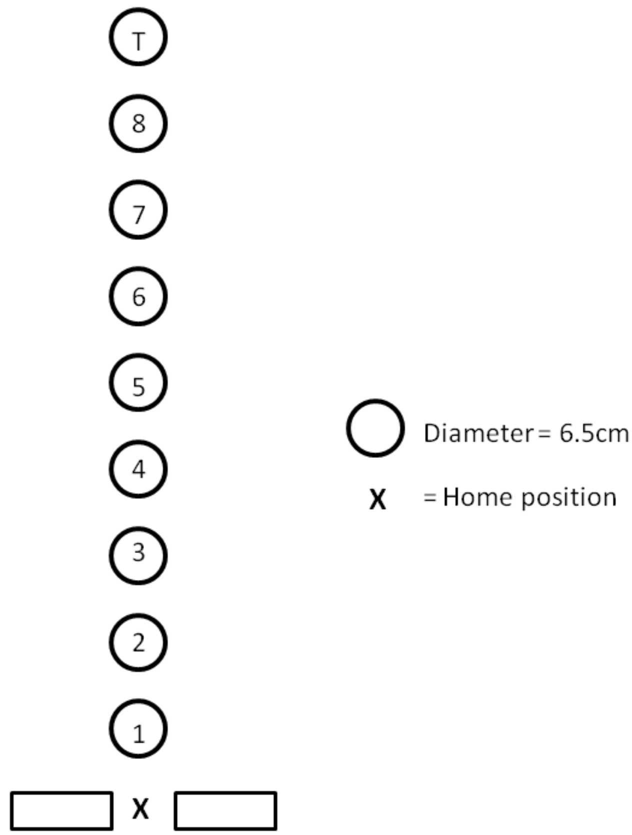

Figure 3.1. Diagram of the location of each of the acquisition and transfer targets in relation to the home position. During the experiment only one target was displayed at a time. Each of the targets is number and is referred to as such in the text.

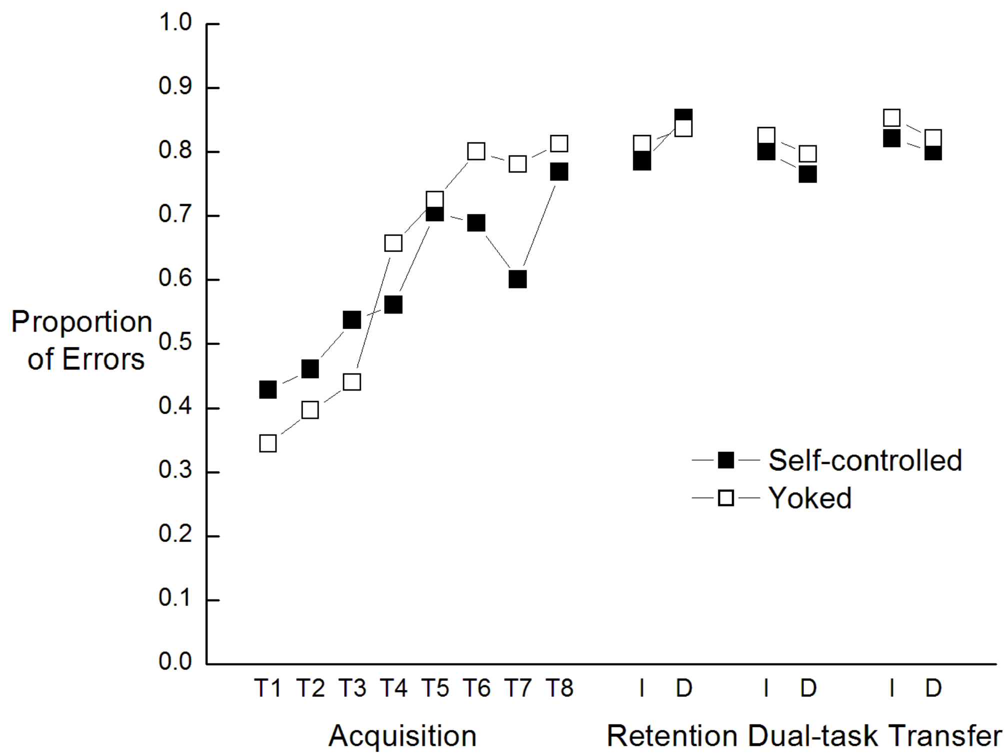

Figure 3.2. Proportion of trials in each block of 25 trials, where the disc did not land within the target for targets one through eight in acquisition as well as immediate and delayed retention, dual-task and transfer tests.

Chapter 4: The facilitation of learner involvement: Understanding self-controlled motor learning protocols through the self determination theory

Abstract

The purpose of the present review was to provide a theoretical understanding of the learning advantages underlying a self-controlled practice context through the tenets of the self-determination theory (SDT). Three micro-theories within the macro-theory of SDT (Basic psychological needs theory, Cognitive Evaluation Theory & Organismic Integration Theory) are used as a framework for examining the current self-controlled motor learning literature. A review of 26 peer-reviewed, empirical studies from the motor learning and medical training literature revealed an important limitation of the self-controlled research in motor learning: that the effects of motivation have been assumed rather than quantified. The SDT offers a basis from which to include measurements of motivation into explanations of changes in behavior. This review suggests that a self-controlled practice context can facilitate such factors as feelings of autonomy and competence of the learner, thereby supporting the psychological needs of the learner, leading to long term changes to behavior. Possible tools for the measurement of motivation and regulation in future studies are discussed. The SDT not only allows for a theoretical reinterpretation of the extant motor learning research supporting self-control as a learning variable, but also can help to better understand and measure the changes occurring between the practice environment and the observed behavioral outcomes.

Keywords: self-control, practice, feedback, motor tasks, motivation, autonomy support

Chapter 4: Understanding self-controlled motor learning protocols through the self determination theory

Introduction

Self-controlled Practice

There are many instances where individuals engage in movement activities, unprompted in order to try something new, challenge themselves on an already learned skill, or develop new skills. Ryan and Deci (2007, p.2) describe this type of inherent inclination to engage in activities as intrinsic motivation. However, there are many additional aspects to practice, performance and learning that can influence the individual and their behaviour. For example, the characteristics of the environment where practice takes place can influence performance and learning as well as the quality of motivation experienced (see Lewthwaite & Wulf, 2012 for recent review). When it comes to learning motor skills, we often rely on the coach or teacher to organize the practice session and provide us with guidance as to how to practice. In the case of a basketball jump shot this may include the coach prescribing how many shots to take and from where, providing demonstrations of proper form and maybe providing feedback after some or all of the physical attempts. In this case, the practice context is defined by the coach (externally) rather than the learner themselves (termed self-controlled).

Challenging the athlete to achieve high levels of movement expertise in an externally defined practice context is commonly referred to as deliberate practice. Deliberate practice is defined by Ericsson, Krampe and Tesch-Römer (1993) as being effortful, designed to improve performance and not be inherently enjoyable. Ericsson et al. (1993) suggests that athletes engage in deliberate practice because they know it will improve their performance, at the expense of being a 'fun' way to practice. Yet, would there be performance advantages if the performer retained some control over their practice context? Would practice become more fun and intrinsically motivating, or would it be burdensome? Would it positively or negatively affect learning?

In recent years, a number of studies in the motor learning domain have examined the advantages of providing the learner control over a portion of their practice context as a method of expediting skill acquisition. Collectively, the motor learning research suggests that providing choice to the learner during their practice positively impacts skill learning compared to when choice is not provided (Wulf, 2007). Learners have been provided the opportunity to control the following practice variables: the receipt of augmented feedback, including knowledge of results (KR; e.g., Patterson, Carter and Sanli, 2011), knowledge of performance (KP; e.g., Patterson and Lee, 2010),concurrent feedback (e.g., Huet, Camachon, Fernandez, Jacobs and Montagne, 2009), the repetition order during multi-task learning, (e.g., Keetch and Lee, 2007) and the amount of physical practice repetitions (e.g., Post, Fairbrother and Barros, 2011). Other practice variables include controlling the frequency of observing a model or instructional video (e.g., Brydges, Carnahan, Rose and Dubrowski, 2010) and the use of an assistive device (e.g., Hartman 2007). The results from the aforementioned experiments suggest that providing the learner with control over a specific practice variable is a robust practice characteristic that facilitates motor skill acquisition. Although these findings appear conclusive, a theoretical understanding of the mechanisms underlying these advantages has remained elusive. Therefore, our purpose for the present review is to provide a theoretical interpretation of the motor learning advantages underlying a self-controlled practice context through the tenets of the self-determination theory (SDT).

Self-determination theory

Self-determination theory is a macro-theory comprised of several micro-theories that can inform predictions made in self-controlled motor learning studies. Ryan and Deci (2007, p.7) discussed three of these micro-theories in relation to sport and exercise and we have further applied them to a motor learning, self-controlled practice context.

The first of the micro-theories presented in Figure 1 (Basic psychological needs theory) addresses the three basic psychological needs of autonomy, competence and relatedness which can influence the quality of motivation experienced by an individual. Autonomy involves feelings of willingness and choice in regards to activities undertaken; relatedness refers to feelings of closeness to other people; and competence involves feeling able to master challenges and having effective interactions with the environment (Katz and Assor, 2007). The quality of motivation is *enhanced* when any of these needs is satisfied and *optimized* if all three are satisfied. This micro-theory provides an illustration of the beginning of the motivational process and can illuminate individual differences in how well each of the needs are satisfied within a given practice context (Ryan and Deci 2007, p 7).

In the motor learning literature examining self-control, satisfaction of the psychological needs has not been explicitly examined, although they may have been influenced by features of the skill acquisition practice environment. As we will illustrate below, environmental or procedural supports for autonomy, competence and relatedness may be included within the design of the practice contexts used in motor learning studies. Some designs may also include characteristics that could be detrimental to the satisfaction of the psychological needs for autonomy, competence and relatedness.

The second micro-theory presented in figure 1 is the Cognitive Evaluation Theory which describes circumstances within the person and the environment that can lead to behaviour that is intrinsically or extrinsically motivated. If the behaviors undertaken by participants are *intrinsically-motivated*, an activity will be performed out of interest, enjoyment and/or satisfaction, where the purpose of the activity is the activity itself without the influence of consequences or threats of external or internal origin (Deci, Ryan and Williams, 1996). In contrast, behaviour can be extrinsically motivated, in which case the activity is performed with the intention of supporting personally held values, avoiding guilt, obtaining approval or a reward or avoiding punishment (Deci et al., 1996).As mentioned earlier, deliberate practice is undertaken as a means to improve performance, rather than for purely intrinsic reasons. According to Ericsson's definition, deliberate practice would be an example of an *extrinsically-motivated* behavior.

The third micro theory is the Organismic Integration Theory, which postulates that extrinsic motivation can be further divided across a continuum of four subtypes of behavioural regulation. At one end of the scale is *external regulation* which represents activities controlled by external demands or contingencies such as rewards or punishments (Deci et al., 1996). *Introjection* represents activities controlled by internal demands or contingencies such as guilt or embarrassment (Deci et al., 1996). Behaviors that are regulated by introjections are more likely to be maintained than externally-regulated behaviors, but are still relatively unstable in terms of maintenance (Deci and Ryan, 2000). *Identified regulation* represents activities chosen because the person identifies with the importance of the activity and it may be important to achieve self-selected goals. Activities that are regulated by indentified regulation are associated with increases in commitment, performance and maintenance, compared to those discussed above (Deci and Ryan, 2000). Closest to intrinsic motivation is *integrated regulation*, which is represented by activities that are experienced freely because they have been integrated within the person's sense of self. The difference between intrinsic motivation and integrated regulation is that integrated regulation is performed freely because it is important to an important outcome and not for the sake of the activity itself (Deci et al., 1996). These different types of motivation fall along a continuum of feeling of ownership of the behavior. In other words, the amount of *self-determined motivation* increases in moving from external- to introjected- to identified- and finally integrated behavior (Katartzi and Vlachopoulos, 2011). According to the SDT, the process of internalizing motivation occurs when moving along the continuum from external and controlling to ones that are more autonomous (Katartzi and Vlachopoulos, 2011). By definition, deliberate practice is extrinsically motivated, but factors within the environment, such as supports for autonomy could influence self-determined motivation to align closer to indentified regulation. Thus, the reasons participants engage in the behavior requested of them falls somewhere along the continuum from external to integrated regulation. The practice environment during acquisition, including the provision of choice such as in a self-controlled practice environment can influence where on the continuum any one participant may fall by either facilitating or inhibiting internalization in the learning process.

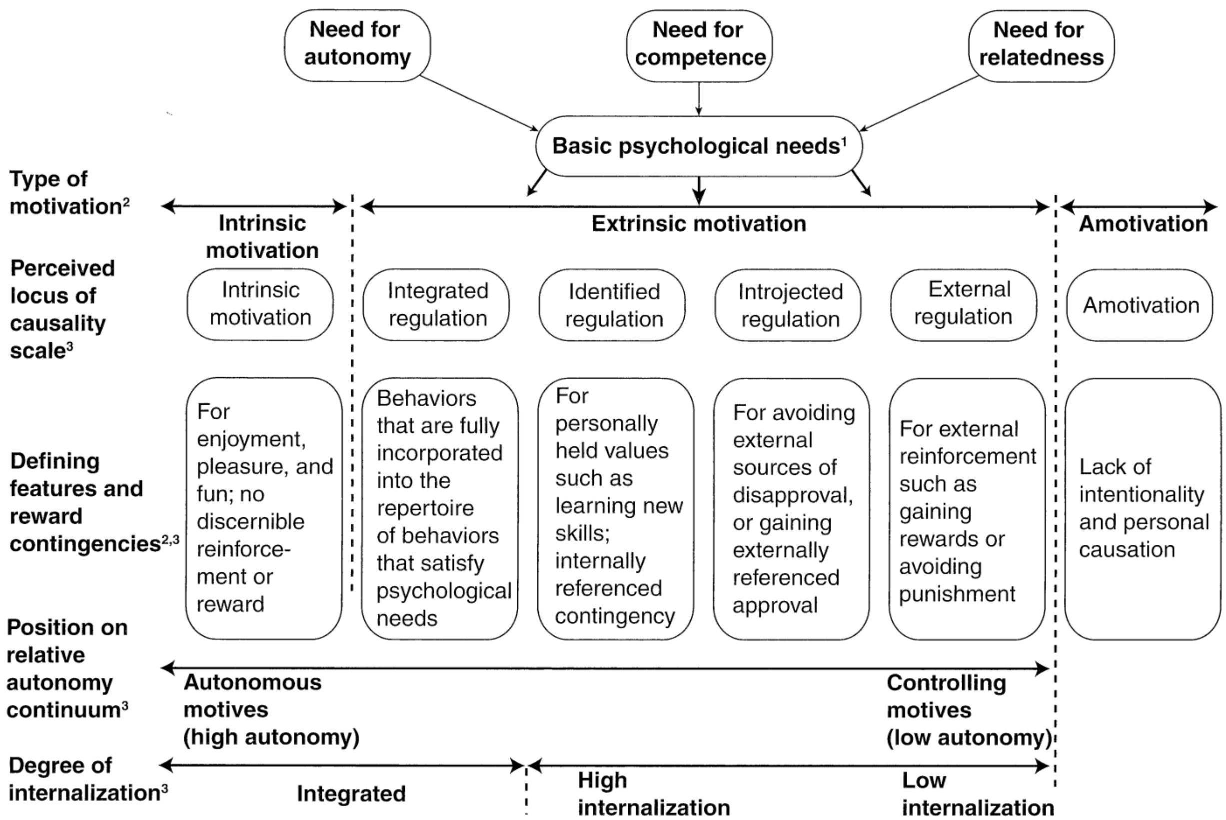

Figure 4.1. Schematic representation of self-determination theory illustrating the features of three of the component subtheories: Basic psychological needs theory, cognitive evaluation theory, and organismic integration theory. © Martin S. Hagger. Reprinted, with permission, from R.M. Ryan and E.L. Deci, 2007, Active human nature: Self-determination theory and the promotion and maintenance of sport, exercise, and

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The SDT can be used to make predictions regarding motor learning within a particular practice protocol. The practice environment can be structured to provide varying levels of support for the satisfaction of the need for the three basic psychological needs, which subsequently can affect self-determined motivation and behaviour. The consequences of internalization (or lack thereof) may be evaluated by looking at changes in cognition (concentration), affect, and behaviour (Katartzi and Vlachopoulos, 2011). Studies in the motor learning domain infer persistent changes to motor behaviour from measures such as movement time (e.g., Patterson et al., 2011), movement accuracy (e.g., Wrisberg and Pein, 2002), and movement form (e.g., Bund and Wiemeyer, 2004). In contrast, studies from the self-regulated learning literature examining changes in the social environment infer changes in self-determined motivation using such measures as engagement (e.g., Reeve, Jang, Carrell, Jeon and Barch, 2004), autonomous or intrinsic motivation (e.g., Vansteenkiste, Simons, Lens, Sheldon and Deci, 2004), and positive affect (e.g., Joussemet, Koestner, Lekes and Houlfort, 2004). One factor suggested to underlie the learning advantages in a self-controlled practice motor learning context is the increased motivation of the learner to adhere to the task goal. Despite the importance of motivation in facilitating motor skill learning (see Lewthwaite & Wulf, 2012 for review), a limitation of the motor learning research examining the benefits of a self-controlled practice context is that heightened motivation underlying the learning advantages has been assumed rather than directly measured and quantified.

The purpose of the present review is to offer an updated theoretical interpretation of the learning advantages commonly demonstrated in practice contexts providing the learner control over a portion of their practice context. We reviewed 26 peer-reviewed, empirical studies from the motor learning and medical training literature (requiring learning a motor skill), examining the learning benefits associated with the learner controlling at least one practice variable. Though several published abstracts were identified as relevant, they were not included in this review based on the limited information regarding the methodology. As well, studies that included clinical populations were also excluded. The focus of this review will be to: 1) examine and make explicit links from the body of motor learning literature reviewed examining self-control to each of the three micro theories of the SDT, and 2) present explicit links between the SDT and the self-controlled practice contexts used to facilitate motor learning.

The environment during acquisition

Supports for autonomy, competence and relatedness in the practice environment

Su and Reeve (2011) operationally defined five interpersonal conditions of autonomy support (based on Deci et al., 1994; Williams et al., 1999; Reeve et al., 2004) which can be identified within the motor learning protocols as a method of describing the psychological aspects of the environment during practice. Consistent across the reviewed motor learning experiments using self-control is the provision of *choice*, the most relevant of the conditions identified by Su and Reeve (2011). The choice provided to a learner over a specific practice variable (e.g., KR, assistive device, repetition schedule, etc.) is the common manipulation in the reviewed motor learning research) Table 1 provides an overview of key features of the practice environment for the papers reviewed. The use of a yoked condition in the motor learning research provides a method of distinguishing between the cognitive or motivational processes underlying the learning advantages of self-control, or the frequency at which the motor learning variable was received as the mechanisms responsible for learning. The yoked condition replicates the structure of the practice context individualized by a self-controlled counterpart, yet without the choice. This practice context resembles a *controlling* (yoked) verses *autonomy supportive* (self controlled) environment as outlined by the SDT. The yoked group is not offered choice within the protocol and thus the protocol could be viewed as controlling because it decreases the opportunity for a person to experience a sense of autonomy.

One benefit of allowing participants control over at least one aspect of their practice environment is the opportunity for the learner to tailor their practice to their own individual needs and capabilities (Wulf, 2007). For example, participants choosing to use ski poles to facilitate their motor performance on every practice attempt during an acquisition session would be considered a less challenging environment than if they never asked for the ski poles or if they gradually faded the requests across the acquisition period. The opportunity for the learner to adjust their practice environment as a method of optimally challenging the cognitive and motor processes of the learner provides support for the basic need for feelings of competence as well as autonomy as outlined by Su and Reeve (2011).

The other four interpersonal conditions identified by Su and Reeve (2011) as having an impact on feelings of autonomy are; 1) the provision of a meaningful rationale,

2) acknowledgement of feelings that may be negative, 3) attempts to nurture inner motivational resources and 4) the use of non-controlling language. The provision of a meaningful rationale or explanations as to why the activity would be useful to the learner can facilitate the learners' understanding of why they are being requested to complete the task (Su and Reeve, 2011). Acknowledging that what is being requested of the learner may not be desirable and that any feelings of conflict are legitimate can also support feelings of autonomy (Su and Reeve, 2011). Though, no specific instances of acknowledging negative feelings were reported in the reviewed motor learning literature, it is impossible to rule out that feelings of fatigue or boredom may have occurred in participants, especially in the yoked or control conditions where they were not encouraged to be actively involved in their learning, and as a result, demonstrated inferior learning to their self-controlled counterparts. Attempts to nurture inner motivational resources are described by Su and Reeve (2011) as the vitalization of the learners' enjoyment, needs satisfaction or sense of challenge or curiosity, during the activity. In other words, explicit attempts to satisfy the need for autonomy, competence or relatedness can be found (though rarely) in the motor learning, self-controlled literature. The use of non-controlling language means the avoidance of words such as "should"," must" and "have to" to convey a sense of choice or flexibility (Su and Reeve, 2011). Although, the specific scripts or instructions are often not included in the methodologies of the motor learning experiments reviewed, some examples of both non-controlling and controlling language were identified. For example, Brydges et al. (2010) told participants that "if you feel that you have learned the task proficiently, you do not need to stay the full 2 hours",

which could be viewed as non-controlling whereas Bund and Wiemeyer (2004) and Janelle et al. (1997) told participants to focus on movement form or mechanics rather than outcome, which could be viewed as more controlling.

In summary, we can see that there are many opportunities to influence the amount of support for feelings of autonomy, competence and relatedness within a motor learning protocol. Presently in the motor learning, self-controlled literature, some examples of both supporting and thwarting factors can be identified. In the future, explicit attempts to address the support of the three basic needs in the design, execution and reporting of experiments would provide a more complete picture of the influence of motivation on learning of a motor skill.

In the following sections of this chapter, instances of these conditions and other indications of support for the three basic needs central to the basic psychological needs theory will be discussed in the context of protocol design.

Control of augmented feedback

The most commonly manipulated aspect of the learning environment is the scheduling of augmented feedback. The learner has been provided the opportunity to control three types of feedback in the motor learning literature examining self-control. Knowledge of results (KR) informs the learner about the outcome of their motor action compared to the goal, whereas knowledge of performance (KP) provides information to the learner regarding the technical aspects (e.g., movement form). Both KR and KP are provided to the learner *after* the motor task has been completed (Schmidt and Lee, 2011, p.394). Concurrent feedback on the other hand, provides information to the learner in regards to their approximation of the task goal *during* the performance of the motor task (Schmidt and Lee, 2011, p.394).

A number of studies have provided participants the opportunity to request KR (e.g., Chen Hendrick and Lidor, 2002) or KP (e.g., Janelle, Barba, Frehlich, Tennant and Cauraugh, 1997) after the completion of each trial or after a pre-determined number of trials. Huet et al. (2009) provided learners the opportunity to request concurrent feedback during acquisition trials, to the advantage of learning. The motor tasks examined in the aforementioned studies have ranged from fine-motor key-pressing tasks with specified timing goals (Chen et al., 2002) to gross-motor tasks such as a ball toss, (Janelle et al., 1995; 1997), and a virtual reality task (Huet et al., 2009).

In addition to a group provided with self-control, at least one yoked control group was included in the experiments examining self-controlled feedback. Participants in these groups replicated the augmented feedback of that chosen by a self-controlled counterpart, but without the choice. In some experiments, additional experimental or control groups were incorporated to examine the utility of a self-controlled context. For example, Janelle et al. (1995) included control groups with feedback provided for varying percentages of the total number of acquisition trials, in addition to the self-controlled feedback and yoked conditions as a method of examining the influence of the absolute amount of KP and self-control. In a follow-up experiment, Janelle et al. (1997) expanded the control groups used by Janelle et al. (1995) to include one group that received no augmented information during acquisition. Chen et al. (2002) included a self-controlled KR condition and an experimenter-induced KR condition along with their respective yoked counterparts to examine the effects of differing levels of autonomy in the choice of whether or not to receive KR. In another example, Patterson et al. (2011) manipulated the amount of KR provided in the first half of acquisition (all trials, a faded schedule or a self-controlled schedule), prior to a period of self-controlled KR. A yoked group was also included for each of those conditions. Hansen et al. (2011) included a self-controlled KR group and two different yoked groups. The first yoked group replicated the KR schedule of a self-controlled counterpart (e.g., traditional yoked condition), whereas the second yoked group were provided an absolute number of KR trials, based on the number of KR trials requested by the self-controlled counterpart, and were subsequently provided the opportunity to request KR based on their provisional limit. The experimental groups differed in the cognitive demands placed on the learner. Those in the yoked condition with control over their receipt of KR had fewer opportunities to request KR and experienced having higher cognitive demands compared to the traditional yoked or self-controlled group. According to the SDT, the yoked group provided choice over the number of times and the timing of feedback would be expected to experience a greater feeling of autonomy than those given choice over their receipt of KR on all acquisition trials. In attempts to examine factors that modulate the learning advantages of a self-controlled KR context, Chiviacowsky and Wulf (2005) asked learners whether or not they required KR in one of two conditions, either before or after the trial. Chiviacowsky, Wulf, Medeiros, Kaefer and Wally (2008) recently examined whether usefulness of a self-controlled KR context for children was based on the proportion of trials for which KR was requested. Though in these instances the experimental groups were all provided choice, a support for feelings of autonomy, other factors differing between groups may have had an influence on motivation. For example, those who were able to choose to receive KR after a trial rather than making the choice prior to an attempt, could use a request for KR after what they felt to be a good attempt as a way to support feelings of competence while the group that chose prior could not.

Examples of meaningful rationales are limited within the motor learning protocols examining self-control. However, Janelle et al. (1997) explained to learners that they would learn to throw better through improved form rather than just focusing on outcome. In many studies examining a self-controlled practice schedules, participants were told to request task information *only when necessary* as a method of increasing the meaningfulness of the task related information (e.g., Chiviacowsky and Wulf, 2002). Several of the studies specifically indicated that participants were told that they would later be tested *without* the use of the practice variable that they were able to control during the acquisition period (e.g., Chiviacowsky and Wulf, 2002). Such instructions to the learners suggest a rationale for practicing at least some of the time without the requested practice variable. The encouragement of participants *to do their best* by Janelle et al. (1995) is an instance of nurturing inner motivational resources. The opportunity to request feedback in order to confirm a good trial or to correct a poor trial may have differential effects on feelings of competence, subsequently providing the opportunity to nurture inner motivational resources.

Some of the language used in the reviewed motor learning literature could be considered controlling rather than autonomy supportive. For example, Janelle et al. (1997) told participants to focus on movement form or mechanics rather than outcome. Chiviacowsky and Wulf (2002, 2005) told their participants in the self-controlled group that they "had to" control feedback frequency. Some self-control opportunities presented to learners came with qualifiers such as "request feedback only when you think you need it" (e.g., Chiviacowsky and Wulf, 2002) or "request feedback on 3 of 10 trials in each block" (Chiviacowsky and Wulf, 2005). These qualifiers may have been viewed as controlling and therefore would detract from the feeling of autonomy. Further, protocols that provide an opportunity for the learner to control one or more aspects of augmented feedback have been manipulated in various ways that either provide more or less support for feelings of both autonomy and competence.

Control of access to video or augmented information

Studies such as Wrisberg and Pein (2002) provided the learner the opportunity to control when to view a videotaped demonstration of the to-be-learned motor task. The studies providing control over access to a video demonstration used gross motor sport skills such as a badminton serve, a table tennis stroke and basketball jump shot.

Brydges et al. (2009) provided learners with access to specific instructions in regards to completion of a fine-motor surgical suturing skill while Patterson and Lee (2010) required learners to produce novel cursive handwriting characters while being provided the opportunity to view a visual display of the required character either before or after the required motor action. In most cases, at least one yoked control group was included, which followed an augmented information or viewing of a video schedule identical to one chosen by a self-controlled schedule counterpart, but without the choice. Wrisberg and Pein (2002) did not make use of a yoked condition, but instead used a control group that viewed the model on all trials and another control group that viewed the model on none of the acquisition trials. Both control groups in Wrisberg and Pein's (2002) study were in situations that could be considered more controlling than the self-controlled group. One group may have had to watch a model when they did not want to while the other group may have wanted to view a model but were unable to. In both cases participants may have felt they were in a controlling environment. Bund and Wiemeyer (2004), Brydges et al. (2009) and Patterson and Lee (2010) each made use of two different self-controlled conditions with respective yoked counterparts. Differences in the satisfaction of the three basic needs may have occurred between self-control groups, despite the common autonomy supportive condition of the provision of choice. Bund and Wiemeyer (2004) provided one group with control over what was determined to be a preferred variable (viewing of a model) and another over a non-preferred variable (direction and length of serves). This manipulation addresses a possible difference in feelings of autonomy (preferred variable) and control (non-preferred variable.) Brydges et al. (2009) yoked participants to the specific portions of the video viewed for both a process goal and an outcome goal subgroup. The manipulation of goal type may have created differences in the feelings of autonomy and competence. Patterson and Lee (2010) asked one group to decide whether or not to view the appropriate typographical symbol prior to the beginning of the trial and the other group after the trial was completed. Similar to Chiviacowsky and Wulf (2005) with KR, those that were able to choose to view the symbol after an attempt could choose to confirm a perceived good trial influencing feelings of competence, whereas those choosing prior to an attempt could not. These study designs allowed the examination of factors that modulated the usefulness of a self-controlled context.

Evidence for the provision of meaningful rationale can be seen in the explanation by Wulf et al. (2005) to participants that the video of the expert model performing a basketball jump shot could be used as a general reminder or for the observation of specific details. In another example, Bund and Wiemeyer (2004) stressed to participants that increased accuracy would result from correct form during practice, however focussing on movement form or mechanics rather than outcome suggests these instructions are controlling rather than autonomy supportive. As a more explicit example of providing a meaningful rationale, Brydges et al. (2009) provided participants with a list of goals for the to-be-learned motor task suggesting a rationale as to why the task should be performed in a certain way.

Control of use of an assistive device

Wulf and Toole (1999), Wulf et al. (2001) and (Hartman 2007) provided learners the opportunity to use an assistive device (ski poles) during performance of a ski simulator task or a pole for a stabilometer task. All three of the above studies used both a self-controlled use of the assistive device condition as well as a yoked condition. Wulf et al. (2001) had participants complete acquisition in self-controlled/ yoked pairs in order to examine if the benefits of a self-controlled schedule would persist under dyad conditions, where motivational level may have been similar between the groups.

In all three studies discussed above, it was explained to participants that use of an assistive device to aid balance during acquisition could facilitate learning of a task and participants were told that they would later be tested *without* the use of the device. This information provided to the learners is suggested to resemble the provision of meaningful rationales for the use and scheduling of the assistive devices. In addition the study by Wulf et al. (2001) provides the only example to our knowledge in the current motor learning self-controlled literature where the satisfaction of feelings of relatedness may have come into play.

Control of practice schedule and task difficulty

Learners have also been provided the opportunity to control the practice schedule itself. This includes the order of practicing multiple motor tasks during acquisition (e.g., Keetch and Lee, 2007) or the total number of physical trials to be completed (e.g., Post et al., 2011). Keetch and Lee (2007) compared self-controlled and yoked practice conditions to externally-defined, blocked and random practice schedules for both easy and hard versions of a motor task. Wu and Magill (2011) compared a self-controlled condition controlling the practice order of timing goals, and a respective yoked condition.

Andrieux, Danna and Thon (2012) recently provided participants the opportunity to control the difficulty of the motor task. Manipulating task complexity was accomplished by asking participants to choose the racquet width to be used in an interception task. Andrieux et al., (2012) showed participants the most difficult version of the task at the beginning of acquisition and explained that it would be used in the later retention tests. This instance is an example of providing a meaningful rationale for the choice of task difficulty where the ability to choose task difficulty could appeal to the learner's sense of challenge. In contrast, Post et al. (2011) provided a monetary incentive based upon performance in retention. However, introduction of an external reward such as money has been shown to be controlling, rather than supporting of an autonomous context (Joussemet et al., 2004).

Control of multiple aspects of the practice environment

Three of the studies reviewed provided the learner the opportunity to control multiple aspects of the learning environment. For example, Brydges et al. (2010) allowed participants in one condition control over both the *timing of progression* from easier to more difficult versions of the task and *when to stop practice.* Those in a second condition were provided the freedom to move between all difficulties of the task as well as when to end practice. A yoked group as well as a proficiency-based progression group were also included. Brydges et al. (2010) required nursing students to learn an intravenous catheterization on a simulator. In another example, Jowett et al. (2007) provided all participants with unlimited access to a multimedia training video during acquisition of a novel surgical knot-tying task. Participants were also provided the opportunity to cease practice when they felt they had reached a proficient level of skill. Jowett et al. (2007) did not include a yoked group but rather split the self-controlled group into two conditions, one of which allowed participants to stop practice when requested, and those in the other condition were prescribed additional practice after the decision to stop had been made. Hodges et al. (2011) included two conditions where participants were given control over the number of attempts made, the order of trials when practicing the three disc throwing tasks, the amount of rest during practice, the frequency of access to verbal instructions, a video replay of the just-completed trial and a video demonstration. Participants were also able to select which part of the attempt that they could receive instruction about. The two self-controlled groups differed in terms music playing expertise, however all participants were novices in the disc- throwing tasks used in the experiment. A group yoked to the music experts was also included.

Similar to Brydges et al. (2009), Brydges et al. (2010) provided participants with a list of goals for the to-be-learned motor task suggesting a rationale as to why the task should be performed in a certain way. They also made use of process goals which might be considered nurturing to inner motivational resources. In the Brydges et al. (2010) protocol, participants were afforded the opportunity to directly manipulate the difficulty of the task for any given trial, by choosing when to progress to a higher fidelity (more difficult) simulator, appealing to the learners' sense of challenge. Brydges et al. (2010) also provided a good example of non-controlling language telling participants "if you feel that you have learned the task proficiently, you do not need to stay the full 2 hours."

Jowett et al. (2007) included an example of differing levels of autonomy support between groups. They provided choice as to when participants believed they had reached a sufficient level of proficiency and could decide when to stop practice. One group did stop practice when requested, but another group was required to complete additional practice, which would undermine feelings of autonomy. Similar to Post et al. (2011), discussed above, Hodges et al. (2011) provided a monetary incentive based upon performance in retention, potentially undermining feelings of autonomy.

Table 4.1.

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
Andrieux, Danna & Thon (2012)	Computer-based target interception	Task difficulty	CE distance between center of racquet and target & indication if target interception was early or late VE distances from the target AE difference between target and end position Number of intercepted targets	Self-control* Yoked	A Completed on one day IR 15 minutes post acquisition DR 24 hours post acquisition
Brydges, Carnahan, Rose & Dubrowski (2010)	Intravenous catheterization using simulators	Practice schedule	Measures of technical skills (GRS and CL) Global clinical performance (IPPI rating tool) Time spent on each simulator Time spent and exact portions of video viewing Total number of trials on each simulator Rating of educational value of each simulator	Open-ended* Progressive* Proficiency-based Yoked control	A Completed on one day IPT DT one week post acquisition

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
Brydges, Carnahan, Safir & Dubrowski (2009)	Wound closure skills	Access to video	Hand motion efficiency (time on task and total number of hand movements) Measure of technical skills (GRS and CL)	Self-process* Control-process Self-outcome* Control-outcome	A Completed on one day DR one week post acquisition DT one week post acquisition
Bund & Wiemeyer (2004)	Forehand topspin table tennis stroke	Access to video Practice schedule	Accuracy score Form score based on a number of criteria assessed by independent raters	SC+* SC-* YO+ YO-	A Completed on one day IR five minutes post acquisition DR 24 hours post acquisition
Chen, Hendrick & Lidor (2002)	Timed key-pressing	Augmented feedback	VE variability in the difference between goal and actual times |CE| difference between goal time and actual performance	SI-KR* EI-KR* SI-Yoked EI-Yoked	A Completed on one day IR five minutes post acquisition DR 48 hours post acquisition
Chiviacowsky & Wulf (2002)	Key pressing with absolute and segmental goal times	Augmented feedback	AE difference in time between goals and actual performance (both relative and overall timing)	Self* Yoked	A Completed on one day DR 24 hours post acquisition DT 24 hours post acquisition
Chiviacowsky & Wulf (2005)	Key pressing with absolute and segmental goal times	Augmented feedback	AE difference in time between goals and actual performance (both relative and overall timing)	Self-after* Self-before*	A Completed on one day DR 24 hours post acquisition DT 24 hours post acquisition
Chiviacowsky, Wulf, Medeiros, Kaefer & Tani (2008)	No-vision, beanbag toss	Augmented feedback	Accuracy score	Self-control* Yoked	A Completed on one day DR 24 hours post acquisition
Chiviacowsky, Wulf, Medeiros, Kaefer & Wally (2008)	No-vision, beanbag toss	Augmented feedback	Accuracy score	More KR* Less KR*	A Completed on one day DR 24 hours post acquisition
Hansen, Pfeiffer & Patterson (2011)	Timed key-pressing	Augmented feedback	Number of error trials CE amount of	SC* TY YSC*	A Completed on one day DR 24 hours

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
			time and whether attempt was too fast or too slow VE variability in the difference between goal and actual times |CE| difference between goal time and actual performance		post acquisition DT 24 hours post acquisition
Hartman (2007)	Stabilometer	Use of assistive device	Time in balance	Self-control* Yoked	A Practiced on two consecutive days DR 24 hours post acquisition
Hodges, Edwards, Luttin & Bowcock (2011)	Right-handed backhand Left-handed backhand Right-handed forehand flying disc throws	Practice schedule Access to video Access to augmented information	3D RE score distance between landing and target Movement form score from an eight-point scale	Expert_Self-Schedule* Novice_Self-Schedule* Novice_Expert-Schedule	A Completed on one day DR 48 hours post acquisition
Jowett, LeBlanc, Xeroulis, MacRae & Dubrowski (2007)	One-handed square knot	Access to video Practice schedule	Expert global rating scale assessments Economy of hand movements (total time and number of hand movements and path length)	Additional Practice Group* No Additional Practice group*	A Completed on one day DR one week post acquisition
Huet, Camachon, Fernandez, Jacobs & Montagne (2009)	Walk through a virtual corridor and pass through open doorways at the correct aperture	Augmented feedback	Variability of walking speed Success rate Variability in current error Variability in current error at time of FB request	Control Gauge* Ghost doors* Yoked	A Practiced over four days PT on all four days of acquisition DR 24 hours post acquisition
Janelle, Barba, Frehlich, Tennant & Cauraugh (1997)	Tennis ball throw with non-dominant hand	Augmented feedback	MRE distance between landing and target SRE distance between landing and target	KR only Summary KP Self-controlled KP* Yoked control	A Completed on two days, separated by two days DR four days post acquisition

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
			BVE variability in distance between landing and target Developmental stage of throwing Throwing speed		DT four days post acquisition
Janelle, Kim & Singer (1995)	Underhand golf ball toss	Augmented feedback	AE difference between target and end position of trials	Performance – summary Fifty percent Subject-controlled* Yoked Control Control	A Completed on one day IR 10 minutes post acquisition
Keetch & Lee (2007)	Sequence of aim –and-click movements with a computer mouse	Practice schedule	Pattern error (incorrect button press) Cursor error MT	Hard-Random Hard-Blocked Easy-Random Easy-Blocked Hard –Yoked Hard-Self-Regulated* Easy-Yoked Easy-Self-Regulated*	A Completed on one day DR 24 hours post acquisition
Patterson & Carter (2010)	Key-pressing with absolute and segmental goal times	Augmented feedback	% |CE| difference between goal time and actual performance	Self-regulated* Yoked	A Completed on one day IR 15 minutes post acquisition DR 24 hours post acquisition DT 24 hours post acquisition
Patterson, Carter & Sanli	Timed key-pressing	Augmented feedback	VE variability in the difference between goal and actual times |CE| difference between goal time and actual performance	Self-Self* All-Self* Faded-Self* Yoke-Yoke All-Yoke Faded-Yoke	A Completed on one day IR 10 minutes post acquisition DR 24 hours post acquisition DT 24 hours post acquisition
Patterson & Lee (2010)	Production of PDA symbols matching English cues	Access to augmented information	Recall	Proactive Self-regulated* Proactive Yoked Proactive	A Completed on one day IR 10 minutes post acquisition DR 48 hours post acquisition

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
				every trial Retroactive Self-regulated* Retroactive Yoked Retroactive every trial	
Post, Fairbrother & Barros (2011)	Dart throw with non-dominant hand	Practice schedule	VE variability in distance from the target RE distance from innermost target to the tip of the dart Average preparation time Recall of number of trials completed	Self-control* yoked	A Completed on one day DR 24 hours post acquisition DT 24 hours post acquisition
Wrisberg & Pein (2002)	Badminton long serve	Access to video	Accuracy score Expert scores for 5 task-specific components	ALL LC* NM	A Practiced over three days DR 24 hours post acquisition
Wu & Magill (2011)	Key-pressing with relative time sequences	Practice schedule	AE deviation of performance from goal time E overall performance accuracy taking response bias and variability into account RTE	Self-control* Yoked	A Completed on one day IT five minutes post acquisition DT 24 hours post acquisition
Wulf, Clauss, Shea & Whitacre (2001)	Ski simulator	Use of assistive device	Amplitude Frequency of movements Relative force onset of movements	Self-control* Yoked	A Practiced on two consecutive days DR 24 hours post acquisition
Wulf, Raupach & Pfeiffer (2005)	Basketball jump shot	Access to video	Accuracy score Movement quality score from 6 task-specific criteria	Self-control* Yoked	A Completed on one day DT one week post acquisition

Elements of Self-Controlled Practice Environment

	Motor Task Practiced	Practice variable controlled	Dependent Variables	Experimental groups	Temporal organization of experimental protocol
Wulf & Toole (1999)	Ski simulator	Use of assistive device	Amplitude	Self-control* yoked	A Practiced on two consecutive days DR 24 hours post acquisition

Note. * denotes groups that controlled the practice variable; CE = constant error; VE = variable error; AE = absolute error; GRS = Global Rating Scale; CL = The procedural checklist; IPPI = Integrated Procedural Performance Instrument; LC = learner controlled; NM = never model; |CE| = absolute constant error; 3D RE = three dimensional radial error; FB = feedback; MRE = mean radial error; SRE = subject-centroid radial error; BVE = bivariate radial error; MT = movement time; RE = radial error; E = total variability; RTE = relative timing error; A = acquisition; IR = immediate retention; DR = delayed retention; IPT = immediate post test; DT = delayed transfer; PT = post test; IT = immediate transfer

Consequences of the environmental conditions during acquisition

Psychological measures

Though all the reviewed motor learning experimental protocols reported changes in behaviour, only one study measured changes in concentration (mental effort) and affect (satisfaction) (Hodges et al. (2011) found that a group of music experts that chose a schedule with frequent switching (high contextual interference) amongst motor tasks increased their satisfaction with practice more-so than those experts that switched less frequently or the novices that switched frequently. For the group of music experts, satisfaction and mental effort were correlated, but not for the novices.

Similarly, Bund and Wiemeyer (2004) measured self efficacy throughout the experimental protocol and found that those in the self-controlled groups reported higher self-efficacy beliefs than those in the yoked groups. In particular they showed less of a decrease in self-efficacy beliefs after the first half of practice and higher efficacy expectations prior to each retention test.

Behavioural measures

Measured variables

The measures of motivational consequences that have been used most often by motor learning researchers are measures of changes in behavior. The variety of dependent variables used in the papers reviewed is substantial and largely dependent upon the task (see table 1). The most widely used class of dependent variables for measuring changes in behaviour (learning) is that of error measures. The precision of measurement of error ranges from simple measures of accuracy (e.g., Bund and Wiemeyer 2004) to very specific measures of the amount and direction of error (e.g., constant error measured by Hansen et al. 2011). Many of the studies reviewed used accuracy scores, often when referring to where a projectile has landed based upon preset targets (e.g., Wrisberg and Pein, 2002). In some cases the number (or average number) of trials for which an error was committed were reported (e.g., Hansen et al., 2011). Keetch and Lee (2007) reported both pattern error, which consisted of an incorrect button press, and cursor error which occurred when a button press took place when the cursor was not in the correct place. More specific measures of error used amongst the protocols reviewed are included in table 1. Constant error measures the average response error and reports both magnitude and direction (Schmidt and Lee 2011, p.27), whereas variable error measures the inconsistency of the outcomes performed by the learner and compares participants' outcomes to each other, without taking the goal into account (Schmidt and Lee 2011 p.28). Absolute error measures overall accuracy and reports the absolute difference between a target and the actual performance, disregarding direction (Schmidt and Lee, 2011, p.27). The use of absolute constant error provides less misleading group results than CE. Some studies used two dimensional (e.g., Janelle et al., 1997) or three dimensional (e.g., Hodges et al., 2011) error scores for accuracy. Wu and Magill (2011) used RTE to measure the accuracy of the performance of relative timing across the entire trial.

In addition, motor learning researchers also use measures of movement quality. These include expert ratings and standardized rating scales (e.g., Brydges et al. 2009) as well as movement form or quality scores (e.g., Bund and Wiemeyer 2004; Wulf et al. 2005). Descriptors of movement were included as dependent variables for a number of studies. For example, for a ski-simulator task, both Wulf and Toole (1999) and Wulf et al. (2001) measured amplitude in centimeters. Measurements of movement time were also used as dependent variables such as Keetch and Lee (2007) who measured the overall movement time for each trial. Included in some experiments were measures of memory recall of the required movement pattern (e.g., Patterson and Lee, 2010).

These specific dependent variables, used to measure changes in behaviour, are usually the focus of motor learning self-controlled practice research, however, they are only one category of measures of the three identified by Katartzi and Vlachopoulos (2011) as being useful to describe changes due to motivation. Though measures of changes in behaviour provide the most prominent way to measure the effects of experimental manipulations, the addition of measures of changes in affect and concentration in future experimental protocols would provide a more complete picture of the motivation consequences of manipulations.

Although the variety of dependent variables used to measure changes in motor behaviour is vast, the learning benefits observed are remarkably consistent. Twenty-five of the 26 studies reviewed included one or more retention tests, while nine included a transfer test. Of those nine, eight included both retention and transfer. A retention test measures how well a task that was practiced during acquisition is retained, independent of the practice condition experienced during acquisition, whereas a transfer test measures how well the components learned during acquisition transfer to a novel version of the task (Schmidt and Lee 2011 p.462). Tests of learning, or relatively permanent changes in behavior can be either immediate or delayed. Immediate tests are performed shortly after the acquisition period on the same day. Delayed tests are performed after a longer period of non-practice, preferably after sleep has occurred (Walker, Brakefield, Morgan, Hobson and Stickgold, 2002).

Transfer

It has been suggested that a transfer test may be more sensitive than retention tests in capturing learning effects, as it requires participants to adapt to a novel context (Chiviacowsky and Wulf, 2002; Post et al., 2011). However the majority of papers reviewed did not include a transfer test. Some studies found a significant difference between groups only for transfer and not for retention; though in some cases retention was not measured. For example, Wu and Magill (2011) found that those afforded self-control during acquisition performed better than their yoked counterparts for both immediate and delayed transfer tests for all measured dependent variables. Chiviacowsky and Wulf (2005) found that participants provided choice as to whether or not to receive feedback prior to attempting the task performed with greater overall and relative timing error on a transfer test in comparison to those provided choice following each attempt.

Though Post et al. (2011) and Chiviacowsky and Wulf (2002) found benefits of a self-controlled practice context only in transfer, Brydges et al. (2009) found that the benefit of self-control was evident only in retention and not transfer. Patterson and Carter (2010) found that self-control over feedback provided benefits for performance measured during retention and for transfer tests (%|CE|). Brydges et al. (2010) found that both groups that were provided control over a portion of their practice maintained performance from the post-test to the transfer test while those following experimenter-defined practice significantly decreased in performance, though the self-controlled groups did not maintain this benefit on a post test.

In summary, self-control motor learning studies thus far indicate that those provided with choice over at least one aspect of the practice environment, perform equally, or more often, better than those not provided with choice when asked to transfer skills to a novel task. A more autonomy supportive environment provides one possible explanation for this positive change in behaviour, according to the SDT.

Retention

Along with the benefits found in transfer, Patterson and Carter (2010) found that self-control over feedback provided benefits for performance measured during retention tests (both % |CE| and CV) while Brydges et al. (2009) found that the benefit of self-control was evident only in retention and not transfer and was moderated by the type of goals set. Specifically, those who set *process* goals outperformed their yoked counterparts and those who set *outcome* goals did not outperform their yoked counterparts (Brydges et al. 2009).

In some studies, two or more experimental groups were provided with self-control, and in some cases with yoked counterparts or other experimenter-defined contexts. Patterson et al. (2011) found regardless of what percentage (50% or 100%) of the acquisition trials choice was provided or the type of KR schedule preceding the self-controlled KR portion, those provided self-control over KR outperformed yoked counterparts on retention tests (e.g., absolute constant error for all three self-controlled groups; variable error for two of the three self-control reaching statistical significance). Though measures of VE did not significantly differ between the self-control and yoked groups during transfer, the self-controlled groups demonstrated less |CE| than yoked groups with two of the three differences reaching statistical significance (Patterson et al., 2011). Hansen et al. (2011) found that those provided with an intermediate amount of self-control over their KR schedule (control over when to receive KR but yoked to the absolute number of times KR was provided) committed fewer errors on the retention test than those provided greater (control over schedule and number of times KR was provided) and lesser (schedule and amount of KR was yoked) amounts. Benefits of self-control were seen in transfer tests by Brydges et al. (2010), however, those under one of the experimenter-defined practice contexts performed best on the post-test. These results indicate that providing nursing students the opportunity to choose which simulators to use was as effective as basing progressions on pre-defined proficiency criteria.

The benefits of self-control are still clearly evident in the results of the retention tests conducted. Janelle et al. (1995) measured immediate retention and found those in the self-controlled condition were more accurate on the retention test than the yoked and experimenter-controlled conditions. Andrieux et al. (2012) measured both immediate and delayed retention and found benefits of self control over yoked groups in both tests.

Some studies using immediate and delayed retention tests compared two self-controlled practice conditions to each other as well as to yoked and control groups. Patterson and Lee (2010) found benefits for both immediate and delayed retention over yoked and control groups for those who self-controlled their receipt of augmented information, but only when given task-related information prior to attempting the motor task. The distinction was not evident in those that were given the information after attempting the trial. The results of this experiment showed that information about 'what to do' (e.g., proactive information) was just as beneficial as retroactive information, but only if the learner was provided control over the proactive information. Similar to the findings of the KR research, providing the learner control over receiving information about 'what to do' had a positive impact on motor skill learning (e.g., Patterson and Lee, 2010). Chen et al. (2002) found that for immediate retention, both groups provided with self-control over KR performed with less |CE| than their yoked counterparts. This was also true for the delayed retention test with the addition of a significant difference between the two self-control groups.

Those that received a reminder of the choice provided to them outperformed those that did not receive the reminder on each trial (Chen et al., 2002). Bund and Wiemeyer

(2004) found that regardless of whether choice was given in respect to a preferred or non-preferred element of practice, those who got to choose performed with better form than those in the respective yoked conditions on a delayed retention test. No differences between self-controlled and yoked nor preferred and non-preferred conditions were significant on the immediate retention test. Jowett et al. (2007) found no differences on post tests and delayed retention tests between those that received additional practice after choosing to stop practice and those that did not.

Chiviacowsky, Wulf, Medeiros, Kaefer and Wally (2008) compared one group that chose to receive KR *frequently* when provided control and one group of participants that chose to receive KR *less frequently*. Participants who chose more frequent KR better maintained accuracy scores for the retention test and were significantly more accurate than those who had chosen less frequent KR. Hodges et al. (2011) measured the delayed retention results for one yoked and two self-controlled groups. Music experts who had many years managing practice of a skill unrelated to the one used in the experiment performed more accurately than both novices that had self-control and those yoked to the music experts' schedule for two of the three Frisbee throws in retention. The experts also performed with better form than the novices that were able to self-control practice, but not those with the yoked practice.

Huet et al. (2009) found that how feedback was presented influenced the effectiveness of self-controlled concurrent feedback. A significantly greater increase in performance from the end of practice to the delayed retention period was seen for participants who self-controlled vision of a gauge indicating performance but not a ghost doors condition or a yoked group. Keetch and Lee (2007) found that those in the self-controlled group significantly decreased movement time from the end of practice to delayed retention while yoked, random and blocked groups increased movement time. However, the self-controlled group was significantly faster than only the blocked group in retention. This same pattern of results was also seen for measures of cursor error (Keetch and Lee, 2007). Similarly during delayed retention, Janelle et al. (1997) found that the self-controlled group out-performed summary, yoked and KR groups for throwing form and accuracy (MRE). Wrisberg and Pein (2002) found that participants that viewed a model either following a self-controlled schedule or on every trial out-performed those who never viewed the model. A more autonomy supportive environment and opportunities to increase feelings of competence provide some possible explanation for positive changes in behaviour discussed above, according to the SDT.

Self-controlled use of poles for assistance resulted in greater amplitudes (Wulf and Toole, 1999), longer balance time (Hartman, 2007) and better movement efficiency (Wulf et al., 2001) in delayed retention compared to yoked groups. This is an example of where participants were given an opportunity to increase experiences of competence by choosing to use the poles to assist in the performance of the task. A self-controlled viewing schedule of a model produced better form scores (Wulf et al., 2005) and self-control of the receipt of KR produced better accuracy (Chiviacowsky, Wulf, Medeiros, Kaefer and Tani, 2008) in comparison to yoked groups in delayed retention as well. The motivational factors in the environment of practice, including supports for autonomy and competence may have played a role in these changes in behaviour.

Measures of how the opportunity for choice was used

Another measure of change in behavior is how participants chose to use the opportunity for choice. Those that were provided control over receipt of feedback demonstrated varied patterns of requests, but some consistent patterns emerged across studies. Janelle et al. (1997), Huet et al. (2009) and Chiviacowsky, Wulf, Medeiros, Kaefer and Tani (2008) found that participants decreased requests for feedback across the acquisition period. However, Chen et al. (2002), Patterson and Carter (2010) and Hansen et al. (2011) found that the number of requests remained relatively stable across the acquisition period. In some examples, feedback requests were influenced by their performance such that participants requested feedback more often after perceived good trials than bad trials (Chiviacowsky and Wulf 2002; Chiviacowsky, Wulf , Medeiros, Kaefer and Tani, 2008). Feedback requests were also influenced by previously prescribed practice schedules in a study by Patterson et al. (2011). On average, feedback requests occurred on a relatively low (<50%) number of trials with the exception of the study by Chen et al (2002) in which participants asked for feedback on almost every trial for the duration of the acquisition period.

When participants were given control over when to receive augmented task information, Patterson and Lee (2010) found that participants also faded requests across acquisition and that requests were less frequent for easier compared to more difficult versions of the motor task. Hodges et al. (2011) found that music experts requested information more often and were the only ones to request information after relatively poorer trials. They also found that performance was more accurate when information was requested (Hodges et al., 2011). For all three studies where participants were able to request the use of poles to aid performance (Hartman, 2007; Wulf and Toole, 1999; Wulf et al., 2001) participants faded their requests for the assistive device across the acquisition period. Hartman (2007) found that participants in the self-controlled condition performed with superior balance on the no-pole trials compared to pole trials, whereas the performance of those in the yoked condition was the opposite. Requests to view videos of the requisite motor action decreased across acquisition trials in studies by Wrisberg and Pein (2002) and Wulf et al. (2005). Brydges et al. (2009) found that those given outcome goals made more requests than those given process goals. Those given the opportunity to determine task difficulty by deciding racquet width gradually increased difficulty across practice, based upon the performance of previous trials (Andrieux et al., 2012). In terms of scheduling practice, some studies found evidence of schedules involving progression from easier (e.g., low fidelity or low contextual interference) to more difficult versions or schedules of the task throughout acquisition (Brydges et al., 2010; Wu and Magill, 2011). Keetch and Lee (2007) found that more switches occurred for those that practiced the easy version of the motor task compared to those that practiced the hard version of the motor task. Hodges et al. (2011) found that participants spent more time practicing the most difficult Frisbee throw.

Indicators of individual differences were also evident in the variation in total number of switches observed by Keetch and Lee (2007) and in the number of trials participants completed before choosing to stop observed by Post et al. (2011). Participants chose to switch on relatively “good” trials as indicated by faster trials preceding a switch in the study by Keetch and Lee (2007) and switches on more accurate throws in the study by Hodges et al. (2011).

Trends to decrease supports such as augmented KR or use of an assistive device across practice trials (or not) may interact with feelings of competence. Perhaps once people experience feelings of competence, they choose to decrease support. Conversely, perhaps once support is decreased learners' feelings of competence increase. In the future the examination of how the opportunity for choice was used would benefit from predictions made within a SDT framework.

Explanations for changes in behavior observed

Throughout the motor learning literature, two main categories of explanation emerge when it comes to the differences in learning between self-controlled and yoked groups. The first of these is a series of cognitive explanations and the second are motivational explanations. Earlier research based their results on speculation, but more recently some attempts have been made to explicitly examine the mechanisms underlying the learning differences between the self-controlled and yoked conditions.

Cognitive explanations

In 1995, Janelle et al. hypothesized that the differences in the performance between self-controlled and yoked groups were because the self-controlled group processed information more efficiently and that the low frequency of feedback chosen by participants, allowed for more independent information processing. Janelle et al. (1995) also speculated that deeper information processing occurs when one is confident that they are in control over learning. Janelle et al. (1997) expanded on this explanation to include the development of better learning strategies as a possible reason for the benefits of self-control. Janelle et al. (1997) also hypothesized that the most comfortable strategy may enhance information processing.

Since then, many papers have cited increased, deeper or more efficient information processing as a possible reason for the learning differences observed between the self-control and yoked conditions (e.g., Wulf et al., 2001, 2005; Patterson et al., 2011; Hartman, 2007). Post et al. (2011) further examined this reasoning by measuring the amount of preparation time engaged in at the beginning of trials. Post et al. (2011) stated that longer preparation times paired with the better performance in retention were indicators of deeper information processing occurring in the self-controlled group compared to the yoked group.

Closely tied to the information processing explanation is the idea of cognitive effort and its possible role in the beneficial effects of self-controlled practice. Bund and Wiemeyer (2004) stated that in acquisition, self-control creates more strain on cognition, requiring decision making, monitoring and evaluating and correction. Cognitive resources are split between learning and self-controlled processes during acquisition, however, in retention the motivational conditions and cognitive strain are equated for the self-controlled and yoked groups. Several studies discuss the importance of cognitive effort and/or investment in facilitating skill acquisition. One example of cognitive effort is discussed by Chiviacowsky and Wulf (2005) who suggested that spontaneous error estimations might contribute to the learning advantages. In another example, Patterson and Lee (2010) explain the role that an optimal amount of cognitive effort can play in expediting motor learning. In the case of a retroactive presentation of task information, the level of cognitive effort is already at a desirable difficulty so the additional cognitive processing induced by self control did not provide additional learning benefits. However, the cognitive effort required to retrieve task information in the self-controlled proactive condition (e.g., no feedback trials) was beneficial for skill acquisition.

The results of Patterson et al. (2011) and Hansen et al. (2011) further support the idea of an optimal amount of cognitive effort in facilitating motor skill acquisition. Patterson et al. (2011) found that contrary to previous studies, some of the participants in the self-controlled condition did not choose to receive KR on perceived good trials. However those participants were still required to make a judgement on performance in order to resolve (or not) any metacognitive discrepancies between their perceived and actual motor performance, suggesting an optimal amount of cognitive effort could have still been experienced. Hansen et al. (2011) discussed how the heightened cognitive processing involved in making a choice under restrictions (e.g., predetermined amount of trials choice was provided) emphasized perceived accuracy as underlying the KR requests. This group also avoided the processing demands for correction of poor trials which in turn strengthens the error-detection mechanism in comparison to the traditional self-controlled and yoked groups (Hansen et al., 2011). Andrieux et al. (2012) showed that even in a typical self-controlled group for example, those that adjusted task difficulty on each trial experienced a greater cognitive load compared to the yoked group. Andrieux et al. (2012) suggested the self-controlled group spent more time evaluating conditions, preparing their motor response and interpreting the outcome of their motor response. Those in the self-controlled group were able to explore different strategies or select a strategy based upon perceived progress towards the goal. Jowett et al. (2007) hypothesized that cognitive effort ceased after reaching self-assessed proficiency which in turn prevented further learning during the remainder of acquisition trials suggesting a limitation to the extent to which self-control can elicit cognitive effort.

Referring back to Janelle et al.'s (1997) discussion of strategy, much of the cognitive effort taking place may be in the form of strategies encompassing movement, cognitive and/or informational aspects (Bund andWiemeyer 2004). Building upon the discussion of strategy, Wulf and Toole (1999) predicted that if participants tried out different strategies while using the ski poles, they may have engaged in a more effective exploration of their perceptual-motor workspace with the use of the poles freeing up the cognitive resources to do so. They also explained that learners provided the opportunity to control a practice variable, arrange the environment to their own benefit. Learners in a self-controlled condition learnt how to approach and learn the motor task and have the opportunity to apply strategies to enhance their metacognitive behavior (Chen et al., 2002). Wulf et al. (2001) hypothesized that self-controlled practice encourages more active engagement in the task, and strategy exploration including an optimal task solution search. A pre-determined schedule (e.g., yoked schedule) is suggested to inhibit the ability to choose, use, evaluate or change strategies creating a situation where participants could not confirm or adjust a strategy as necessary, a self controlled practice would diminish these limitations (Wu and Magill, 2011).The self-controlled group in the study by Wu and Magill (2011) was better at confirmation and refining of strategies and they self-evaluated and changed practice based on their motor performance. The self-controlled participants used self-regulatory processes required for searching, evaluating and choosing the correct motor solution based on feedback (Wu and Magill, 2011). In a study by Patterson and Carter (2010), learners were believed to be engaged in the metacognitive strategies required to update their decision of whether or not to receive KR. Patterson and Carter (2010) suggested that feedback on good trials confirms for participants their knowledge of the task requirements in fact coincides with the actual task requirements. In the case of multiple tasks, it is used to strengthen the inhibition of incorrect responses and further establish the link between cue and target. This strategy is used to economize invested effort. For example, Hartman (2007) showed that participants in a self-controlled condition used a pole to try out new strategies, test their effectiveness and then modify them again on a subsequent trial.

It has also been hypothesized that self-controlled practice may increase instructional efficiency (Wrisberg and Pein, 2002) and this was elaborated upon by Chiviacowsky and Wulf (2002) who suggested that self-controlled practice is more consistent with participants' needs. Huet et al. (2009) stated that the active role of observers benefitted perception and learning, and that learners extracted perceptual information as well as information that might also guide learning. An example of how information use can be individualized is illustrated in the study by Hodges et al. (2011) where augmented information was hypothesized to play a more conformational role for novices and a more error-correcting role for music experts. In order to further examine the idea that self-controlled schedules may be more congruent with the learners needs, Chiviacowsky and Wulf (2005) manipulated this capability by preventing one group from using the information inherent in the completion of a motor action to aid in their decision of whether or not to receive KR. This group experienced degraded performance suggesting that self-control itself is not a determining factor in the success of self-controlled practice.

Arguments for both specific and general effects of self-controlled practice appear in the literature. Wulf et al. (2005) proposed that there may be additional benefits specific to the controlling a practice variable, such as the ability to extract more relevant information during observation of a model. Keetch and Lee (2007) state that learning benefits are general in nature rather than specific to the control of a particular part of practice.

Cognitive explanations have most often been discussed separately from motivational explanations, but they may be interconnected. For example, cognitive effort may also have merit as a motivational explanation. Attempts to increase the cognitive effort used during acquisition may also serve as a way to nurture an inner motivational resource though the vitalization of the learners' sense of challenge, which can contribute to the satisfaction of the need for autonomy, a key aspect of the SDT.

Motivational explanations

Janelle et al. (1995) proposed that those provided self-control over a practice context may experience increased confidence in their ability to perform the task. Janelle et al. (1997) expanded upon this by hypothesizing that a responsibility of reaching proficiency placed on the learner by a self-controlled practice may result in a higher motivation to perform well. Janelle et al. (1997) also suggested that it was the active involvement of the learner that resulted in motivational influences on the cognitive processes of the learner. Wulf et al. (2005) stated that a more active involvement in the learning process may lead to increased motivation, a concept echoed by Hansen et al. (2011), who suggested that increased information processing in the restricted self-control group in order to individualize practice under restrictions increased motivation to do better.

More specific to the tenets of SDT, Wulf and Toole (1999) stated that those in a yoked group had perceived control removed and therefore experienced less intrinsic motivation and invested less effort, though this was not empirically evaluated. Hartman (2007) reported that the perception of control was enough to elicit learning advantages. This conclusion was based on the lack of evidence for a beneficial effect on performance of the use of a pole over trials where no pole was used during a pilot test. Wulf et al. (2001) hypothesized that those provided with self-control over practice were more motivated to try out different strategies.

Chen et al. (2002) explained that self-initiated KR (as opposed to when participants were prompted by the experimenter) requires self-regulation and self-control and hypothesized that implicitly-enhanced intrinsic motivation through self-control benefitted cognitive processes. Chen et al. (2002) argued that self-regulated learners understand why they are learning and value it, which is in line with the process of internalization in the SDT. Chen et al. (2002) also hypothesized that those in a self-control group use more effective strategies, which are more comfortable and which in turn enhance information processing.

Though Andrieux et al. (2012) suggested that self-control increases self efficacy and motivates better performance, this was not quantified in their study. Bund and Wiemeyer (2004) measured self-efficacy and concluded that self-control has positive effects on psychological states and processes as evidenced by a smaller decrease in self-efficacy perceptions after a poor trial for the self-controlled group. Bund and Wiemeyer (2004) concluded that this might result in learning because it encourages learners to try out different strategies. They also concluded that self-control results in an increased sense of self-efficacy and the option to set goals.

Some of the studies reviewed reference autonomy, though to date it has not been measured within the motor learning protocols. According to Brydges et al. (2009), increased autonomy tailors to the production of knowledge in regards to the specific needs of the learner, resulting in increased motivation suggesting that differences observed were due to the differences in how autonomy was used. According to Brydges et al. (2010), self-guided students benefitted from autonomy in selection of scheduling and tailoring practice to their own needs.

Motivation has also been discussed in terms of how participants chose to control the practice variable. According to Chiviacowsky and Wulf (2002), motivational factors could underlie the preference for feedback requests after perceived good trials.

Chiviacowsky and Wulf (2002) suggested it is easier to repeat a good trial than to try and correct errors from a poor trial. This difference in the required amount of effort might be a motivation to try harder for a correct response. For the yoked participants, the absence of feedback when they may have wanted it could have made the practice context less than desirable and as a result, decreased the motivation of these participants (Chiviacowsky and Wulf 2002). This was supported by Patterson and Carter (2010) in the case of learning multiple tasks. Chiviacowsky, Wulf, Medeiros, Kaefer and Tani (2008) suggested that the main benefit of self-controlled practice may be motivational. Chiviacowsky et al. (2008) suggested that KR was chosen after perceived good trials leading to a “success” experience than after poor trials, which increases motivation and therefore enhances learning. Chiviacowsky and Wulf (2005) present a case of motivational factors that may contradict each other. Participants who were required to decide whether or not to receive KR about a motor response *before* that response was made may have tried harder because they requested KR, whereas the group who could request KR *after* their motor response had the opportunity to confirm a perceived good trial with a KR request. Both of these situations suggested heightened motivational factors; however results suggested that the latter of the two explanations is more likely as those who chose after a trial performed better on tests of learning.

Measuring satisfaction of psychological needs and changes in motivation and behavioral regulations

Conditions during acquisition may provide an environment conducive to the satisfaction of the need for feelings of autonomy and competence. However, to date, self-controlled motor learning protocols have not attempted to explicitly measure this. Changes in the participants' motivation as a function of learning have not been explicitly measured within the motor learning self-controlled protocols. However, these measurements would provide a clearer explanation for behavioural changes measured as a function of self-controlled practice, rather than one based upon speculation.

One study measured feelings of self-efficacy, which is a concept similar to perceived competence and one the authors described as a "major source of intrinsic motivation" (Bund and Wiemeyer, 2004, p.6). Bund and Wiemeyer (2004) used a custom task-specific scale, across the entire protocol, for a total of five measurements. They found that on average, participants in the self-controlled conditions reported greater self-efficacy beliefs than those in the yoked conditions. While a measure of self-efficacy gives us some insight into motivational differences between self-control and yoked conditions, these differences require further investigation.

In future experiments, the inclusion of the Intrinsic Motivation Inventory (Deci and Ryan n.d.) would be beneficial in measuring missing steps such as motivation and regulation. The Intrinsic Motivation Inventory is used to measure, in laboratory experiments, participants' subjective experience in relation to the task. The full version of the instrument measures seven subscales and includes 45 items (Deci and Ryan n.d.). Many researchers have chosen to use only the subscales relevant to the research questions they were exploring, with no reported negative effects seen on the used subscales due to the removal of the others (Deci and Ryan n.d.). The most relevant choice for the protocols currently used in motor learning studies would be the standard, 22-item version, with four subscales used in many past studies (Deci and Ryan n.d.). The first of the four subscales is the interest/enjoyment subscale which is used to measure self-reported intrinsic motivation. The other subscales measure perceived competence, perceived choice, and pressure/tension. The value/usefulness subscale, from the original seven, could also be useful in measuring internalization. The inclusion of scales that have been validated to measure these intermediate steps in the motivation model, would clarify the currently assumed role of motivation in the self-controlled motor learning process.

Though indicators of motivation in terms of the mechanism of SDT in a learning experimental protocol have not been measured, five of the twenty-six studies have attempted to measure the motivation for the *choices* made by participants during acquisition. Chiviacowsky and Wulf (2002) were the first to use a questionnaire, post-practice, to assess when and why those in the self-controlled KR group chose (or did not choose) to receive KR during a practice period. Those in the yoked group were asked if they received KR on the correct trials and if not, when it would have been preferred (Chiviacowsky and Wulf 2002). Since the initial use of the questionnaire, it has been used in its original form by Patterson and Carter (2010) and Patterson et al. (2011) adapted to the choice of when to use an assistive device by Hartman, 2007, and the choice of the order of the practice schedule by Wu and Magill, 2011. Chiviacowsky and Wulf (2002) found that most participants, whether they were given the choice or not, preferred to receive KR after what they perceived were good trials and not after what they perceived were poor trials. This was also true when participants were required to learn multiple versions of a task (Patterson and Carter, 2010). When Patterson et al. (2011) preceded self-controlled trials during practice with varying externally defined KR schedules; the differing schedules resulted in differential responses on the questionnaire. However, two of the three self-controlled conditions were consistent with the previous findings of Chiviacowsky and Wulf (2002) and Patterson and Carter (2010) while the third (self-controlled trials preceded by self-controlled trials) most often reported requesting feedback equally on trials perceived as good and trials perceived as poor.

Wu and Magill (2011) found that participants also preferred to switch to another task following trials perceived as good as opposed to those perceived as poor; and participants in both the self-controlled and yoked condition felt that they were able to attempt as many strategies as they wanted. In the case of requests for the use of an assistive device (pole), Hartman (2007) revealed that participants frequently asked for the assistive device when attempting a new movement strategy rather than whether the trial was perceived as either good or poor. Wulf and Toole (1999) measured feelings of security and certainty about reaching maximum amplitudes (the task goal) across practice and found that participants became less fearful of falling across practice and were uncertain about their ability to reach the task goal regardless of following a self-controlled or yoked protocol. Though some insight has been gained in terms of motivation, particularly in the case of motivation for making decisions within the practice environment, the use of valid, more specific measures of needs satisfaction, changes in quality of motivation and internalization in future research would be valuable and should be the focus of future research.

Conclusions

The purpose of the present review was to offer a theoretical interpretation of the motor learning advantages associated with a self-controlled practice context. The tenets of the self-determination theory (SDT) proposed by Deci and Ryan (2000) offered a logical and alternative interpretation of the extant motor learning literature examining self-control. As outlined in figure 1, the *psychological environment* and *psychological needs* of the learner are critical mechanisms facilitating early initiation of self-determined behavior. Such components as autonomy and competencies of the learner are identified as factors that subsequently impact a long-term change in behavior. Within the motor learning literature, our review suggests that a self-controlled practice context is facilitating such factors as autonomy and competence of the learner, thereby supporting the psychological environment and psychological needs of the learner, leading to long term changes to a desired behavior. A desirable practice context created by attending to the psychological environment and psychological needs of the learner, subsequently leads to changes in motivation experienced by the learner. In fact, this component of the SDT is consistent with notions in the motor learning literature such that the mechanism underlying learning in a self—controlled practice context is believed to be attributed to heightened motivation to achieve the motor task goals. Finally, motor learning researchers suggest that increased motivation as a function of self-control leads to a relatively permanent change in behavior of the motor skill. This finding is consistent with the *motivational consequences* of the SDT such that increased motivation as a result of practice contexts that facilitate autonomy and competencies of the learner results in a change in behavior. Collectively, the SDT not only allows for a theoretical reinterpretation of the extant motor learning research supporting self-control as a learning variable, but also a conduit for further inquiry into understanding the mechanisms underlying learning in a self-controlled motor learning environment.

Through the vast variety of tasks, timing of protocols and variables over which control has been given, the benefit of self-control of practice to the learning of a motor task persists. These benefits are robust and present implications for teaching, coaching and anyone responsible for organizing a practice of motor skills. Despite these findings, the question of why these benefits occur largely still remains. Two hypothesized areas of explanation may, as suggested by Bund and Wiemeyer (2004), be antagonistic in their effects. When looking at motivational reasons, the lens of SDT can help us to better understand and measure the changes occurring between the practice environment and the observed behavioral outcomes.

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Chapter 5: Discussion

Chapter 5: Discussion

Responses to Research Question and Objectives

The purpose of this thesis was to develop an overall picture of the influence of learner involvement on measures of motor learning and to reconcile seemingly contradictory theoretical perspectives supporting the benefits of minimization and facilitation of learner involvement during acquisition of a motor skill.

Four specific objectives stemmed from this overall research question, which were subsequently addressed in chapters two, three and four.

The influence of progressive and reverse protocols on measures of learning.

Supporting evidence.

The first specific objective was to determine the influence of progressive and reverse practice scheduling protocols on delayed measures of learning (retention and transfer tests). Poolton and Zachry (2007) identified this gap in the errorless learning literature and explained that experiments that examined errorless verses errorful acquisition protocols typically have included a test of immediate but not delayed retention. This is also true with tests of transfer to a novel version of the task. In order to provide a more comprehensive picture of the effects of learner involvement on measures of motor learning, delayed retention and transfer tests are essential. Earlier, motor learning was defined as a set of processes resulting in a relatively permanent change in performance of a skilled movement due to practice or experience (Schmidt & Lee, 2011 p. 327). It was also explained that motor learning can be inferred from a relatively permanent change in motor performance which can be measured using experimental designs that include tests of retention and transfer. A retention test allows us to comment on how well performance of a task is maintained over some time of non-practice, while a transfer test allows us to comment on how well rules, strategies and motor components, developed during practice, transfer to performance of a new task.

In chapter two, three experiments were reported that assessed the effects of progressive and reverse acquisition protocols. Experiments one and two measured both immediate and delayed retention and transfer. Due to design constraints, experiment three measured immediate and delayed transfer, but not retention.

In experiment one, no differences in performance between the progressive and reverse groups were found during the retention and transfer tests. It was suggested that this may have been due to participants not modulating their goals along with the size of the target and thus not distinguishing the direction of progression between the groups. If in fact, most participants were aiming for the center of the target, regardless of its size, then no differences in retention or transfer performance would be predicted between groups because there is no difference in how the groups practiced.

In experiment two, when participants were more strongly guided in terms of progression of difficulty, participants in the progressive group performed with a significantly greater proportion of error trials compared to the reverse group on both transfer tests. However no differences were found on the retention tests.

In experiment three those that practiced using the further targets did not experience a decrease in performance across testing sessions while those who practiced using the easier targets did experience a decline in performance from immediate to delayed transfer tests. However, the progression of difficulty (progressive or reverse) did not produce significant differences in any of the tests of learning.

Taken together, these results suggest that the progressive and reverse protocols themselves may not differentially impact retention and transfer performance. However, certain characteristics of the practice protocols seem to afford a benefit to transfer of learning to a novel task. The most strongly-supported characteristic is that of task difficulty during acquisition.

To place these results pertaining to the tests of learning in context for theoretical interpretation of the results, the measures of performance during practice should also be taken into account. In experiment one, no differences in performance during acquisition were seen between the progressive and reverse groups. In experiment two, the progressive group performed with more error during acquisition than the reverse group. In experiment three the groups that used the further targets for practice, regardless of progression performed with more error during acquisition than those that used the nearer targets regardless of progression.

Theoretical interpretations of results.

Retention.

While the finding of no differences in performance on retention tests in experiment one is consistent with the predictions of Adams' (1971) theory, the finding of no differences in retention performance in experiment two is contradictory to Adams' (1971) predictions. In experiment one, the proportion of errors per block were equated between groups during acquisition and each of the overall acquisition task requirements were the same between groups. According to Adams' (1971) theory viewpoint, the strength of the perceptual trace should be similar between groups, leading to similar performance in retention. In experiment two, the proportion of error during acquisition differed between groups, which according to Adam's (1971) viewpoint would produce differences in the strength of the perceptual trace, resulting in retention differences. Adams' (1971) theory would predict that the participants in the progressive group would perform with more error in retention.

Since the amount of variability within each protocol compared for experiments one and two was equated, Schmidt's Schema Theory (1975) is supported by the lack of differences in retention. The number of trials and the accuracy of feedback during acquisition were equated between groups. Schmidt's (1975) theory would predict that the schema would be equally strengthened in each group.

The theory of reinvestment (Masters & Maxwell, 2008) does not allow for predictions specific to retention tests. Previous experiments examining errorless and errorful practice protocols (Maxwell et al., 2001) have predicted and found a benefit for errorless practice on retention tests. The basis for this prediction was that conditions (e.g., provision of feedback) did not change between acquisition and retention; however, the theoretical basis for this prediction was not stated.

The lack of differences in performance on retention tests between groups would suggest, according to the challenge point framework (Guadagnoli & Lee, 2004) that the combination of nominal and functional task difficulty during acquisition was equally optimal for each group. The combined nominal task difficulties of the trials at each target during acquisition were equated, and it appears that any possible differences in functional task difficulty due to the type of progression followed did not arise.

An interpretation of the lack of differences between groups in retention from a self-determination theory perspective would suggest that learners in each group experienced equated support for feelings of autonomy, competence and relatedness. Further interpretation is difficult as measures specific to motivation were not included in the reported experiments.

Transfer.

From the Adams' (1971) theory perspective, a reasonable prediction could be made that the closer the last acquisition trial requirements were to the requirements of the transfer test, the greater the likelihood of success. While Adams' (1971) theory does not make specific predictions about transfer, the closer the strongest part of the perceptual trace (the correct trace) is to the required transfer task, the more likely the response is to be successful. The results of experiment two do not support this prediction as the task closest to the one used in transfer was completed at the very beginning of practice by the group that was more successful in retention (reverse group).

Schmidt's (1975) theory would predict that since each group experienced the same spread of experiences during acquisition, in other words, the same amount of variability, the groups should perform equally well on transfer tests. The results of experiment two also do not support this prediction as the progressive group performed with more error during transfer tests than the reverse group.

The theory of reinvestment (Masters & Maxwell, 2008) does not allow for predictions specific to transfer tests. Previous experiments examining errorless and errorful practice protocols (Maxwell et al., 2001) have predicted a decrement for errorless practice on transfer tests. The basis for this prediction was that previous studies using simpler (serial tracking, Macrae & Holding, 1965 & discrimination, Prather 1971) tasks had found poor transfer to novel tasks; however, the theoretical basis for this prediction was not stated.

An explanation for the differences in transfer performance, consistent with the challenge point framework (Guadagnoli & Lee, 2004) would be that since the nominal task difficulty across acquisition remained the same (e.g., each participant practiced each target which reflected a certain level of nominal task difficulty), the functional task difficulty differed in a way such that the reverse protocol was beneficial to learning. Guadagnoli and Lee (2004) explained that according to the challenge point framework, learning is directly related to the available, interpretable information. The amount of interpretable information for a given attempt at the task is determined by functional task difficulty. In the protocols used in experiment two, the functional task difficulty differed in an important way; the experience of the learner differed at each target such that at the most nominally-difficult target, one group had experienced 175 trials while the other none. We can hypothesize that the information that is interpretable by the learner changes with experience such that the more experience a learner has, the more information they are able to interpret. The challenge point framework would predict that the group that received the most appropriate amount of interpretable information during acquisition would perform better on transfer tests. The results of experiment two are consistent with the predictions of the challenge point framework for a task of relatively low nominal difficulty.

An interpretation of the differences between groups in transfer for study two from a self-determination theory perspective would suggest that learners in the reverse protocol group may have experienced greater support for feelings of autonomy, competence /or relatedness than those in the progressive protocol group. Perhaps feelings of autonomy were better supported through a more optimal challenge of the learner through a reverse protocol (Su & Reeve, 2011). Further interpretation is difficult as measures specific to motivation were not included in the reported experiments.

The influence of self-controlled and yoked practice on performance on dual-task tests.

Supporting evidence.

The second objective was to determine the influence of self-controlled and yoked practice scheduling protocols on performance under a secondary task (dual-task test). In the extensive review of the motor learning self-controlled practice literature found in chapter four, no studies examining the effects of self-controlled and yoked practice schedules on dual task tests were identified. In order to reconcile the perceived clashes between recommendations for successful performance on retention, transfer and dual-task tests, the influence of self-controlled and yoked practice schedules on dual task tests must be determined.

In chapter three, yoked verses self-controlled practice schedules were compared in order to determine if they would induce similar differences in dual-task performance to those seen for errorless verses errorful practice schedules. No differences in performance on retention, transfer or dual-task tests were found.

Theoretical interpretations of results.

The findings for the dual-task tests are difficult to interpret due to the uncharacteristic lack of differences for retention and transfer. If we consider performance under secondary task conditions as another form of transfer test, The predictions of Adams' (1971) theory, Schmidt's (1975) theory and the challenge point framework (Guadagnoli & Lee, 2004) can be discussed.

Adams' (1971) theory does not make specific predictions about transfer, and unlike the consistent progressive and reverse schedules discussed earlier, predictions based upon the location of the final practice trials cannot be made.

Similar to the comparison of progressive and reverse protocols, Schmidt's (1975) theory would again predict that since each group experienced the same spread of experiences during acquisition, in other words, the same amount of variability, the groups should perform equally well on transfer tests. The results of chapter three support this prediction as the self-controlled and yoked groups performed equally well on the dual-task transfer tests.

An explanation for the lack of differences in dual-task transfer performance, consistent with the challenge point framework (Guadagnoli & Lee, 2004) would be that the nominal task difficulty and the functional task difficulty across acquisition remained the same for each group. However, the functional task difficulty of the task for those who chose their practice schedule should have been higher due to the increased cognitive demands of choosing the schedule. This suggests that the results of chapter three do not support the predictions of the challenge point framework.

Using the theory of reinvestment, (Masters & Maxwell, 2008) the lack of differences between the self-controlled and yoked groups would suggest that a similar amount of implicit learning took place, particularly at the beginning of practice. More studies are needed, perhaps with previously examined tasks and self-controlled protocols, in order to examine the influence of self-controlled and yoked practice schedules on dual-task tests when differences for retention and transfer are present.

An explanation for the lack of differences for the tests of learning from a self-determination theory perspective is that the basic psychological needs of the learners in each group were met equally well (Sanli, Patterson, Bray & Lee, 2013). Since the same instructions were presented in an identical fashion from a script to each of the participants, perhaps each group felt that the need for feelings of autonomy was satisfied to the same degree. These feelings may have been supported through the provision of a meaningful rationale when both groups were shown the test target at the beginning of practice and through the ability to choose how to propel the target for each trial. A limitation of the study in Chapter three is that measures of motivation were not included.

The contributions of progressive and reverse protocol characteristics to performance on measures of learning.

Supporting evidence.

The third objective was to examine the characteristics of progressive and reverse practice scheduling protocols in order to better understand the contributions of each characteristic to performance on tests of learning. Maxwell et al. (2001) attributed the differences between errorless and errorful (analogous to progressive and reverse in chapter two) to the minimization of error and therefore minimization of hypothesis formation and testing. There are other characteristics that differentiate between progressive and reverse protocols, such as, task difficulty, progression in relation to the home position and progression in relation to the eventual test target that could also be examined.

In chapter two, the third experiment was designed to tease apart these separate factors using four experimental groups. The targets to which participants aimed differed in overall distance from the home position as well as following either a near-to-far progression in distance or the reverse protocol.

In acquisition, the overall difficulty of the task was revealed as important for performance. Those who practiced using the further targets performed with a greater proportion of error trials overall than those who practiced using the nearer targets.

For the transfer tests, overall difficulty during acquisition remained the key factor for performance differences, however the effect was in the opposite direction in comparison to acquisition. Participants that practiced using the more difficult targets did not experience a decrease in performance across testing sessions while those who practiced using the easier targets did see performance deteriorate from immediate to delayed tests. The direction of transfer from acquisition, could also be considered as an explanation, however the results from study two in chapter two support an overall task difficulty hypotheses and oppose the direction of transfer hypothesis.

For the dual-task tests, the key factor for differences in performance was the progression in relation to the test target. The groups that started practice using the targets farthest from the test target experienced a decrease in performance across testing sessions while those that started practice at the targets closest to the test target did not.

Theoretical interpretations of results.

Overall task difficulty.

The finding that the more difficult task (the set of further targets) produced more error than the easier task (the set of closer targets) during acquisition for study three in chapter two does not contradict predictions from any of the theories or frameworks.

Adams' (1971) theory would predict that those who performed with more error during acquisition (e.g., the groups that used the more difficult set of targets in experiment 3 in chapter 2) would also perform with more error during tests of learning based upon a more degraded perceptual trace. The findings of experiment 3 in chapter two contradict this prediction. Those who practiced using the more difficult tasks and produced more error during acquisition did not degrade in performance from the immediate to the delayed transfer tests while those who practiced using the easier tasks did. Interestingly the findings of experiment two in chapter two, where those who performed with less error during acquisition (the reverse group) also performed with less error on transfer tests support this prediction.

When the amount of variability of tasks between each of the groups in experiments two and three in chapter two was equated, Schmidt's schema theory does not support our findings for transfer. Since the spread of experiences is equal between the progressive and reverse protocols, an equally strong schema should have been developed for use in the transfer task.

The challenge point framework point of view (Guadagnoli & Lee, 2004) would suggest that for experiment three in chapter two, those that practiced using the more difficult targets during acquisition were more optimally challenged by the interpretable information available in comparison to those that practiced using the easier targets. This may be due to the relative simplicity of the task. In fact, this point of view may aid us in determining why the results in chapter two differ from those previously found by Maxwell et al. (2001). Arguably a golf putting task would have a greater nominal level of difficulty than the disc propulsion task used in chapter two and as a result the optimal amount of interpretable information would also differ. This may explain differences in acquisition performance results between Maxwell et al. (2001) and those presented in chapter two. Those in the errorless (progressive) group in Maxwell et al.'s (2001) study performed with less error in acquisition than the reverse progression while in study two of chapter two the reverse occurred. In one case, the more complex (golf putting) task used by Maxwell et al. (2001) the progressive protocol was beneficial to learning, providing the optimal amount of challenge. However, in the other, less complex task used in chapter two, the reverse protocol provided the more optimal amount of challenge.

The theory of reinvestment (Masters & Maxwell, 2008) does not make predictions about the influence of practice on transfer tasks. Maxwell et al. (2001) predicted but did not find a difference between errorless and errorful learning protocols on transfer performance. This prediction was based upon simpler, less motor-driven tasks. Perhaps errorless (or progressive) practice is detrimental for performance of transfer on simple but not more complex tasks.

The provision of the optimal challenge through a greater overall task difficulty would be predicted to influence a change in behaviour (learning) through the support for the need of feelings of autonomy. From a self-determination theory viewpoint, optimal challenge can be viewed as nurturing to inner motivational resources which has been shown to be autonomy supportive (Reeve, 2009).

Progression in relation to test target

Though Adams' (1971) does not address the transfer of learning, it can be predicted that those that finish practice closest to the transfer task would have the strongest perceptual trace closer to the test target than those who finished practice further away. The findings of experiment three in chapter two contradict this prediction; in fact the findings are exactly opposite to the prediction.

Schmidt's (1975) schema theory would predict no differences in performance on tests of learning when participants follow a different progression through the same targets because the same spread of experiences is encountered. The findings of experiment three, in particular the differences in dual task performance based upon progression in relation to the test target do not support the predictions of the schema theory (Schmidt 1975).

An explanation of the differences in dual-task performance that is consistent with the challenge point framework (Guadagnoli & Lee, 2004) is that those that began practice closest to the test target experienced the optimal amount of challenge. For the easier set of targets beginning at the most difficult location may have been the most appropriate, while for the more difficult set of targets beginning at the easiest target may have been the most appropriate.

A hypothesis consistent with the theory of reinvestment is that those who started practice closest to the target location experienced more implicit learning during acquisition than those that started further away. Poolton, Masters and Maxwell (2005) found that implicit learning was most important at the beginning of practice and the later introduction of explicit information was not detrimental. The results of experiment three in chapter two support this hypothesis as those that began practice closest to the target (either slightly closer or slightly further) did not experience the degradation of dual-task performance from the immediate to the delayed tests, while those that began further away from the test target did.

Once again the provision of the optimal challenge would be predicted to influence a change in behaviour (learning) through the support for the need of feelings of autonomy. The optimal challenge of a starting target, from a self-determination theory viewpoint, can be viewed as nurturing to inner motivational resources (Reeve, 2009).

The contributions of self-controlled and yoked protocol characteristics to performance on measures of learning.

Supporting evidence.

The fourth objective was to examine the characteristics of self-controlled and yoked practice scheduling protocols in order to better understand the contributions of each to performance on tests of learning. In particular, increased motivation is often cited as a reason for why self-controlled practice is beneficial for learning; however this has largely been assumed rather than quantified.

Theoretical interpretations.

Adams' (1971) theory would predict no differences between a self-controlled versus a yoked practice schedule protocol on measures of learning unless a difference in the number of errors made was found between the groups. In that case the group with fewer errors during acquisition would be predicted to have had the most beneficial practice characteristics for learning.

Similarly, the theory of reinvestment would predict that no differences between a self-controlled versus a yoked practice schedule protocol would be found on measures of learning unless a difference in the number of errors, or another variable influencing implicit versus explicit learning style made was found between the groups.

Schmidt's schema theory (1975) would perhaps allow for some predictions to be made about differences between self-controlled and yoked practice protocols. Since the recognition schema is built upon information about the relationships between desired outcome, initial conditions, the knowledge of past relationships between sensory consequences, and outcomes, it is possible that allowing the learner to choose the order in which to practice the blocks of trials may provide more information and a stronger schema than following a predetermined schedule.

The self-controlled motor learning literature was reviewed in chapter four, and a theoretical reinterpretation of the literature through the self-determination theory was provided. In this manuscript many factors in the practice protocol environment that can influence motivation and, in turn, behaviour, were identified and discussed. Two major explanations for the changes in behaviour (e.g., learning) that have occurred in experiments using self-controlled protocols were summarized and discussed as well. Cognitive explanations encompass information processing and cognitive effort explanations. These explanations were discussed in the context of self-determination theory as a way that inner motivational resources could be nurtured through the learners' sense of challenge. Motivational explanations to date have not been objectively measured and chapter four provided suggestions as to how this can be done in the future. However, the common theme of increasing autonomy of the learners fits well into the self-determination theory perspective.

The challenge point framework point of view (Guadagnoli & Lee, 2004) is another context where the challenge presented to learners by increased information processing or cognitive effort has the opportunity to be beneficial for learning. These increased cognitive processes provide more information, which in turn can be either beneficial or detrimental to learning, depending upon other task and learner variables.

Future Directions

The four experiments and one review presented in this thesis bring forth many new questions to be addressed in future research. Three avenues for future work are discussed below.

The first avenue to be explored stems from our findings that a progressive protocol does not always produce less error in acquisition than a reverse protocol. Future studies should attempt to identify parameters (e.g., task difficulty, open versus closed tasks or fine versus gross motor skills) which define the limits of the benefit of progressive protocols. The viewpoint of the challenge point framework seems like a good place to start for this avenue of inquiry as it takes into account features of the learner and environment that may account for differing benefits for similar protocols.

Another avenue that should be continued to be explored is the effect of self-controlled and yoked learning protocols on performance on dual-task tests. In chapter three we proposed that the self-controlled verses yoked manipulation was not as strong as it could have been. Future studies should use protocols that have been shown to effectively manipulate self-controlled versus yoked practice schedules (e.g., Keetch & Lee, 2007, Wu & Magill, 2011) and include immediate and delayed dual task tests.

A major avenue for future research was proposed in chapter four. Though many attempts at explaining differences between the effects of self-controlled and yoked learning protocols on learning have included motivation as a reason, none have included objective measures of motivation and regulation. The use of questionnaires such as the Intrinsic Motivation Inventory (Deci & Ryan, n.d.), in self-controlled motor learning protocols will help build a better understand of the effects on learning.

Concluding Remarks

In conclusion, the examination of the influence of learner involvement on the learning of motor tasks provides many avenues for exciting research in the future. Currently no one theoretical perspective can reconcile the effects of learner involvement on performance on retention, transfer and dual-task tests. However, several theories and perspectives can aid us in the developing of an overall picture of the influence of learner involvement on learning.

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