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Declarative and nondeclarative memory systems and the acquisition, retention, and transfer of a fine motor skill.

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DECLARATIVE AND NONDECLARATIVE MEMORY SYSTEMS AND THE ACQUISITION, RETENTION, AND TRANSFER OF A FINE MOTOR SKILL

by

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ABSTRACT OF DISSERTATION
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This study examined motor learning on two rotary pursuit tasks in 80 young adults. Subjects were randomly assigned to either a Simple Task or Complex Task group. Subjects practiced under either constant speed, variable speed, variable rotation training conditions, or were assigned as no training controls. Acquisition was assessed through a trend analysis of training trials. Retention and transfer were assessed by comparing each experimental group's performance after training to a no-training control group's performance on three tasks before and after training. This study: (a) evaluated motor schema formation under conditions in which task demands and training conditions simulated a motor skill continuum of perceptual-motor complexity, from simple to complex, and a memory continuum encompassing both nondeclarative and declarative memory processes; (b) considered the broad question of how Schmidt's (1975, 1988) schema theory and Magill and Hall's (1990) explanation of the contextual interference effect of motor learning relate and interact when the amount of variable training is held constant and when the variable training experiences are within the same or different motor programs; and (c) incorporated Magill and Hall's (1990) contextual interference

hypothesis and Schmidt's (1975, 1988) schema theory on the effect of practice conditions on motor skill learning into Squire's (1994) notion that many skill learning paradigms give rise to both nondeclarative and declarative knowledge. Consistent with Magill and Hall's (1990) hypothesis, results indicated that between-motor practice conditions promoted higher levels of contextual interference, resulting in significantly better transfer performance than within-motor practice conditions. Evidence suggested motor skill learning, engaging either procedural or declarative memory systems, occurs as schemata are formed which integrate the perceptual-motor response over time and/or training trials. Procedural schemata are formed when the perceptual-motor response required by both task and training conditions remains relatively invariant. The more variable the context for each occasion of practice and the more contextual interference that is present across training trials, the more training will engage declarative rather than procedural memory processes. It seems likely that variability in sensory-perceptual context and variability in between-motor response lead to optimal motor schemata formation.

DEDICATION

To my wife, Cathy, and children, Wallis, Brittany, and Warren, for their unending love and support through my graduate school years.

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CHAPTER 1

INTRODUCTION

Motor Skills

To meet the demands placed on an individual by the environment, a person must acquire and efficiently perform numerous motor skills that allow for the accomplishment of functional tasks. Walking, manipulating tools, and operating various kinds of equipment are all essential to daily living, whereas recreational activities such as skiing, tennis, or baseball enhance an individual's daily existence. Highly skilled movement will naturally lead to more successful performance of a specific motor skill. Thus, it is incumbent upon researchers and teachers to develop effective training methods for motor skills. To accomplish this goal, it is essential to understand the process of motor skill acquisition and transfer.

Until recently, one of the most neglected types of learning was that of the acquisition, retention, and transfer of motor skills. Early research (Lanier, 1934; Lincoln & Smith, 1951; Lordhal & Archer, 1958; Namikas & Archer, 1960) suggested that if a motor task is to be performed at a certain speed, it should be practiced at that speed, to facilitate learning of the task. On a rotary pursuit task, Lordhal and Archer (1958) and Namikas and Archer (1960) reported that substantial negative transfer occurred with a change in target speed, and transferring to the same speed gave the best results. More recent research, Schmidt's (1975, 1988) schema theory and the contextual interference effect as applied to motor learning (Battig, 1972, 1979; Magill & Hall, 1990; Shea & Morgan, 1979; Shea & Zimny, 1983), challenged and contradicted the evidence of these early investigators. These investigators suggested that variable practice conditions lead to positive transfer, whereas the early investigators (Lordhal & Archer, 1958; Namikas & Archer, 1960) found constant practice best facilitated transfer of a motor skill. The current study attempted to understand and reconcile previous research in terms of motor schema formation and the schemata's potential interdependence with memory systems. It assumed that all training will lead to the formation of motor schemata. However, increasing or decreasing the complexity of environmental, sensory, and perceptual-motor demands may differentially engage procedural and declarative memory systems within the skill learning paradigm. It is likely that when task demands remain simple, procedural memory is engaged, and the resultant motor schema is relatively inflexible and will evidence limited ability to generalize learning to a novel task. However, increasing the complexity of the task by expanding sensory-motor variation both within and across learning trials might engage declarative memory and stimulate the formation of the most flexible motor schemata.

Memory Systems

Current memory researchers (Eichenbaum, 1994; Nadel, 1994; O'Keefe & Nadel, 1978; Schacter & Tulving, 1994; Squire, 1994; Squire & Zola-Morgan, 1988; Sutherland &

Rudy, 1989) now posit theories of multiple memory systems, functioning under two subsystems in which some forms of learning are hypothesized to be critically dependent on the hippocampus and related structures and other forms of learning are not.

The hippocampal-dependent and hippocampal-independent systems have been labeled by various terms including explicit and implicit (Schacter, 1987), declarative and procedural (Cohen & Squire, 1980), declarative and nondeclarative (Squire & Zola-Morgan, 1988), configural associations and simple associations (Sutherland & Rudy, 1989), relational learning and nonrelational learning (Cohen & Eichenbaum, 1991), and locale and taxon (O'Keefe & Nadel, 1978) memory systems. Regardless of termi-nology, hippocampal-dependent memory, henceforth referred to as declarative memory, is considered to involve overt reference to a previous learning experience and conscious recollection of some previous experience (Schacter, 1987; Schacter & Tulving, 1994). It is fast, flexible, and available to multiple response systems (Squire, 1994). The hippocampus is necessary for the rapid acquisition of relational, configural, or declarative information (Cave & Squire, 1991). Declarative memory is generally assessed through tests of recall and recognition.

Hippocampal-independent, procedural, or nondeclarative memory is revealed when information acquired from previous experience facilitates or alters subsequent performance on a task. Squire (1994) asserted that nondeclarative memory is nonconscious and less flexible, providing limited access to response systems not involved in the original learning. An example of such learning is when performance of a motor skill, such as rotary pursuit, is facilitated by practicing this skill (Schacter, Chiu, & Ochsner, 1993; Schacter & Tulving, 1994).

Limbic structures in the medial temporal lobe and related diencephalic and basal forebrain structures are thought to be essential for declarative memory (Nadel, 1994; Squire, 1994; Zola-Morgan & Squire, 1993). Nondeclarative memory is hypothesized to embrace several kinds of memory and may depend on multiple brain systems (Squire, 1994; Nadel, 1994). An example of one such brain system is motor memory. A recent positron emission tomography (PET) study examined neural brain regions activated when normal right-handed subjects performed rotary pursuit across a number of trials. Grafton et al. (1992) found that motor execution was associated with cortical, striatonigral, and cerebellar activation. Rotary pursuit learning was linked with increasing activation of the primary motor cortex, the left supplemental motor area, and the left pulvinar of the thalamus.

As described, the declarative and nondeclarative memory systems appear to be discrete and independent systems where a specific task operates within a distinct system. For instance, free recall is often referred to as an episodic or declarative memory task, and rotary pursuit learning as a procedural or nondeclarative task. However, performance of a particular task does not necessarily rely exclusively on the output of a single system. Squire (1994, p.205) asserted that many skill-learning paradigms give rise to both declarative and nondeclarative knowledge: "Some tasks tap primarily what has been acquired declaratively; some tap nondeclarative knowledge; still other tasks measure the contribution of both declarative and nondeclarative knowledge."

Memory Systems and Motor Research

The study of learning and memory for motor skills is generally investigated and understood in terms of procedural or nondeclarative learning. However motor skills range from simple reflex behavior to complex perceptual-motor tasks that require sensory integration, memory processes, motor integration, and feedback of relational information during acquisition and later performance of the skill. The hippocampal-dependent or declarative memory system is likely required in complex motor tasks to encode relational representations into unique combinations of inputs defining relational units. These relational representations then allow the individual to use simple stimuli flexibly, both within and between specific units of stimuli (Shapiro & Olton, 1994). Given the assumed dichotomies of the memory system and the appearance that motor skill learning results under conditions suggesting a continuum of perceptual-motor complexity from simple to complex skills, the current research hypothesized that skill learning needed to be represented in memory along a similar continuum encompassing both nondeclarative and declarative memory systems. It is not clearly the case that motor skill learning would only use some nonconscious system, which is not hippocampal mediated, rather than engaging a system that involves processing by the hippocampus. It is possible that motor skills are represented, more or less, in both memory systems depending upon the perceptual-motor demands of the task. This study investigated a learning paradigm on rotary pursuit that employed both a simple and complex perceptual-motor stimulus to simulate conditions of a motor continuum and then assessed the potential contribution of procedural and declarative learning to the acquisition and transfer of a fine motor.

Rotary Pursuit and Procedural Memory Processes

Rotary pursuit learning (circular "simple" stimulus) under training conditions of both constant and variable speed practice is procedural in nature. Many researchers (Dick, Nielson, Beth, Shankle, & Cotman, 1995; Eslinger & Damasio, 1986; Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Schacter et al., 1993; Schacter & Tulving, 1994; Squire, 1994) agreed that training under constant practice conditions will lead to increased motor performance on a circular rotary pursuit apparatus and cited such learning as an example of procedural or nondeclarative memory processes. Beth, Duke, Marson, and Rickert (1998) studied motor learning on rotary pursuit in young adults, elderly adults, and Alzheimer's disease patients. They argued that learning the circular rotary pursuit under conditions of variable speed training was also an example of procedural or nondeclarative memory processes. Their data and inter-individual differences on MMSE, Grooved Pegboard Test, and Finger Oscillation Test from the Halstead-Reitan Battery suggested that this motor task required little or no hippocampal processing. On a memory continuum from nondeclarative to declarative knowledge, it appeared that the simple stimulus rotary pursuit was primarily assessing nonconscious and less flexible procedural memory.

Rotary Pursuit and Declarative Memory Processes

In the current study, changing the pattern of rotation on rotary pursuit from a simple (circular) to a "complex" (triangular) stimulus was hypothesized to change the nature of this motor skill from a procedural to a declarative memory task. A review of the literature showed that the triangular pattern of rotation is more difficult (Jensen, 1975, 1976) and requires motor integration of multiple and complex perceptual-motor stimuli (Whitehurst & Del Rey, 1983). The perceived speed of rotation changes as the target approaches and then recedes from the vertices of the stimulus pattern. It appears that the target alternatively increases and then decreases its speed. Performance on this task inherently involves comparisons between multiple stimuli and demands the integration of compound perceptual, spatial, and motor stimuli.

Citing both animal and human studies with amnestics, Squire (1994) stated that the hippocampal formation and related structures are specialized for rapidly forming conjunctions between arbitrarily different stimuli. Declarative memory is adapted for the rapid acquisition of relational information involving multiple stimuli. In animal models, lesions of the hippocampus and related structures severely impaired spatial memory tasks (Nadel, 1994; O'Keefe & Nadel, 1978) including odor-discrimination tasks (Eichenbaum, Fagan, Mathews, & Cohen, 1988), place learning tasks (Eichenbaum, Stewart, & Morris, 1990), timing tasks (Meck, Church, & Olton, 1984), and some tasks of configural memory (Rudy & Sutherland, 1994, 1995). In humans, explicit memories of an episodic nature (Schacter & Tulving, 1994) consist of multifeature representations of various kinds including spatial, temporal, and contextual information. The acquisition of explicit memories depends on the integrity of the medial-temporal lobes (Schacter & Tulving, 1994). On rotary pursuit, motor learning of this complex task was hypothesized to involve the utilization of the declarative memory system because the triangular pattern of rotation required the rapid acquisition of relational information involving multiple and complex perceptual-motor stimuli.

The Contribution of Declarative Memory to Motor Schema Formation

The formation of motor schemata requires the capacity to manage, integrate, and store relational data. The successful encoding of this information thus involves processing of the declarative memory system. Theories of motor learning (Schmidt, 1975, 1988), which are based on research with children and healthy young adults, suggest that the type of practice an individual received while performing a motor task played an important role in learning. These theories assume that practice under a wide variety of conditions generally leads to better retention and transfer in normal adults than practice of a task under identical or constant conditions. This ability to acquire a task through varied practice suggests the learner is forming a schema, an abstract set of rules which can be applied to successfully achieve the goal movement even when task demands change or are novel. To benefit learning, practice should involve variations within the same class or group of movements.

According to Schmidt, movements within the same class are governed by a generalized motor program. Schmidt's (1975) model asserted that motor skills are learned and that experience is deposited in memory structures called motor schemata. Schmidt (1975) recognized two motor schemata, the recognition schema (controlling the ongoing response) and the recall schema (initiating the response). In the recall schema, the execution of the movements is not an exact reproduction of earlier training, but a fresh construction of a constantly refined schema. Thus, variable training in the initial practice of a task enables the individual to develop a more environmentally valid schema that should allow successful transfer to novel situations not encountered in the initial learning condition. According to Schmidt (1975, 1988), this schema formation depends on the capacity to process, integrate, and store information about motor movement. A schema is based on knowledge about the (a) initial task conditions, (b) actual execution of the movement (e.g., sensory consequences of movement), (c) potential parameters of the movement (e.g., speed, direction, force), and (d) success of the response. In the current study, the ability to successfully encode and integrate the multiple stimuli containing this type of information was hypothesized to involve processing of the declarative memory system. Subsequent researchers have proposed alternative hypotheses to explain why variable practice enhances schema formation. Shea and Morgan (1979) and Shea and Zimny (1983) incorporated Battig's (1972, 1979) concept of the contextual interference effect into theories of motor learning. According to Battig's (1979) interpretation, contextual interference results from closely associated changes across trials in the experimental and processing contexts. Battig asserted that contextual interference is a major determinant for the use of multiple processing strategies by individual subjects. He argued that the entire learning or training context, including the task, practice schedule, and cognitive processing of the learner, were all potential sources of contextual interference that might lead to inferior performance during acquisition but are likely contribute to enhanced retention and transfer of the learned material. Shea and Morgan (1979) and Shea and Zimny (1983) proposed that contextual interference caused by random (nonrepetitive) practice rather than blocked practice led to a better appraisal of movements, thus facilitating schema formation. In their interpretation of Battig's conceptualization, contextual interference facilitated delayed retention of the motor skill and transfer to a novel motor task. Shea and Morgan (1979) and Shea and Zimny (1983) hypothesized that subjects who performed tasks with high levels of contextual interference compared with subjects who performed tasks involving low levels of contextual interference were forced to use multiple processing strategies, and this variability produced a more elaborate and distinctive processing of the material to be learned.

Magill and Hall (1990) asked why the contextual interference effect occurred, and they asserted that the effect has its roots in cognitive processing operations (Gabriele, Hall, & Lee, 1989; Lee & Magill, 1983, 1985; Shea & Morgan, 1979; Shea & Zimny, 1983, 1988). Magill and Hall (1990) argued that conditions of high contextual interference during practice encouraged learners to employ multiple and variable processing strategies in working memory, thereby allowing greater encoding activity in terms of within- and between-skill characteristics and relationships. The authors supported this view of the contextual interference effect with research in which explicit memory tests were evaluated (Shea & Morgan, 1979; Shea & Zimny, 1983, 1988). These studies suggested that subjects trained in random practice conditions engage in a number of different strategies and made multiple comparisons between tasks to aid learning during practice. Magill and Hall (1990) posited that the various tasks being practiced resided in working memory and could therefore be compared and contrasted. The cognitive processing of these multiple stimuli in working memory led to a more distinctive and elaborate representation of the task. Schacter (1987) and Schacter and Tulving (1994) theorized that processing in working memory is a function of the explicit or declarative (Cohen & Squire, 1980; Squire, 1994) memory system.

Schema theory and the contextual interference hypothesis both assume that motor schema formation involve processes that must manage, store, and integrate multiple sensory and perceptual-motor cues both within and across trials. Complex and elaborate cognitive processing leads to the formation of motor schema. Arguably, the processing of these multiple motor stimuli falls within the domain of declarative memory.

Reconciling the Contextual Interference Effect and Schema Theory

The schema theory of motor learning (Schmidt, 1975, 1988) and the contextual interference hypothesis (Battig, 1972), as interpreted by Shea and Morgan (1979) and Shea and Zimny (1983), both attempted to account for motor schema formation. Both are likely to require access to the declarative memory system if variable practice conditions are to successfully generalize to a novel transfer situation.

Schema theory assumes that motor schemata are created as a consequence of variable practice conditions that are parameter modifications (e.g., speed, spatial configuration) of the same motor program (Schmidt, 1975, 1988). However, Magill and Hall (1990) argued that practice schedule manipulations were not sufficient to produce the contextual interference effect when the practiced variations of a skill involve only motor program parameter modifications. Thus, conditions of high contextual interference are induced only when variations of the skill are controlled by different motor programs. Such conditions can occur by restructuring essential composite features of a task, such as the order of events a subject must perform to learn a particular motor task. For instance, on rotary pursuit, alternatively reversing the direction that the target rotated is a variation of the skill controlled by a different motor program.

Magill and Hall (1990) found support for their modification of the contextual interference effect hypothesis in a number of experiments that varied only parameter estimates during practice. When the overall speed parameter was modified in experiments (Lee, Wulf, & Schmidt, 1989, 1992), when overall force was varied (Pigott & Shapiro, 1984), or when five different speeds on rotary pursuit were practiced (Whitehurst & Del Rey, 1983), blocked (low contextual interference) rather than random (high contextual interference) practice schedules did not produce the contextual interference effect (i.e., improved delayed retention and transfer to a novel motor task). However, an experiment performed by Wood and Ging (1991) directly compared different levels of similarity in a task where subjects practiced moving their arm as fast as possible through a multi-segment movement pattern. Subjects performing "high similarity" variations of a task (within-motor program) did not evidence the contextual interference effect, whereas subjects performing "low similarity" variations of a task (between-motor program) showed the effect on novel transfer tasks.

Magill and Hall (1990) argued that the same practice schedule variations (variable practice) produced different retention and transfer effects depending upon whether the practiced variations were from the same or different motor programs. Magill and Hall (1990) had to reconcile this modification of the contextual interference effect with the observations of Shea and Morgan (1979) and Shea and Zimny (1983). Magill and Hall (1990) observed that Battig (1972) noted that the degree of the contextual interference effect could also be a function of task difficulty or complexity, where more complexity led to greater amounts of contextual interference. Thus, they argued that between-motor program variations were a more complex learning task than the within-motor program variations and, so, created high levels of contextual interference.

Addressing this modification of the contextual interference effect, the current investigation determined whether parameter modifications of the same motor program or variations of the skill controlled by different motor programs led to motor schema formation. If Magill and Hall (1990) are correct in their interpretation of the contextual interference effect, then modifying parameter specifications (within-motor program) by changing tracking speed on rotary pursuit is a sufficiently easy task that randomizing speed would lead only to "low levels of contextual interference" (Whitehurst & Del Rey, 1983). On the other hand, restructuring essential composite features of the task by alternately reversing the direction the target rotates would be a variation of the skill controlled by a different or between-motor program, and would create a complex task likely to produce "high levels of contextual interference" similar to those found by Wood and Ging (1991). Logic suggested that, if Magill and Hall (1990) are correct in their explanation of motor schema formation, manipulating practice schedules would differentially influence the learning of skill variations controlled by different motor programs, showing greater transfer than the learning of skill variations, which require parameter modifications of only one motor program. That is, when stimulus variations require control by different motor programs, practice conditions inducing high contextual interference will yield more effective retention and transfer benefits than practice conditions that induce low levels of contextual interference.

Goals of the Present Study

This study was designed to evaluate motor schema formation and transfer performance under conditions in which task demands and training conditions simulated a motor skill continuum of perceptual-motor complexity, from simple to complex, and a memory continuum encompassing both nondeclarative and declarative memory processes. In order to complete this evaluation of motor schema formation and reveal motor schema's potential interdependence with memory systems, two experimental group's (simple stimulus and complex stimulus) performance after training (constant speed, variable speed, and variable rotation practice) were compared to a no-training control group's performance on two transfer tasks before and after training.

Magill and Hall (1990), Schmidt (1975, 1988), and Van Rossum (1990) all assert that the critical issue in the research on schema formation and variation of practice is generalization, and Schmidt (1975) noted that practice under variable conditions should most benefit performance on new or "novel" situations rather than earlier encountered ones. As noted earlier, there were two transfer tasks. One transfer task required the subject to transfer to a faster speed, a parameter modification of the same motor program. The second transfer task was to a novel stimulus that was controlled by a different motor program. By employing two transfer variations, one controlled by the same motor program and the other controlled by a different motor program, this study was able to consider the broad question of how schema theory and the contextual interference effect relate and interact when the amount of variable training is held constant and when the variable training experiences are within the same or a different motor program. More specifically, this study attempted to determine whether constant speed (no contextual interference), variable speed (low contextual interference), or variable direction of rotation (high contextual interference) practice conditions facilitated schema formation for the rotary pursuit skill. This study was designed to established whether parameter modifications (e.g., speed, spatial configuration) of the same motor program (Schmidt, 1975, 1988) were sufficient to elicit motor skill transfer to a novel condition. Concurrently, these same parameter modifications were hypothesized to create low levels of contextual interference, whereas skill variation by a between-motor program was hypothesized to create high levels of contextual interference. Strong support for Magill and Hall's (1990) hypothesis that the contextual interference effect prompts schema formation would be found if conditions of higher contextual interference promoted significantly more transfer to a novel condition than conditions inducing less contextual interference.

Magill and Hall's (1990) contextual interference hypothesis and Schmidt's (1975, 1988) schema theory on the effect of practice conditions on motor skill learning have also been incorporated into Squire's (1994) notion that many skill learning paradigms give rise to both nondeclarative and declarative knowledge. The current study investigated this continuum of two memory systems and motor representation within each memory system. It was hypothesized that the product of motor skill learning is a schema regardless of the motor task. The schema that are formed will integrate the perceptual-motor responses over time or over training trials. Procedural memory is engaged when the motor response is consistent and there is minimal variation during training. The resultant motor schema is diminished and will likely show limited flexibility in generalizing learning to novel tasks. Declarative memory is engaged by increasing task variability for each occasion of practice. This variability may be induced through task demands, which require the integration of multiple or complex perceptual-motor stimuli, or variability may be present across practice conditions. The resultant schema is flexible and learning will generalize to novel task conditions.

Specific Aims and Hypotheses

Aim 1 hypotheses. The assumption that procedural learning is relatively inflexible and can only result under simple closely replicated learning conditions allowed for the generation of the following hypotheses regarding the acquisition and transfer of a simple motor skill.

Hypothesis 1a: All subjects who receive simple-task training will evidence increasingly higher time on target (TOT) during acquisition with practice .

Hypothesis 1b: All simple-task experimental subjects will demonstrate significantly higher TOT on retention trials after training than no-training control subjects.

Hypothesis 1c: Subjects trained under conditions of variable practice will not show more positive transfer to a new task on the simple stimulus than subjects trained under constant practice conditions.

Hypothesis 1d: Subjects, irrespective of training conditions, will not show positive transfer to the complex stimulus.

Aim 2 hypotheses. The recognition that declarative memory facilitates the integration of arbitrarily different stimuli and the rapid acquisition of relational information involving these multiple stimuli allowed for the generation of the following hypotheses regarding the acquisition and transfer of a complex motor skill.

Hypothesis 2a: All subjects who receive complex-stimulus training will evidence increasingly higher TOT during acquisition with practice.

Hypothesis 2b: All complex-stimulus experimental subjects will demonstrate significantly higher TOT on retention trials after training than no-training control subjects.

Hypothesis 2c: Subjects trained under conditions of variable practice will show significantly more positive transfer to a new task on the complex stimulus than subjects trained under conditions of constant practice.

Hypothesis 2d: Subjects trained under conditions of variable practice will evidence significantly more positive transfer to a novel task on the simple stimulus than subjects trained under conditions of constant speed practice.

Aim 3 hypotheses. This proposal's investigation of motor schemata formation and its contrast of Schmidt's schema theory to the contextual interference effect in the same experiment allowed for the generation of the following hypotheses regarding the formation of motor schemata.

Hypothesis 3a: Subjects trained under conditions of variable rotation (between-motor program) on the complex stimulus will demonstrate significantly more positive transfer to a new task on the complex stimulus than subjects trained under variable speed (within-motor program) practice conditions.

Hypothesis 3b: Subjects trained under variable rotation (between-motor program) on the complex stimulus will evidence significantly more positive transfer to a novel task on the simple stimulus than subjects trained under variable speed practice conditions.

CHAPTER 2

METHODS

Subjects

Subjects selected for participation in the study were recruited from University of Alabama at Birmingham undergraduate psychology students. Subject selection procedures were approved by the Institutional Review Board for Human Use (see Appendix). Subjects (a) did not have a history of major psychiatric illness, chronic alcoholism, other neurological disorders, or cognitive impairment and (b) were free of any physical impairment that would interfere with participation in the motor activity. Health status was assessed with a health status questionnaire. Fine motor ability was assessed using normative data for Grooved Pegboard Test and Finger Oscillation Test from the Halstead-Reitan Battery. Cognitive status was assessed using normative data from two subscales from the Wechsler Memory Scale-Revised (WMS-R), Verbal Paired Associates and Visual Paired Associates; and the Shipley-Institute of Living Scale. The two memory tests assessed verbal and visual learning and retention. The Shipley-Institute of Living Scale assessed intellectual ability. All participants served as subjects for course credit.

Eighty-six subjects were recruited, and eighty subjects (age: $\underline{M}$ = 20.46, SD = 3.22; gender: male = 41, female = 39) were eligible participants in the study (see Table 1).

Table 1

Demographic and Psychometric Characteristics of the Sample

		Sample characteristics						
Group	Age	Pegboard Dominant	Pegboard N-Dominant	Oscillation Dominant	Oscillation N-Dominant	WMS-R Verbal II	WMS-R Visual II	Shipley
Simple Task								
M	20.50	65.17s	71.82s	51.84	47.20	7.93	5.95	103.92
SD	3.53	9.27	10.97	5.77	5.42	0.27	0.32	6.48
Complex Task								
M	20.43	65.22s	71.57s	52.98	48.31	7.95	5.88	103.79
SD	2.93	9.71	10.05	6.14	5.45	0.22	0.46	7.90

Note. s = seconds; Simple Task = subjects trained on circular task; Complex Task = subjects trained on triangular task; Pegboard Dominant/N-Dominant = Halstead-Reitan Grooved Pegboard, dominant hand/non-dominant hand; Oscillation Dominant/N-Dominant = Halstead-Reitan Finger Oscillation, dominant hand/non-dominant hand; WMS-R Verbal II = Wechsler Memory Scale-Revised (WMS-R), Verbal Paired Associates II; WMS-R Visual II = Wechsler Memory Scale-Revised (WMS-R), Visual Paired Associates II; Shipley = Shipley-Institute of Living Scale.

All subjects were randomly assigned to either the "simple task" or "complex task" groups. Within each group, subjects were randomly assigned to one of four training conditions.

Design

This experiment used a 2 Group X 4 Type of Training X (3 Test X 3 Stimulus) mixed factorial design. The between-subject factors were Group and Type of Training. The within-subject factors were Test and Stimulus.

The Group factor compared performance of the simple task and complex task subjects. Subjects assigned to the simple group tracked a target on a circular patterned stimulus with a hand-held stylus. Successful performance required coordination of hand/eye movements to track the target on this simple and unchanging perceptual-motor task. This fine motor skill was thought to primarily access the procedural (non-declarative) memory system. Subjects assigned to the complex task group learned the task on a triangularly patterned stimulus. Successful tracking performance required coordination of hand/eye movements; comparisons between multiple perceptual stimuli; and the integration of compound perceptual, spatial, and motor stimuli. This fine motor skill was thought to access the declarative memory system.

The Type of Training factor compared constant speed, variable speed, variable direction of rotation practice, and no-training controls. The trainees assigned to the constant-speed practice condition learned the task by receiving training at the same speed across all training trials. Trainees assigned to the variable-speed practice condition learned the task by receiving training at each of four speeds presented in randomized fashion across training. Variable speed was a training condition that modified a parameter (e.g., speed) of the same motor program, a within-in motor program (Schmidt, 1975, 1988) variation in training. Trainees assigned to the variable-direction-of-rotation practice condition learned the task by receiving randomized training in both a clockwise and counter-clockwise pattern of rotation. Variable-rotation training, a between-motor program (Magill & Hall, 1990), restructured the essential composite features of the task, randomly reversing the order of events a subject must perform to learn the task. Trainees assigned as control subjects received no training on a photoelectric rotary pursuit apparatus. An equal number of subjects (n = 10) were randomly assigned to each Group X Type of Training condition.

The within-subject factor Test compared pretest, a measure made prior to any training, and posttest. There were two posttests: short delay, a measure made 20 to 25 minutes after the completion of training, and long delay, a measure made 14 days after the completion of training.

The within-subject factor Stimulus had three levels: (a) Retention at baserate training speed (TBR) examined the effect of training on rotary pursuit performance for the same stimulus pattern (simple or complex task) at the subject's assigned training speed; (b) same stimulus transfer (SST) examined the effect of training on rotary pursuit transfer to the same stimulus pattern (simple or complex task) at a faster speed; and (c) novel stimulus transfer (NST) examined the effect of training on rotary pursuit transfer to a novel stimulus pattern. SST is a transfer task in which the variation in speed is a parameter modification. SST is a within-motor program transfer task. NST is a transfer task in which the essential composite features of the task have changed. NST is a between-motor program transfer task. For the simple-task group, NST was related to the triangular stimulus pattern; and for the complex task group, NST was related to the circular stimulus pattern.

This design allowed for the examination of whether training under constant speed, variable speed, or variable rotation practice conditions would differentially effect motor skill acquisition, retention, and transfer to similar and novel task conditions. Differential transfer was deemed likely dependent on the relative contribution of procedural or declarative knowledge required for performance of a specific transfer task. This investigation's pre- and posttest design attempted to demonstrate the relative contribution of procedural (nondeclarative) and declarative memory to the formation of flexible motor schemata. Additionally, the design compared Schmidt's (1975, 1988) schema theory to the contextual interference hypothesis (Battig, 1972) as adapted by Shea and Morgan (1979), Shea and Zimny (1983), and Magill and Hall (1990) to determine which theory best accounted for motor schema formation.

Experimental Task and Procedure

The equipment employed in this experiment was a Lafayette photoelectric rotary pursuit with a variable speed tracking device and timer. The subject used a hand-held light-sensitive stylus to track a light source (target) that moved in a clockwise or counter-clockwise direction. The pattern of the rotation was circular (simple task) or triangular (complex task) and all tasks were performed at speeds from 5 to 100 rpm. The dependent measures--the time a subject kept the stylus on the light source (TOT), and number of impulses (NOI), the number of times the stylus slipped off target--were recorded across all trials.

Before meeting the experimenter, all subjects were randomly assigned to Group and Type of Training. The experimenter administered a health status questionnaire and decided eligibility for participation in the study. The experimenter then determined the subject's baserate speed for each stimulus pattern (simple and complex tasks). Because the turntable can be adjusted to rotate at different speeds, one can equate initial difficulty level across all subjects, preventing floor and ceiling effects (see e.g., Butters, Heindel, & Salmon, 1990; Heindel et al., 1988). The subject's baserate was determined by presenting eight trials for each individual task, at speeds of 15, 30, 45, 60, 60, 45, 30, and 15 rpm. The baserate was the mean of the two trial sets (up and down) in which the subject kept the stylus on target approximately 25% of the time or 5 sec (see e.g., Butters et al., 1990; Heindel et al., 1988). Baserate speed for the stimulus pattern employed during training was designated BR. Baserate speed for the novel stimulus pattern was designated NBR.

The pretraining measures (TBR, SST, NST), consisting of six trials presented in three blocks of two trials each, were randomly administered to all experimental subjects. One block, TBR, was presented at the subject's BR for the stimulus pattern on which the subject's group received training. Two transfer blocks were presented: SST, where SST = (BR + 35% BR); and NST, where NST = (NBR + 35% NBR).

After completing the pretest, initial cognitive tests were administered. All experimental subjects were screened on the Grooved Pegboard Test, Finger Oscillation Test, and two subscales of the WMS-R (Verbal Paired Associates I and Visual Paired Associates I). Additional cognitive testing was completed after the training session.

Control subjects were also administered before training measures and cognitive tests; however, the order of administration was modified. After determining baserate speed, control subjects were administered subscales ofthe WMS-R (Verbal Paired Associates I and Visual Paired Associates I). During a working 20-min delay (delay I), all control subjects were administered the Grooved Pegboard Test, Finger Oscillation Test, and the pretraining measures (TBR, SST, NST). During a second 20- to 25-min delay (delay II), which followed the pretraining measures, all control subjects were administered the delay subscales of the WMS-R (Verbal Paired Associates II and Visual Paired Associates II) and the Shipley-Institute of Living Scale.

There was one training session for the experimental groups, which consisted of 40 trials (Beth et al. 1998; Dick et al., 1995) presented in eight blocks of five trials. There was a 60-sec rest period between each block. During each trial, all subjects tracked the photoelectric light source for 20 sec and then relaxed during a 20-sec intertrial interval (see e.g., Butters et al., 1990, Heindel et al., 1988). In the constant-speed practice condition, all training trials were administered at the subjects' respective BR. In the variable-speed training condition, subjects received all 40 trials presented randomly at the subjects' respective BR +/-(15% BR) and BR +/- (30% BR), such that within eight trials, each speed was presented two times and no more than two speeds appeared in a hierarchical, ascending or descending, order. In the variable-rotation practice condition, all training trials were randomly administered in both a clockwise and counter-clockwise direction at the subject's respective BR. All practice trials were limited to this one training session. The control group was not trained on either stimulus.

Immediately after the training session, cognitive testing was completed. All experimental subjects were administered the delay subscales of the WMS-R (Verbal Paired Associates II and Visual Paired Associates II) and the Shipley-Institute of Living Scale. All control subjects were administered this same battery of cognitive tests following the working delay I.

Posttests consisting of two trials presented at the subjects' respective BR, SST, and NST were randomly administered to all groups approximately 20 to 25 min (short delay) and 14 days (long delay) after the last training trial. Control subjects received the posttests after delay II and at 14 days. Acquisition of the rotary pursuit skill was assessed using two different measures: an analysis of baserate time on target, each subject's time on target used to equate initial task difficulty level across all subjects, and improvement in TOT across the 40 training trials. Rotary pursuit retention short-delay performance at TBR was assessed at the subjects' respective BR and compared to performance on the pretest. Long-delay TBR retention of the rotary pursuit skill was assessed at the subjects' respective BR and long-delay retention performance was compared to both pretest and short-delay performance. Transfer was assessed at two levels: same stimulus task and novel stimulus task transfer. SST transfer of the motor skill was assessed by having subjects perform at their transfer speed on the trained stimulus pattern. NST transfer of the motor skill was assessed by having subjects perform at the novel stimulus transfer speed. SST and NST transfer performance (short delay and long delay) were compared to pretraining performance on the rotary pursuit apparatus.

CHAPTER 3

RESULTS

Data Analysis

The dependent variables for all pretraining, training, short-delay, and long-delay trials were TOT, recorded in milliseconds, and skill development (NOI/TOT), recorded as number of impulses (occurrences) of stylus leaving target as a function of the subject's TOT. For purposes of analysis, the mean of the two trials for each subject used to determine baserate speed, and the mean of all 40 training trials were computed by taking the mean TOT of the appropriate trials for each subject. Each subject's performance under the within-subjects factors--pretraining at TBR, SST, NST; short-delay at TBR, SST, NST; and long-delay at TBR, SST, NST performance--were assessed by taking the mean TOT and NOI/TOT of the two trials for each task. Initial analyses revealed that the difference between the two posttest TOT measures: short-delay and long-delay at TBR, $p = .133$; SST, $p = .159$; and NST, $p = .076$ were not significant. For all subsequent analyses, means of the two posttest measures, delay, were employed. Means for all conditions are presented in Table 2 (TOT) and Table 3 (NOI/TOT). Interindividual differences were examined with one-way ANOVA and correlational analyses of Group with measures of neuropsychological functioning: WMS-R (Verbal Paired Associates and Visual Paired Associates); Shipley-Institute of Living Scale; and from the Halstead-

Table 2

Rotary Pursuit Acquisition and Transfer Descriptive Data: Mean Speed of Rotation and Mean Time on Target (TOT)

Group	Sample means								
	Baserate	Baserate	Baserate	Pretest			Delay		
Simple task training	speed SS	speed CS	TOT	TBR	SST	NST	TBR	SST	NST
Constant speed									
M	48.80	42.80	3.82	5.52	2.87	4.15	9.15	6.19	4.85
SD	10.70	11.18	1.12	1.78	1.30	0.89	1.87	2.16	1.20
Variable speed									
M	51.00	49.50	4.47	5.52	3.74	4.28	9.60	6.27	5.06
SD	7.74	10.12	1.04	1.13	0.64	0.92	0.83	0.93	0.61
Variable rotation									
M	48.00	46.50	5.21	6.64	4.19	3.65	10.84	7.50	5.39
SD	11.83	13.13	1.09	1.93	1.60	1.44	1.01	1.35	0.52
Control									
M	43.50	43.00	4.37	5.90	4.25	4.16	6.01	4.22	4.41
SD	10.29	13.17	0.93	2.92	4.25	1.46	1.04	1.50	1.21

Table 2 (Continued)

Group	Sample means								
	Baserate	Baserate	Baserate	Pretest			Delay		
Complex task training	speed SS	speed CS	TOT	TBR	SST	NST	TBR	SST	NST
Constant speed									
M	50.00	48.50	5.07	5.22	5.31	3.69	8.69	7.34	5.56
SD	12.91	12.48	1.06	0.84	0.78	1.32	1.25	1.14	1.71
Variable speed									
M	54.00	51.00	5.32	5.12	4.65	3.41	7.50	6.40	5.15
SD	7.75	10.49	1.19	0.42	1.11	1.06	0.83	0.95	0.97
Variable rotation									
M	51.75	49.50	4.86	5.00	4.33	3.39	8.32	7.00	6.37
SD	7.46	10.12	0.93	0.71	1.06	0.94	0.87	0.71	0.82
Control									
M	54.00	51.00	4.51	5.01	4.49	3.42	5.28	4.31	3.36
SD	7.75	10.49	1.47	1.08	0.63	1.58	0.92	0.75	1.08

Note. Simple task = subjects trained on circular task; Complex task = subjects trained on triangular task; Constant speed = constant speed training conditions; Variable speed = variable speed training conditions; Variable rotation = variable rotation training conditions; Baserate TOT = Time on Target at base rate speed; Baserate speed SS= baserate rpm on the simple stimulus; Baserate speed CS= baserate rpm on the complex stimulus; TBR = baserate training TOT (sec); SST = same stimulus transfer TOT (sec); NST = novel stimulus transfer TOT (sec).

Table 3

Rotary Pursuit Acquisition and Transfer Descriptive Data: Mean Skill Development (NOI/TOT)

Group	Sample means					
	Pretest			Delay		
	TBR	SST	NST	TBR	SST	NST
Simple task training						
Constant speed						
M	5.59	7.86	10.69	3.86	5.49	11.18
SD	1.45	1.79	1.73	0.94	1.70	2.24
Variable speed						
M	5.82	7.31	12.41	3.78	5.95	12.48
SD	0.71	1.06	0.61	0.64	0.91	1.53
Variable rotation						
M	4.41	5.79	11.11	3.06	4.62	11.10
SD	1.01	1.25	2.13	0.74	1.05	2.17
Controls						
M	5.19	5.77	10.57	5.52	6.87	11.65
SD	1.86	1.66	1.32	1.98	1.89	1.91
Complex task training						
Constant speed						
M	9.95	10.97	7.22	7.93	10.45	7.24
SD	2.21	2.02	2.09	2.25	2.85	1.61
Variable speed						
M	10.40	12.92	7.41	8.74	10.99	7.12
SD	2.45	2.41	1.05	2.03	2.33	1.39
Variable rotation						
M	10.88	13.35	8.57	8.24	10.89	5.53
SD	1.91	2.47	1.92	1.56	1.47	1.24
Controls						
M	10.41	12.35	8.48	10.82	14.02	9.07
SD	1.99	2.06	3.07	1.90	2.76	3.05

Note. Simple task = subjects trained on circular task; Complex task = subjects trained on triangular task; Constant speed = constant speed training conditions; Variable speed = variable speed training conditions; Variable rotation = variable rotation training conditions; TBR = baserate training NOI/TOT; SST = same stimulus transfer NOI/TOT; NST = novel stimulus transfer NOI/TOT.

Reitan Battery Grooved Pegboard Test and Finger Oscillation Test. SPSS MANOVA with appropriate follow-up was used for the analyses. The significance level for all analyses was $\alpha = .05$.

Baserate

Descriptive data and a 2 (Group) X 4 (Type of Training) at baserate TOT ANOVA showed that at the assignment of each subject's baserate speed, initial TOTs for complex task subjects later trained under constant speed ($\underline{M}$ = 4.91), variable speed ($\underline{M}$ = 4.58), variable rotation ($\underline{M}$ = 5.05), control ($\underline{M}$ = 4.55) training conditions, and simple task subjects later trained under constant ($\underline{M}$ = 3.82), variable speed ($\underline{M}$ = 4.47), variable rotation ($\underline{M}$ = 5.21), control ($\underline{M}$ = 4.37) training conditions, were not significantly different. There were no Group $\underline{F}(1,72) = 1.72$, $\underline{p} = .194$; Type of Training $\underline{F}(3,72) = 2.19$, $\underline{p} = .097$; or Group X Type of Training $\underline{F}(3,72) = 1.35$, $\underline{p} = .265$ effects. This analysis demonstrated that all subjects performed at a similar level of expertise before training.

Acquisition

A trend analysis of TOT (see Figure 1) of training trials 1 through 40 (with trials blocked 1 to 10, 11 to 20, 21 to 30, 31 to 40) for both complex task constant speed ($\underline{M}$ all 40 trials = 7.40) with variable speed ($\underline{M}$ all 40 trials = 6.26) and variable rotation ($\underline{M}$ all 40 trials = 6.36), and simple task constant speed ($\underline{M}$ all 40 trials = 7.78) with variable

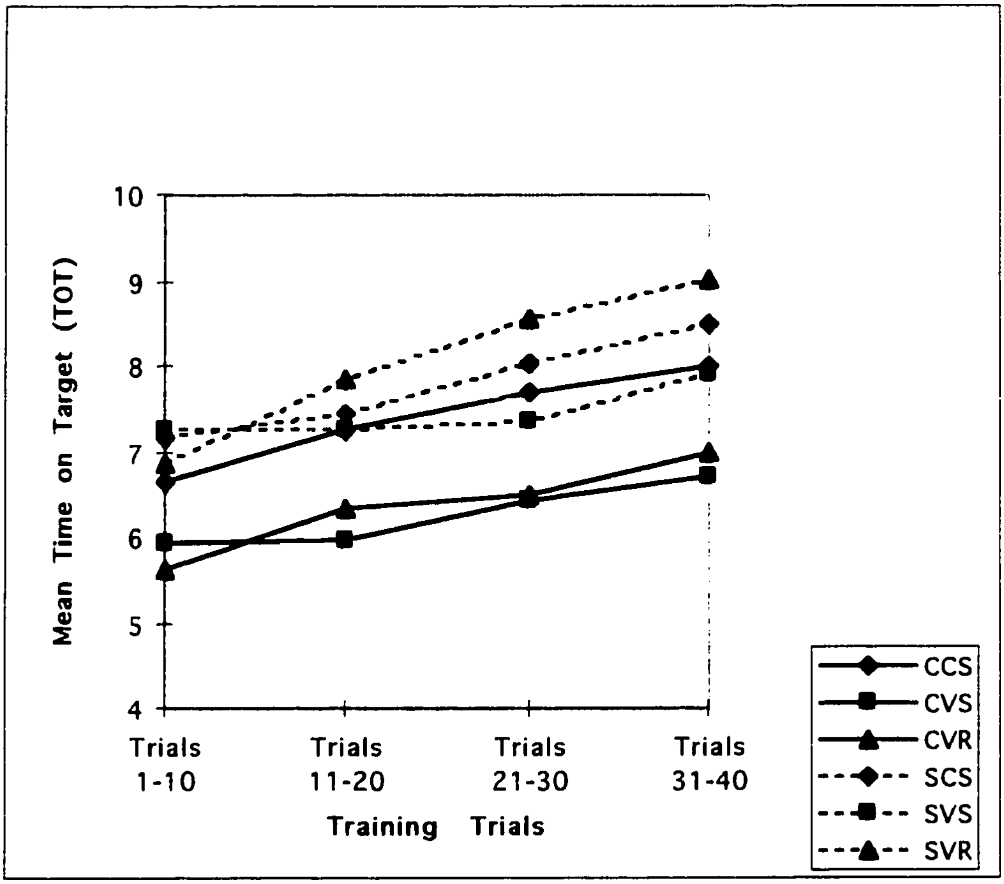

Figure 1. Group X Type of Training acquisition trials 1 to 40 with trials blocked by 10, CCS = complex task constant speed; CVS = complex task variable speed; CVR = complex task variable rotation; SCS = simple task constant speed; CVS = simple task variable speed; CVR = simple task variable rotation.

speed (M all 40 trials = 7.45) and variable rotation (M all 40 trials = 8.07) resulted in a significant effect for Group, $F(1,54) = 72.12$, $p = .000$, and for trials (linear trend), $F(1,54) = 148.18$, $p = .000$. The quadratic, $F(1,54) = .00609$, $p = .938$; and cubic, $F(1,54) = .04470$, $p = .833$, components of trend were not significant. During acquisition trials, the simple task group performed better than the complex task group, but each group's performance increased over trials. The linear trend had significant Type of Training X Trend interaction, $F(2,54) = 7.43$, $p = .001$. The Group X Trend, $F(1,54) = 1.21$, $p = .276$, and Group X Type of Training X Trend, $F(2,54) = 2.76$, $p = .072$, interactions were not significant. These trend analyses indicated that there were significant differences for Group, with the simple task group performing better than the complex task group during acquisition trials; however, all experimental subjects acquired the rotary pursuit skill. Additionally, although both groups showed significant learning across training trials, the type of training (constant speed, variable speed, variable rotation) differentially affected acquisition. Simple main effects analysis of Type of Training X Trend interaction showed that on both tasks, subjects who received training under conditions of constant speed, $F(1,36) = 6.67$, $p = .014$, and variable rotation, $F(1,36) = 13.69$, $p = .001$, practice conditions showed performance superior to those trained under conditions of variable speed practice.

Retention

To determine whether the two groups, complex task subjects and simple task subjects, retained and transferred the rotary pursuit task, a 2 Group (complex and simple subjects) X 4 Type of Training (constant speed, variable speed, variable rotation, no training control) [X 2 Test (pretest, delay) X 3 Stimulus (TBR, SST, NST)] mixed model repeated measures ANOVA was performed with Group and Type of Training as between-subject factors; Test and Stimulus as the within-subject factors; and TOT the dependent variable.

When the overall analysis, a 2 Group X 4 Type of Training [X 2 Test X 3 Stimulus] ANOVA, was performed, the 4-way Group X Type of Training [X Test X Stimulus] interaction, $F(12, 288) = 3.44$, $p = .000$, $\beta = .997$, was significant. For purposes of analysis, it was then determined to individually analyze rotary pursuit retention at TBR and transfer at SST and NST, respectively. Retention of the rotary pursuit task was analyzed with a 2 Group X 4 Type of Training at TBR ANOVA with difference score (delay - pretest) TOT as the dependent variable. Transfer of the rotary pursuit skill was analyzed by performing a 2 Group X 4 Type of Training ANOVA at both SST and NST. Difference score (delay - pretest) TOT was the dependent measure for all analyses. Tabachnick and Fidell (1989) stated that when the covariate(s), which in this analysis is pretest, and the dependent variable (TOT) are measured on the same scale, the use of difference scores is an appropriate option for analysis. This alternative allowed for conversion of the pre- and posttest scores into a dependent variable. As the research question was phrased in terms of "change," this difference score provided the answer. When the overall difference score analysis, a 2 Group X 4 Type of Training [X 3 Stimulus] difference score ANOVA was performed, the 3-way Group X Type of Training [X

Stimulus] interaction, $F(6, 144) = 4.77$, $p = .000$, $\beta = .988$, was significant. Appropriate follow-up analyses with planned comparisons were performed on all significant effects.

Follow-up analyses of the significant 3-way difference score interaction were used to determine how Type of Training affected both groups in the retention of the rotary pursuit task. When a 2 Group X 4 Type of Training ANOVA was performed at TBR, a significant effect was found for the Group X Type of Training interaction, $F(3,72) = 3.11$, $p = .032$, $\beta = .702$. Planned comparisons, based on one-way ANOVA contrasts of the Group X Type of Training interaction (see Figures 2 and 3), showed that all experimental subjects in the three practice conditions made significant improvement in TOT with training compared with the no-training control group. Subjects assigned to the complex task group (triangular stimulus pattern) and trained under constant speed (pretest $M = 5.22$; delay $M = 8.69$; difference $M = 3.47$), variable speed (pretest $M = 5.12$; delay $M = 7.50$; difference $M = 2.38$), and variable rotation (pretest $M = 5.00$; delay $M = 8.32$; difference $M = 3.32$), all retained the task compared with no training controls (pretest $M = 5.01$; delay $M = 5.28$; difference $M = 0.27$), $T(36) = 8.255$, $p = .000$ (see Figure 2). For the complex task group, contrasts showed that training under constant speed was superior to variable speed training, $T(36) = 2.637$, $p = .012$; variable rotation training was superior to variable speed training, $T(36) = 2.270$, $p = .029$; but practice under training conditions of constant speed or variable rotation were not significantly different, $T(36) = 0.367$, $p = .716$. Subjects randomly assigned to the simple task group (circular stimulus pattern) and trained under constant speed (pretest $M = 5.52$;

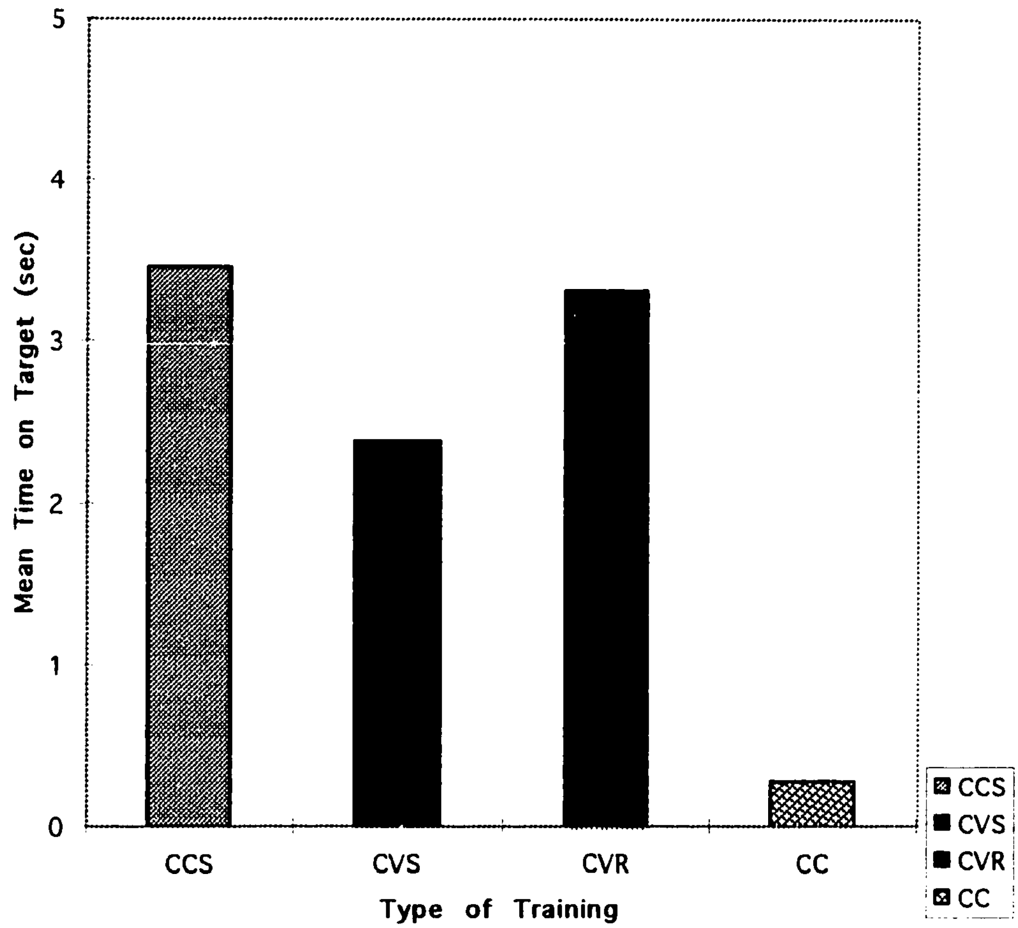

Figure 2. Retention: Mean difference score TOT pretest to delay for the complex task group X type of training at TBR. CCS = complex task constant speed; CVS = complex task variable speed; CVR = complex task variable rotation; CC = complex task control subjects.

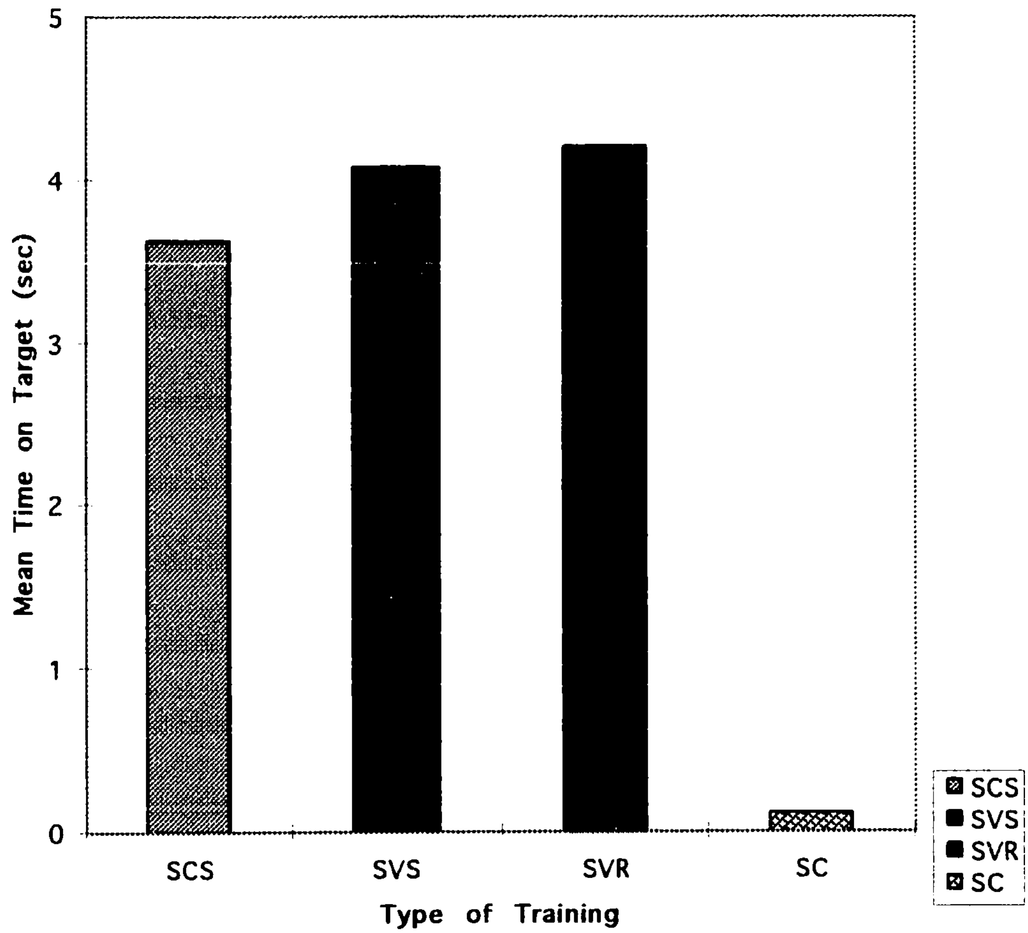

Figure 3. Retention: Mean difference score TOT pretest to delay for the simple task group X of training at TBR. SCS = simple task constant speed; SVS = simple task variable speed; SVR = simple task variable rotation; SC = simple task control subjects.

delay M = 9.15; difference M = 3.63), variable speed (pretest M = 5.52; delay M = 9.60; difference M = 4.08), and variable rotation (pretest M = 6.64; delay M = 10.84; difference M = 4.20), all retained the task as compared to no training controls (pretest M = 5.90; delay M = 6.01; difference M = 0.11), T (36) = 9.048, p = .000 (see Figure 3). For the simple task group, contrasts showed no significant difference for type of training: constant vs. variable speed, T (36) = -0.864, p = .393; constant speed vs. variable rotation, T (36) = -1.102, p = .278; and variable speed vs. variable rotation, T (36) = -0.215, p = .814. These cumulative analyses showed that all experimental subjects retained the rotary pursuit task compared with no training controls. However, training conditions differentially affected rotary pursuit retention for the complex task group, but training conditions did not differentially effect retention for the simple task group.

Skill development, a subject's improvement in accuracy across trials, was also assessed by a 2 Group X 4 Type of Training [X 3 Stimulus] mixed-model ANOVA with difference score (delay - pretest) NOI/TOT as the dependent measure. The three-way Group X Training X Stimulus interaction was significant, $F(6, 144) = 2.22$, $p = .045$, $\beta = .768$. For purposes of analysis, it was decided to individually analyze skill development at TBR, SST, and NST, with difference score NOI/TOT as the dependent measure. Appropriate follow-up analyses with planned comparisons were performed on all significant effects.

Following up the analysis of the significant 3-way skill development interaction with a 2 Group X 4 Type of Training ANOVA at TBR with difference score NOI/TOT as the dependent measure showed a significant effect for Type of Training, $F(3,72) = 20.88$, $p = .000$, $\beta = 1.0$. The Group, $F(3,72) = 1.27$, $p = .264$, $\beta = .197$, and the Group X Type of Training interaction, $F(3,72) = 2.10$, $p = .108$, $\beta = .515$, were not significant. Planned comparisons (see Figure 4) of the significant Type of Training effect collapsed across Group showed that all experimental subjects in the various practice conditions made significant improvement in skill development with training compared with the no-training control group. Subjects trained under constant speed (pretest $M = 7.77$; delay $M = 5.89$; difference $M = -1.88$), variable speed (pretest $M = 8.11$; delay $M = 6.26$; difference $M = -1.85$), and variable rotation (pretest $M = 7.65$; delay $M = 5.65$; difference $M = -2.00$) all showed improvement in keeping the stylus on target compared with no-training controls (pretest $M = 7.79$; delay $M = 8.17$; difference $M = 0.38$), $T(76) = -7.722$, $p = .000$. No significant differences in skill development were found for Type of Training among the experimental subjects: constant vs. variable speed, $T(76) = -0.071$, $p = .994$; constant speed vs. variable rotation, $T(76) = 0.336$, $p = .738$; and variable speed vs. variable rotation, $T(76) = .407$, $p = .685$.

The analyses of TOT and skill development showed that constant speed, variable speed, and variable rotation training conditions all promoted the acquisition and retention of the rotary pursuit skill. All training conditions promoted learning on both stimulus patterns; however, experimental evidence generally suggested that variable rotation and constant speed training enhanced acquisition and retention for the complex task group,

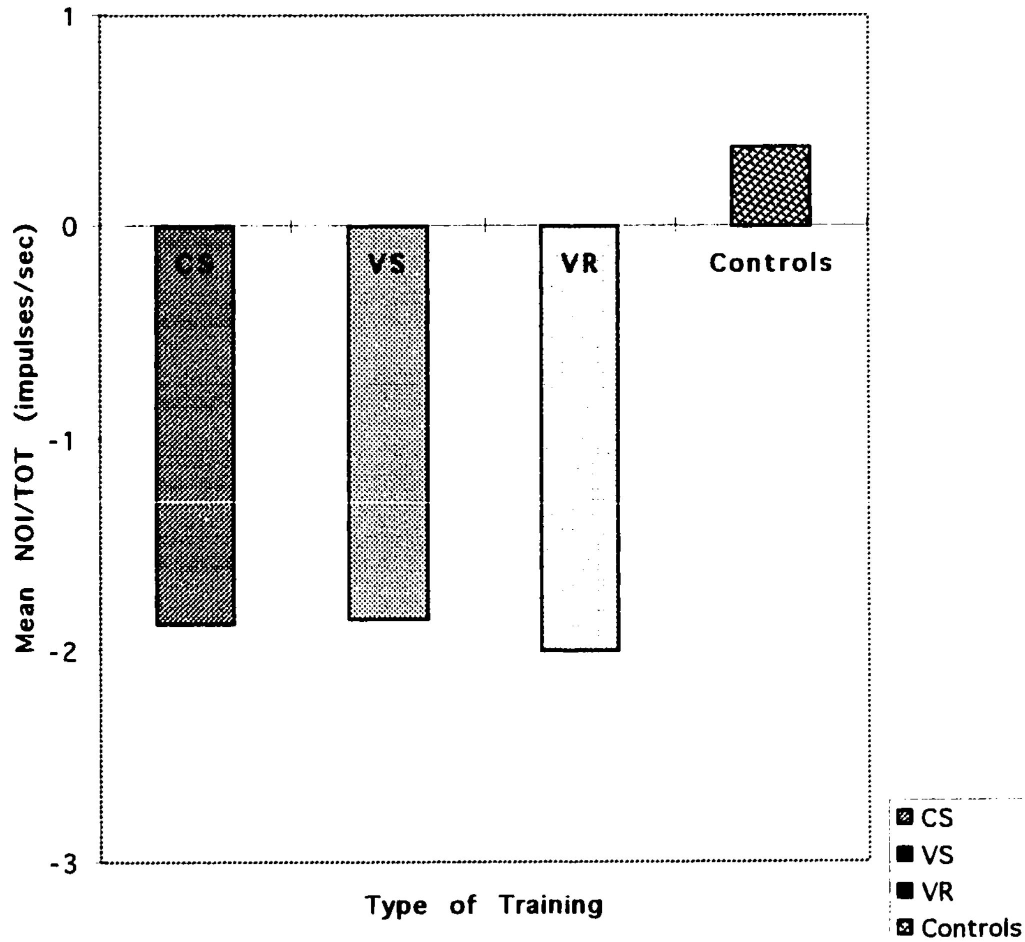

Figure 4. Retention: Mean difference score skill development (NOI/TOT) at TBR collapsed across group. CS = constant speed; VS = variable speed; VR = variable rotation.

relative to variable speed training, but only enhanced acquisition and not retention for the simple task group.

Same Stimulus Transfer

A 2 Group X 4 Type of Training ANOVA was performed at SST to examine whether training conditions affected a group's ability to transfer learning on the rotary pursuit to a faster speed. A significant effect occurred for Group, $F(1,72) = 9.40$, $p = .003$, $\beta = .855$; and Type of Training, $F(3,72) = 36.29$, $p = .000$, $\beta = 1.0$. The Group X Type of Training interaction, $F(3,72) = 1.01$, $p = .394$, $\beta = .263$, was not significant. These analyses showed that overall, the simple task group (pretest $M = 3.76$; delay $M = 6.04$; difference $M = 2.28$) performed better than the complex task group (pretest $M = 4.69$; delay $M = 6.26$; difference $M = 1.57$), and although both groups generalized their training, they did not show differential transfer to same stimulus at a faster speed. Collapsing across group (Figure 5), planned comparisons based on one-way ANOVA contrasts for Type of Training showed that all experimental subjects in the three training conditions made significant transfer compared with the no-training control group. Subjects trained under constant speed (pretest $M = 4.09$; delay $M = 6.76$; difference $M = 2.67$), variable speed (pretest $M = 4.19$; delay $M = 6.34$; difference $M = 2.15$), and variable rotation (pretest $M = 4.26$; delay $M = 7.25$; difference $M = 2.99$) all showed transfer compared with no-training controls (pretest $M = 4.37$; delay $M = 4.26$; difference $M = 0.11$), $T(76) = 9.586$, $p = .000$. Significant difference in the amount of transfer for

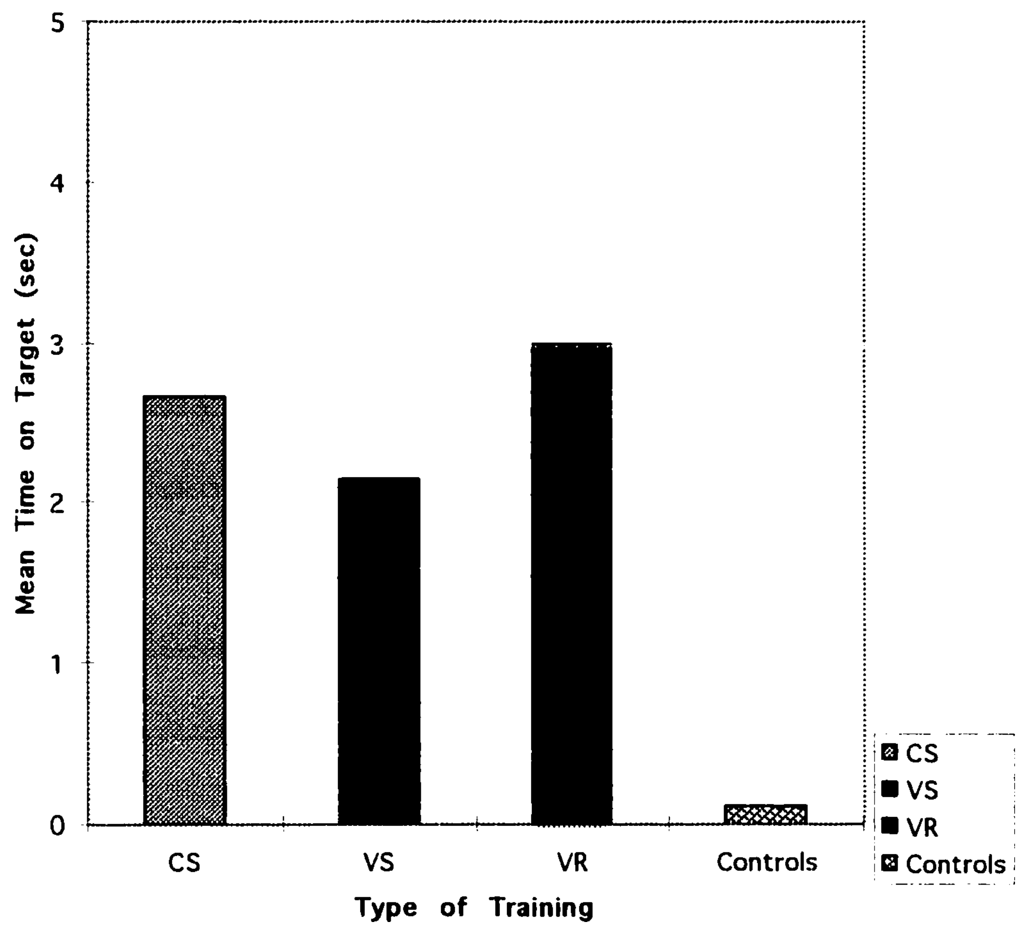

Figure 5. Same stimulus transfer: Mean difference score TOT at SST collapsed across group. CS = constant speed; VS = variable speed; VR = variable rotation.

Type of Training was found for variable rotation vs. variable speed training, $\underline{T}$ (76) = -2.447, $\underline{p}$ = .017. No significant differences were found for Type of Training between constant speed vs. variable speed, $\underline{T}$ (76) = 1.523, $\underline{p}$ = .132, and constant speed vs. variable rotation, $\underline{T}$ (76) = -.925, $\underline{p}$ = .358 training conditions.

Skill development was also analyzed for transfer of the rotary skill to the same stimulus at faster speed. A 2 Group X 4 Type of Training ANOVA at SST showed a significant Group X Type of Training interaction, $\underline{F}(3,72) = 4.43$, $\underline{p}$ = .007, β = .858. Planned comparisons (Figures 6 and 7), based on one-way ANOVA contrasts of this significant interaction effect showed the experimental subjects in both the complex task and simple task groups made significant improvement in skill development with training compared with the no-training control group. Subjects assigned to the complex task group and trained under constant speed (pretest $\underline{M}$ = 10.97; delay $\underline{M}$ = 10.45; difference $\underline{M}$ = -0.52), variable speed (pretest $\underline{M}$ = 12.92; delay $\underline{M}$ = 10.99; difference $\underline{M}$ = -1.93), and variable rotation (pretest $\underline{M}$ = 13.35; delay $\underline{M}$ = 10.89; difference $\underline{M}$ = -2.46), all showed improvement in keeping the stylus on target compared with no-training controls (pretest $\underline{M}$ = 12.35; delay $\underline{M}$ = 14.02; difference $\underline{M}$ = 1.68), $\underline{T}$ (36) = -4.801, $\underline{p}$ = .000. For the complex task group, skill development was significantly enhanced by variable rotation vs. constant speed training, $\underline{T}$ (36) = 2.297, $\underline{p}$ = .028. Differences in improvement were not significant for variable speed vs. constant speed training, $\underline{T}$ (36) = 1.674, $\underline{p}$ = .103; and practice under training conditions of variable rotation vs. variable speed training, $\underline{T}$ (36) = 0.624, $\underline{p}$ = .537. Subjects assigned to the simple task group and trained under constant

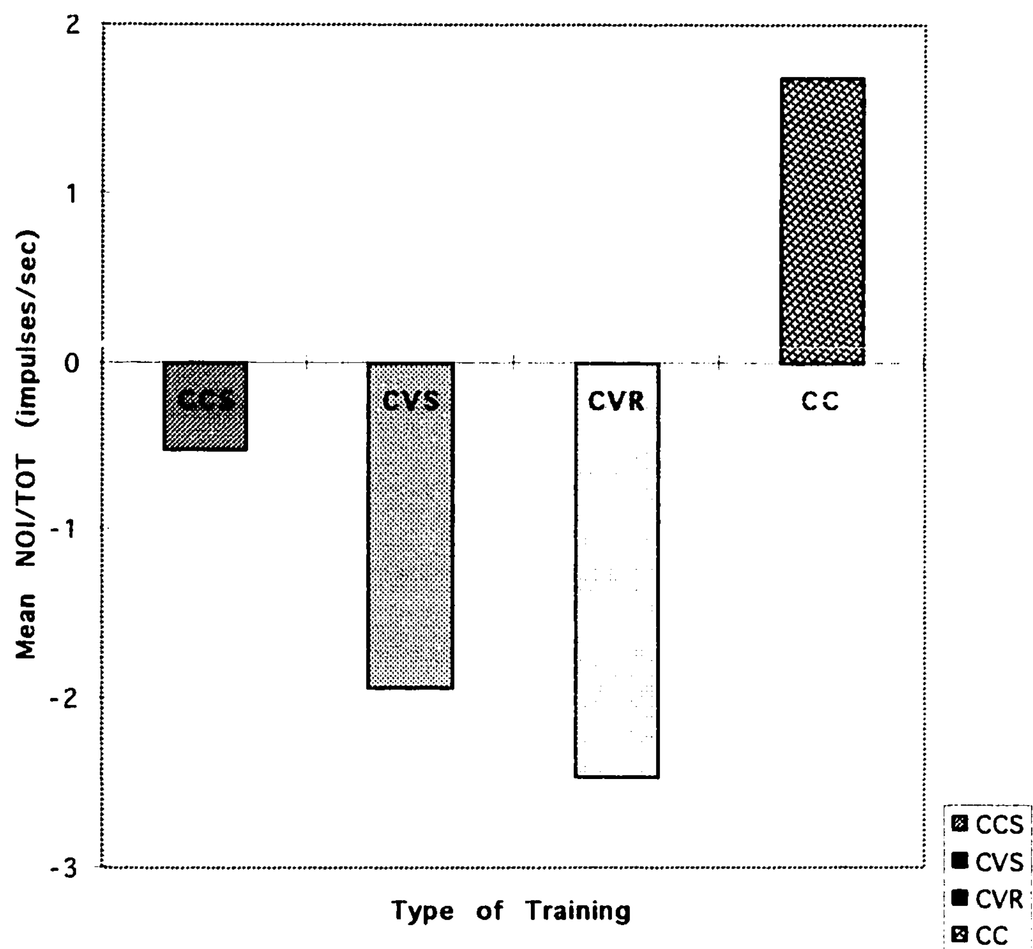

Figure 6. Same stimulus transfer: Mean difference score skill development (NOI/TOT) at SST for the complex task group. CCS = complex task constant speed; CVS = complex task variable speed; CVR = complex task variable rotation; CC = complex task control subjects.

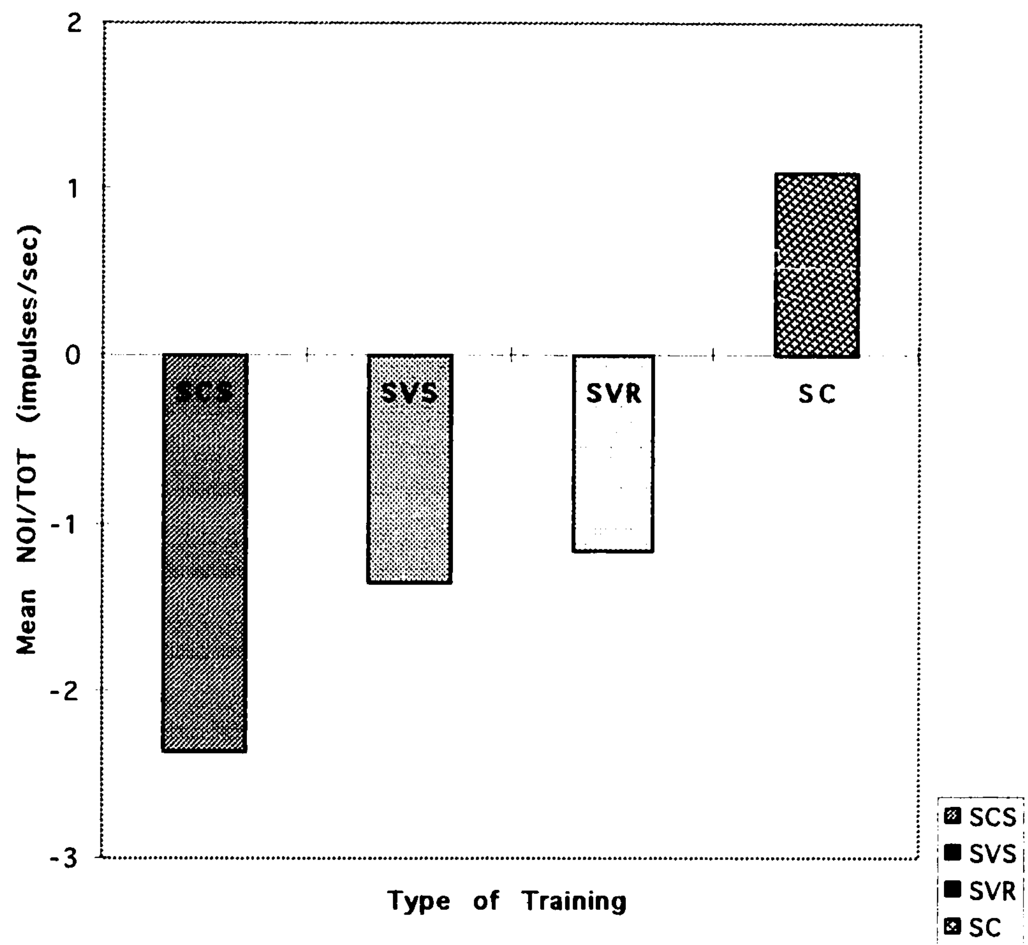

Figure 7. Same stimulus transfer: Mean difference score skill development (NOI/TOT) at SST for the simple task group. SCS = simple task constant speed; SVS = simple task variable speed; SVR = simple task variable rotation; SC = simple task control subjects.

speed (pretest $\underline{M}$ = 7.86; delay $\underline{M}$ = 5.49; difference $\underline{M}$ = -2.37), variable speed (pretest $\underline{M}$ = 7.31; delay $\underline{M}$ = 5.95; difference $\underline{M}$ = -1.36), and variable rotation (pretest $\underline{M}$ = 5.79; delay $\underline{M}$ = 4.62; difference $\underline{M}$ = -1.17), all showed improvement in keeping the stylus on target compared with no-training controls (pretest $\underline{M}$ = 5.77; delay $\underline{M}$ = 6.87; difference $\underline{M}$ = 1.10), $\underline{T}$ (36) = -8.997, $\underline{p}$ = .000. For the simple task group, skill development was significantly enhanced by constant speed vs. variable speed, $\underline{T}$ (36) = -2.718, $\underline{p}$ = .010; and constant speed vs. variable rotation, $\underline{T}$ (36) = -3.212, $\underline{p}$ = .003. Differences were not significant in improvement for variable speed vs. variable rotation training, $\underline{T}$ (36) = -0.494, $\underline{p}$ = .624.

These results generally suggest that when transferring to the same stimulus pattern but at a faster speed (within-motor program transfer), both groups showed enhanced transfer TOT when they learned the task with variable rotation training. However, skill development data allowed the investigator to clarify how training differentially effects transfer between the groups. Overall, variable rotation training (see descriptive data, Table 2) enhanced transfer for the complex task group, whereas constant speed training enhanced transfer for the simple task group.

<u>Novel Stimulus Transfer</u>

A 2 Group X 4 Type of Training ANOVA was performed at NST to examine whether training conditions impacted a group's ability to transfer learning on the rotary pursuit to a novel stimulus pattern. The Group X Type of Training interaction, $\underline{F}(3,72)$ = 2.84, $\underline{p}$ = .044, β = .658 was significant, evidence that complex task and simple task subjects differentially transferred learning to the novel stimulus pattern. Planned comparisons 2.84, $p = .044$, $\beta = .658$ was significant, evidence that complex task and simple task subjects differentially transferred learning to the novel stimulus pattern. Planned comparisons (Figures 8 and 9) of this significant interaction effect showed that complex task subjects in the three experimental conditions made significant transfer with training compared with the no-training control group. Subjects assigned to the complex task group and trained under constant speed (pretest $M = 3.69$; delay $M = 5.56$; difference $M = 1.87$), variable speed (pretest $M = 3.41$; delay $M = 5.15$; difference $M = 1.74$), and variable rotation (pretest $M = 3.39$; delay $M = 6.37$; difference $M = 2.98$) practice conditions all showed transfer to a novel stimulus pattern compared with no-training controls (pretest $M = 3.42$; delay $M = 3.36$; difference $M = -0.06$), $T(36) = 6.718$, $p = .000$. On this novel stimulus, subjects trained under variable rotation conditions showed transfer superior to that of subjects trained under constant speed, $T(36) = -2.686$, $p = .011$, or variable speed, $T(36) = -3.016$, $p = .005$ conditions. Subjects assigned to the simple task group and trained under constant speed (pretest $M = 4.15$; delay $M = 4.85$; difference $M = 0.70$), $T(36) = .988$, $p = .330$; and variable speed (pretest $M = 4.28$; delay $M = 5.06$; difference $M = 0.78$), $T(36) = 1.165$, $p = .252$, practice conditions did not transfer learning to the novel stimulus. Only subjects trained under variable rotation (pretest $M = 3.66$; delay $M = 5.39$; difference $M = 1.73$) practice conditions transferred learning to the novel stimulus compared with no-training controls (pretest $M = 4.16$; delay $M = 4.41$; difference M = -0.25), $T(36) = 3.287$, $p = .002$). On this novel stimulus, subjects trained under variable rotation practice conditions evidenced superior transfer to

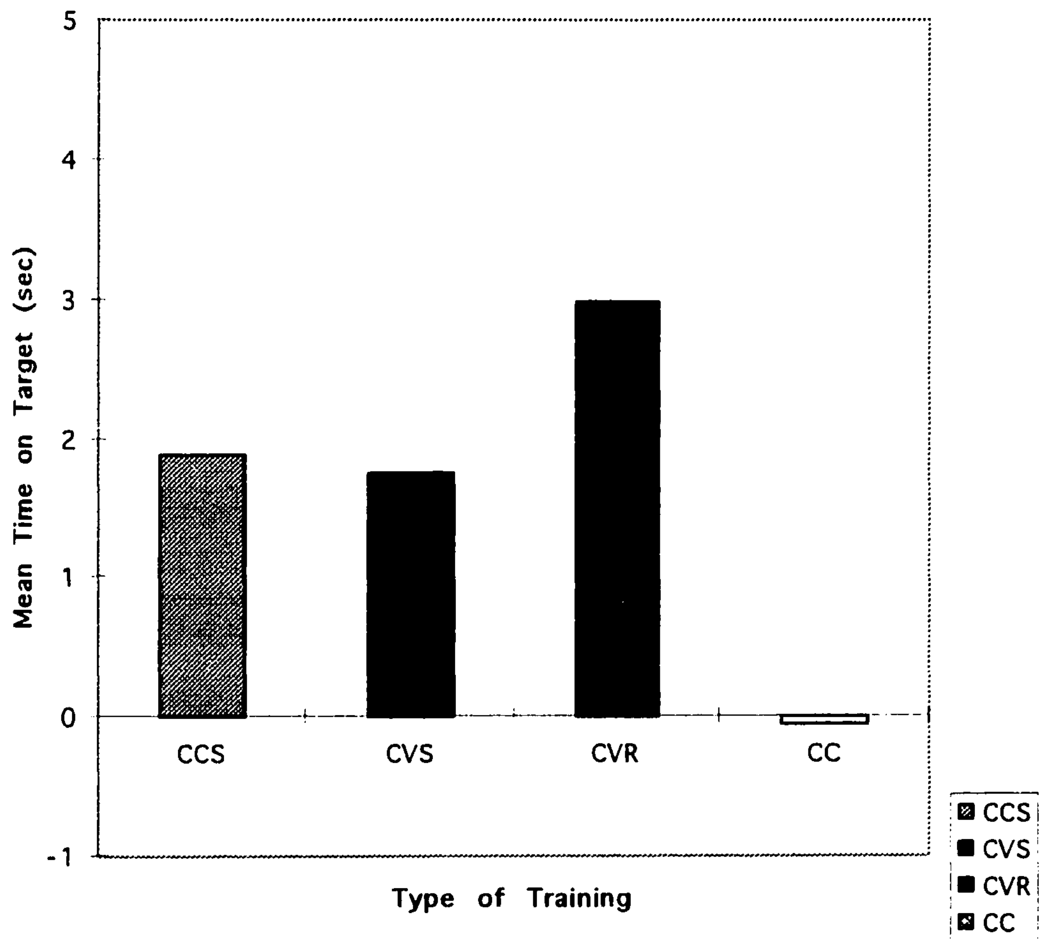

Figure 8. Novel stimulus transfer: Mean difference score TOT pretest to delay for the complex task group X type of training at NST. CCS = complex task constant speed; CVS = complex task variable speed; CVR = complex task variable rotation; CC = complex task control subjects.

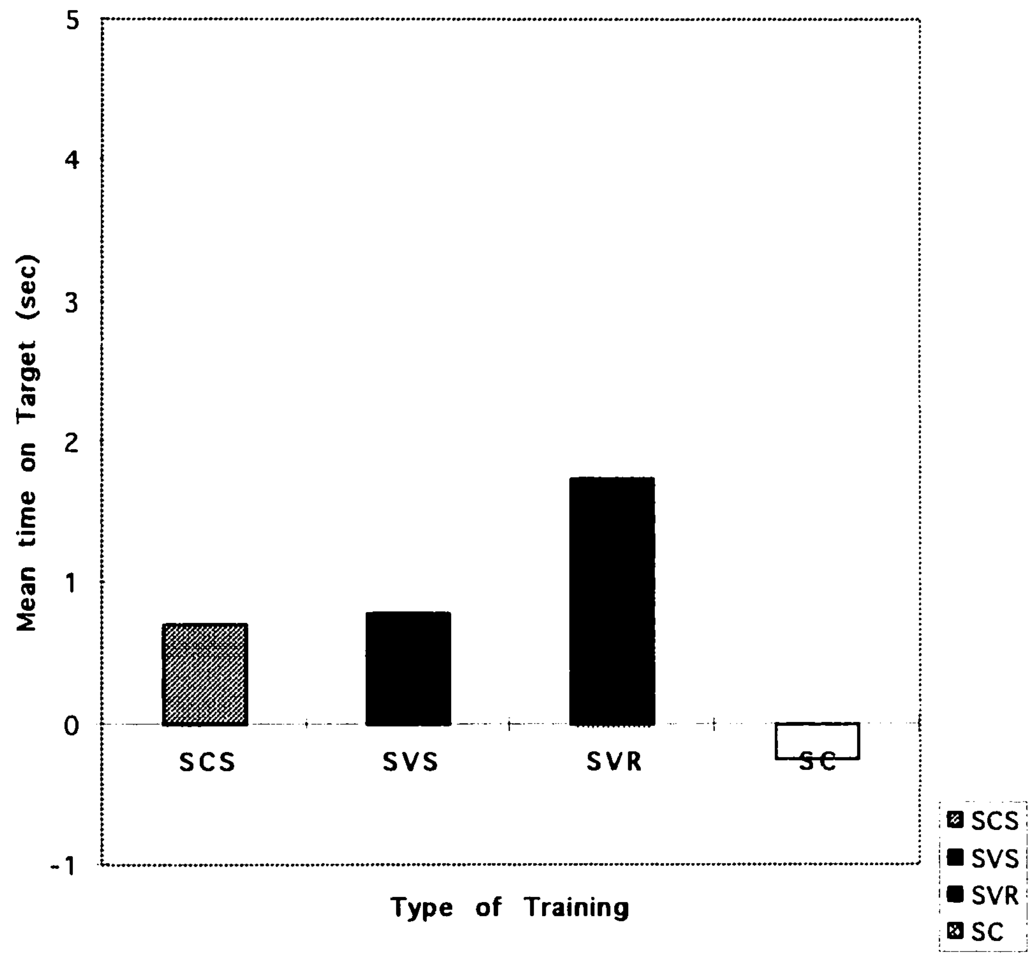

Figure 9. Novel stimulus transfer: Mean difference score TOT pretest to delay for the simple task group X type of training at NST. SCS = simple task constant speed; SVS = simple task variable speed; SVR = simple task variable rotation; SC = simple task control subjects.

subjects trained under constant speed, T (36) = -2.299, p = .027, and variable speed, T
subjects trained under constant speed, T (36) = -2.299, p = .027, and variable speed,
T (36) = -2.123, p = .041, conditions.

Skill development was also analyzed for transfer of the rotary skill to a novel stimulus. A 2 Group X 4 Type of Training ANOVA at NST showed a significant Group X Type of Training interaction, $F(3,72) = 4.42$, p = .007, β = .858. Planned comparisons (Figures 10 and 11) of this significant interaction effect showed that within the complex task group, only subjects receiving variable rotation (pretest M = 8.57; delay M = 5.53; difference M = -3.04) practice showed significant improvement in skill development with training compared with the no-training control group (pretest M = 8.48; delay M = 9.07; difference M = 0.59), T (36) = -8.201, p = .000. All other experimental subjects failed to show improvement in accuracy with training when transferring to a novel stimulus. Subjects assigned to the complex task group and trained under constant speed (pretest M = 7.22; delay M = 7.24; difference M = -0.02), T (36) = -1.297, p = .203, and variable speed (pretest M = 7.41; delay M = 7.12; difference M = -0.29), T (36) = -2.007, p = .052, showed no improvement in keeping the stylus on target compared with no- training controls. Subjects assigned to the simple task group and trained under constant speed (pretest M = 10.69; delay M = 11.18; difference M = 0.49), variable speed (pretest M = 12.41; delay M = 12.48; difference M = 0.07), and variable rotation (pretest M = 11.11; delay M = 11.10; difference M = 0.01) all showed no improvement in keeping the stylus on target compared with no-training controls (pretest M = 10.57; delay M = 11.65; difference M = 1.08), T (36) = -1.465, p = .152.

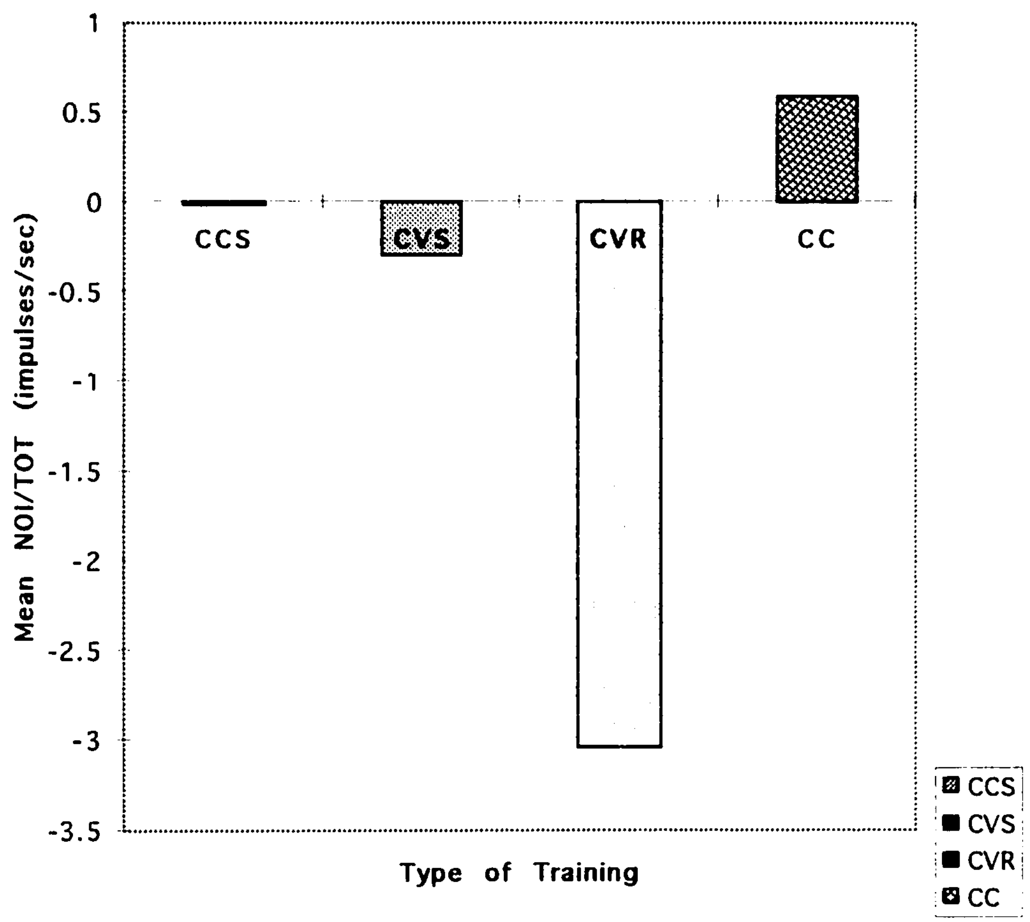

Figure 10. Novel stimulus transfer: Mean difference score skill development (NOI/TOT) at NST for the complex task group. CCS = complex task constant speed; CVS = complex task variable speed; CVR = complex task variable rotation; CC = complex task control subjects.

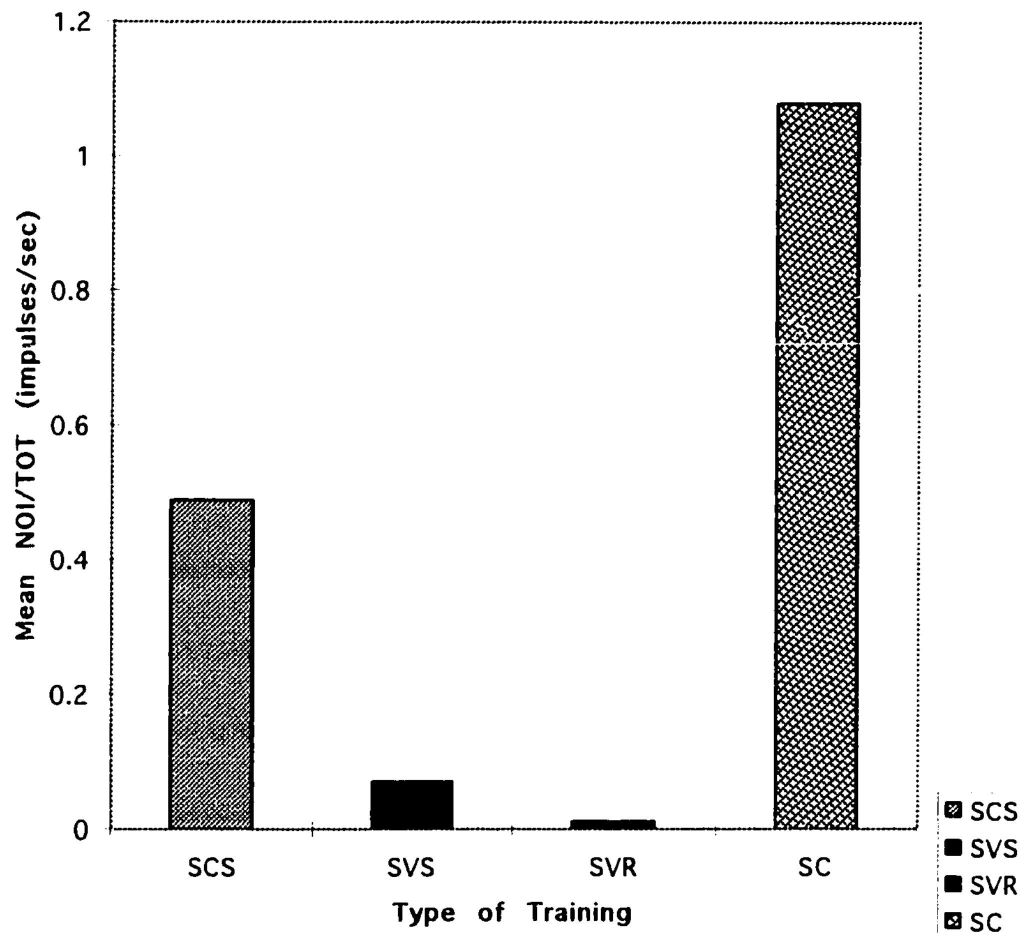

Figure 11. Novel stimulus transfer: Mean difference score skill development (NOI/TOT) at NST for the simple task group. SCS = simple task constant speed; SVS = simple task variable speed; SVR = simple task variable rotation; SC = simple task control subjects.

These results generally suggest that when transfer was to a novel stimulus pattern (between-motor transfer), subjects experienced differential ability to transfer learning. The analyses showed that only those subjects trained on the complex task stimulus made significant positive transfer across types of training employed to learn the original task. Of these, subjects trained on the between-motor task (variable rotation) showed significantly more transfer than subjects receiving the other training conditions. Alternatively, subjects trained on the simple task stimulus showed transfer to a novel task only when trained under variable rotation practice conditions. Subjects trained under the other practice conditions did not transfer learning to a novel stimulus condition. This evidence suggests that between-motor program training allows for the formation and utilization of flexible motor schemata.

Interindividual Differences

One-way ANOVA and correlational analyses examined the relationship of group with measures of neuropsychological functioning and posttest performance. Analyses comprising both groups--simple task and complex task--were performed examining the relationship of Group to WMS-R, verbal paired associates and visual paired associates; Shipley Institute of Living Scale; Grooved Pegboard Test; Finger Oscillation Test; and posttest measures short delay, long delay, and mean delay. In both groups, no neuropsychological test revealed a significant relationship to posttest performance on rotary pursuit. It appeared that the limited variability found in neuropsychological functioning for these healthy subjects precluded the study of any potential relationship between neuropsychological functioning and posttest performance.

CHAPTER 4

DISCUSSION

The results of the present investigation provided support for the following hypotheses: (a) The rotary pursuit skill learning paradigm, comparing simple and complex tasks, showed a memory continuum that included both nondeclarative and declarative motor learning, (b) practice conditions involving high levels of contextual interference led to formation of more flexible motor schema, and (c) optimum schema formation occurred under conditions in which task demands and training conditions stimulated declarative memory processes. It was seen that on rotary pursuit, task demands brought about by the nature of the training stimulus (simple versus complex) resulted in differential transfer that might be directly attributed to a specific memory system (procedural versus declarative) being engaged by a given task. Additionally, it was shown that when the training condition itself provided complex perceptual-motor cues, a simple and strictly procedural task could be advanced along a memory continuum from primarily engaging procedural to engaging declarative memory systems. The study provided strong empirical evidence supporting Magill and Hall's (1990) hypothesis that high levels of contextual interference prompt motor schema formation and allow for generalization of learning to transfer variations controlled by the same or different motor programs. It is likely that when motor skill learning engaged declarative memory systems, the most flexible motor schema were formed.

A Memory Continuum in Motor Skill Learning: How Task Demands and Training Conditions Contribute To Its Formation

Consistent with previous research (Lanier, 1934; Lincoln & Smith, 1951; Lordhal & Archer, 1958; Magill & Hall, 1990; Namikas & Archer, 1960; Schmidt, 1975, 1988; Shea & Morgan, 1979; Shea & Zimny, 1983, 1988), this study's training conditions (constant speed, variable speed, and variable rotation) differentially affected transfer of the motor skill, rotary pursuit. In this study, it was asserted that motor skills are arranged along a continuum of perceptual-motor complexity comprising motor activities ranging from simple reflex behaviors to complex perceptual-motor tasks. The current study hypothesized that skill learning needed to be represented along a similar continuum, encompassing both procedural and declarative memory systems. This study's results suggested that differential transfer might be directly attributed to a specific memory system (procedural or declarative) being engaged by a given task (simple stimulus or complex stimulus) during the initial training of the motor skill.

Arguably, performance of a motor skill must result in a memory representation that may be called a motor program. The results of this study provided support that this motor program will develop under procedural control when the context under which the motor response evolves remains the same. That is, when skill demands remain simple and there is minimal variation (constant speed and variable speed practice) in training conditions. To the extent that context varies across performance of the motor response, increasing its complexity, either through more elaborate sensory-perceptual demands (complex stimulus) or by increasing between-motor program variability (variable rotation practice) in training conditions, the motor program will develop under declarative control.

The differential transfer elicited by task, training conditions, or both may be understood in terms of the inherent properties of each memory system. When motor learning engages procedural memory processes, learning is, as Squire (1994) asserted, less flexible and provides limited transfer or access to response systems not involved in the original learning. However, when motor learning required access to declarative memory systems, learning became flexible and available to multiple response systems not involved in the original learning. This study's results suggested that when transfer was to a novel task, subjects trained on the simple stimulus under constant and variable speed practice conditions did not transfer learning. Hence, learning on the simple task under constant speed and variable speed practice conditions was likely accessing procedural memory. However, on the complex task, motor learning involved the integration of multiple perceptual, spatial, and motor stimuli. The complex task itself appeared to stimulate access to declarative memory systems. Subjects trained under conditions of constant and variable speed practice were able to transfer learning to a novel task. They showed flexibility in learning that is a hallmark of declarative memory.

Transfer to a novel task has also provided evidence of a memory continuum in rotary pursuit learning. Between-motor training conditions involved in the original acquisition of the motor skill appeared to stimulate access to declarative learning and memory.

Although this study erroneously hypothesized that variable rotation practice conditions would not enhance procedural transfer to a novel complex task, analyses have indicated that significant transfer of learning did occur. It appears likely that the richness of the between-motor training condition and its provision of complex perceptual-motor cues stimulated access to declarative memory.

The results of this study provided strong support for a skill learning paradigm that engaged a memory continuum of both nondeclarative and declarative motor learning on rotary pursuit. Subjects trained on the simple task showed evidence of differential learning at transfer compared with subjects trained on the complex task. Both task and training conditions contributed to the formation of this continuum. When the motor skill remained perceptually and physically simple and the variation in training required the subject to make a response that varied in only one dimension (increasing or decreasing speed), procedural memory was accessed. However, when task (complex task) or training conditions (variable rotation practice) provided complex perceptual-motor or contextual cues, a continuum toward engaging declarative memory was established. Squire's (1994) assertion was strongly supported by the evidence presented in this study. Motor skill learning may access nondeclarative memory, declarative memory, or a combination of both memory systems.

Schmidt's Schema Theory and the Contextual Interference Hypothesis

The experimental data and analyses of this investigation provided strong support for Magill and Hall's (1990) hypothesis that the contextual interference effect prompts schema formation. Van Rossum (1990) argued that the critical issue in the research on schema formation and variation of practice is generalization. Schmidt (1975) noted that practice under variable conditions should most benefit performance on new or novel rather than earlier encountered situations. Consistent with Magill and Hall's (1990) hypothesis, evidence from this study generally showed that between-motor practice conditions promoted high levels of contextual interference, resulting in significantly better transfer performance than within-motor practice conditions involving lower levels of contextual interference. On the simple task, within-motor program transfer was enhanced by constant speed training. However, the only training condition that elicited transfer to the novel transfer task (different-motor program), was between-motor or variable rotation training. On the complex task, variable rotation training elicited significantly more transfer of learning to both transfer tasks than any other training condition. This evidence suggests that high levels of contextual interference created by between-motor training allowed for the formation and utilization of flexible motor schemata.

Memory Systems and the Formation of Motor Schemata

This investigation has presented experimental evidence that suggests motor skill learning, whether engaging procedural or declarative memory systems, occurs as schema are formed which integrate the perceptual-motor response over time or training trials. Procedural schemata are likely formed when the perceptual-motor response required by both task and training conditions remains relatively invariant. However, the more variable the context for each occasion of practice and the more contextual interference that is present across training trials, the more training will engage declarative verses procedural memory processes. It seems likely that variability in sensory-perceptual context and variability in between-motor response lead to more relational learning and optimal motor schema formation.

This hypothesized relationship between motor skill learning and memory systems provides a milieu in which previous motor research can be understood and reconciled. On a rotary pursuit task, using a simple circular stimulus, Lordhal and Archer (1958) and Namikas and Archer (1960) reported constant speed practice conditions promoted superior transfer compared with variable speed practice conditions. Similarly, Barto (1986) reported that subjects throwing darts at a stationary target also showed that constant practice conditions promoted superior transfer compared with variable practice conditions. This evidence is consistent with this study's model of motor learning and memory systems. On the Lordhal and Archer (1958) and Namikas and Archer (1960) rotary pursuit task, and on Barto's (1986) simple throwing task, procedural motor schema were formed, and predictably, constant speed practice promoted superior transfer benefits. More recent studies found support for the variability of practice hypothesis when constant practice conditions were compared to variable practice conditions. Various researchers--including Newel and Shapiro (1976) displacing a handle over a specified distance in a specified time; Del Rey, Wughalter, and Whitehurst (1982) depressing the button coincident with the arrival of the moving lights at the last lamp at the end of the runway; Barto (1986) throwing darts at a moving target; and Shea and Morgan (1979) knocking down barriers as fast as possible in a prescribed order--employed motor tasks that involved the integration of relatively complex perceptual-motor cues. Similar to the current investigation's complex task, these studies found support for variability in practice leading to enhanced transfer and are consistent with this study's model. Finally, in the experiment performed by Wood and Ging (1991), subjects practiced moving one arm as fast as possible through a multisegment movement pattern. Practice conditions directly compared different levels of task similarity. The within-motor program practice condition did not evidence the contextual interference effect, whereas the between-motor program practice condition showed the effect on novel transfer tasks. The results reported by Wood and Ging (1991) are compatible with this study's model of motor learning and memory systems.

In summary, this study's model of a skill learning paradigm in which motor skills range on a continuum of perceptual-motor complexity from simple to complex and are represented in memory along a similar continuum encompassing both nondeclarative and declarative memory systems has been supported by the analyses of the current investigation. Furthermore, this model can account for motor schema formation and it is consistent with reported results in past research on motor learning.

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APPENDIX

IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Office of the Institutional Review Board for Human Use

FORM 4: IDENTIFICATION AND CERTIFICATION OF RESEARCH PROJECTS INVOLVING HUMAN SUBJECTS

THE INSTITUTIONAL REVIEW BOARD (IRB) MUST COMPLETE THIS FORM FOR ALL APPLICATIONS FOR RESEARCH AND TRAINING GRANTS, PROGRAM PROJECT AND CENTER GRANTS, DEMONSTRATION GRANTS, FELLOWSHIPS, TRAINEESHIPS, AWARDS, AND OTHER PROPOSALS WHICH MIGHT INVOLVE THE USE OF HUMAN RESEARCH SUBJECTS INDEPENDENT OF SOURCE OF FUNDING.

THIS FORM DOES NOT APPLY TO APPLICATIONS FOR GRANTS LIMITED TO THE SUPPORT OF CONSTRUCTION, ALTERATIONS AND RENOVATIONS, OR RESEARCH RESOURCES

PRINCIPAL INVESTIGATOR: **Richard E. Beth**

PROJECT TITLE: **The Effects of Type of Practice on Motor Learning in AD Patients, Elderly, and Young Adults**

____ 1. THIS IS A TRAINING GRANT. EACH RESEARCH PROJECT INVOLVING HUMAN SUBJECTS PROPOSED BY TRAINEES MUST BE REVIEWED SEPARATELY BY THE INSTITUTIONAL REVIEW BOARD (IRB).

_X_ 2. THIS APPLICATION INCLUDES RESEARCH INVOLVING HUMAN SUBJECTS. THE IRB HAS REVIEWED AND APPROVED THIS APPLICATION ON 8-29-97 IN ACCORDANCE WITH UAB'S ASSURANCE APPROVED BY THE UNITED STATES PUBLIC HEALTH SERVICE. THE PROJECT WILL BE SUBJECT TO ANNUAL CONTINUING REVIEW AS PROVIDED IN THAT ASSURANCE.

_X_ THIS PROJECT RECEIVED EXPEDITED REVIEW.

____ THIS PROJECT RECEIVED FULL BOARD REVIEW.

____ 3. THIS APPLICATION MAY INCLUDE RESEARCH INVOLVING HUMAN SUBJECTS. REVIEW IS PENDING BY THE IRB AS PROVIDED BY UAB'S ASSURANCE. COMPLETION OF REVIEW WILL BE CERTIFIED BY ISSUANCE OF ANOTHER FORM 4 AS SOON AS POSSIBLE.

____ 4. EXEMPTION IS APPROVED BASED ON EXEMPTION CATEGORY NUMBER(S) ______.

DATE: 8-29-97

Marguerite Kinney

MARGUERITE KINNEY, DNSc
VICE CHAIR OF THE
INSTITUTIONAL REVIEW BOARD

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GRADUATE SCHOOL
UNIVERSITY OF ALABAMA AT BIRMINGHAM
DISSERTATION APPROVAL FORM
DOCTOR OF PHILOSOPHY

Name of Candidate Richard E. Beth

Major Subject Psychology

Title of Dissertation Declarative and Nondeclarative Memory Systems and the Acquisition, Retention, and Transfer of a Fine Motor Skill

I certify that I have read this document and examined the student regarding its content. In my opinion, this dissertation conforms to acceptable standards of scholarly presentation and is adequate in scope and quality, and the attainments of this students are such that _he may be recommended for the degree of Doctor of Philosophy.

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