

**OBSERVATIONAL LEARNING OF A BIMANUAL COORDINATION TASK:
UNDERSTANDING MOVEMENT FEATURE EXTRACTION, MODEL
PERFORMANCE LEVEL, AND PERSPECTIVE ANGLE**

A Dissertation

by

NOAH J. DEAN

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

DOCTOR OF PHILOSOPHY

December 2009

Major Subject: Kinesiology

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Approved by:

Chair of Committee,	John Buchanan
Committee Members,	Charles Shea
	David Wright
	Steve Smith
Head of Department,	Richard Kreider

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ABSTRACT

Observational Learning of a Bimanual Coordination Task: Understanding Movement Feature Extraction, Model Performance Level, and Perspective Angle. (December 2009)

Noah J. Dean, B.S.; M.S., Angelo State University

Chair of Advisory Committee: Dr. John J. Buchanan

One experiment was administered to address three issues central to identifying the processes that underlie our ability to learn through observation. One objective of the study was to identify the movement features (relative or absolute) extracted by an observer when demonstration acts as the training protocol. A second objective was to investigate how the performance level of the model (trial-to-trial variability in strategy selection) provided by the demonstrations influences movement feature extraction. Lastly, a goal was to test whether or not visual perspective of the model by the observer (first-person or third-person) interacts with the aforementioned variables. The goal of the task was to trace two circles templates with a 90° relative phase offset between the two hands. Video recordings of two models practicing over three days were used to make three videos for the study; an expert performance, discovery performance, and instruction performance video. The discovery video portrayed a decrease in relative phase error and a transition from high trial-to-trial variability in the strategy selection to use of a single strategy. The instruction video also portrayed a decrease in relative phase error, but with no strategy search throughout practice. The expert video showed no

strategy search with trial-to-trial variability within 5% of the goal relative phase of 90° across every trial. Observers watched one of the three video recordings from either a first-person or third-person perspective. In a retention test, the expert observers showed the most consistent capability (learning) in performing the goal phase. The instruction observers also showed learning, but to a lesser degree than the expert observers. The discovery group observers showed the least amount of learning of relative phase. The absolute feature of movement amplitude was not extracted by any observer group, results consistent with postulations by Scully and Newell (1985). Observation from the 1P perspective proved optimal in the expert and instruction observation groups, but the 3P perspective allowed for greater learning of the goal relative phase (90°) in the discovery observation group. Hand lead, a relative feature of motion, was extracted by most observers, except those who observed the discovery model from the 3P perspective. It's concluded that the trial-to-trial variability in terms of strategy selection interacted with the process of mental rotation, which prevented the extraction of hand lead in those observers that viewed the discovery model.

DEDICATION

*To Jesus, my wife, Lauren, and my daughter, McKinlee, all of whom continue to love me
unconditionally.*

ACKNOWLEDGEMENTS

Words cannot describe the gratitude I have for my savior Jesus Christ. I'm blessed with a beautiful, loving family, who represent all that is good in me. They have patiently stood by my side despite the stresses involved in this arduous process. I would also like to thank my advisor, Dr. John Buchanan for his guidance and wisdom during my time at Texas A&M University.

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CHAPTER I

INTRODUCTION

The ability to learn a motor skill through observation is vital for the normal development of motor skills in children and adults (Newell, 1991; Brass, Bekkering, & Prinz, 2001; Iacoboni et al., 1999; Shea, Wright, Wulf, & Whitacre, 2000; Prinz & Meltzoff, 2002; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009; Zaal, Bingham, & Schmidt, 2000). A recent review by Vogt and Thomaschke (2007) summarized research investigating demonstration, or modeling, as a training protocol and discussed the link between action observation and motor skill acquisition. One intention of the authors was to distinguish between two common methods of demonstration used as training methods in motor learning research: 1) observational practice contexts and 2) observational learning contexts. Observational practice occurs when an individual observes numerous demonstrations of a motor skill while being denied any physical rehearsal of the skill prior to a retention test (Buchanan, Ryu, Zihlman, & Wright, 2008). In contrast, observational learning occurs when demonstration of a motor skill is interspersed with physical practice of the skill (Hodges & Williams, 2007). The current study used an observational practice context to: 1) identify what movement features (relative or absolute) can be extracted through observation; 2) determine how the performance level of the model influences this extraction; and 3) reveal whether or not the observer's visual perspective (first-person or third-person) interacts with movement feature extraction and/or model skill level.

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

Features Extracted During Observation: Relative or Absolute

Theories of visual motion perception have argued that motor actions are comprised of three distinct movement characteristics known as relative motion, absolute motion, and common motion (Johansson 1973; Cutting & Proffitt, 1982). Relative motion features describe the motion of the individual elements of a system relative to one another. Absolute motion features describe the motion of the individual elements of a system, as they move through space and time, in an external environment. Common motion is the motion that all elements of a configuration share, such as the general direction of motion of all the systems' elements.

Scully and Newel (1985) drew upon the ideas of relative, absolute, and common motion to develop a theory of observational motor skill learning based on demonstration as a training protocol. The primary thesis proposed by Scully and Newell (1985) was that relative motion features are available for pick-up through visual perception processes, whereas the extraction of absolute motion features requires physical practice. This idea was founded on the notion that the identification of actions from point-light displays resides in the invariant relationship that emerge in the relative motion among the components. The absolute features, however, require a scaling linked to specific muscle activation levels and therefore require physical practice to learn. This concept, labeled the visual-perception perspective to observational learning, has been scrutinized extensively in the past three decades, resulting in considerable debate as researchers have attempted to understand how motor learning occurs through observational processes (e.g., Ullen & Bengtsson, 2003; Hodges, Williams, Hayes, & Breslin, 2007).

Previous research has investigated Scully and Newell's proposal with regard to bimanual coordination skills in an *observational learning* context (e.g., Hodges et al., 2003). One purpose of the current research is to test the idea of Scully and Newell (1985) regarding the extraction of relative and absolute motion features of a bimanual coordination skill within an *observational practice* context. Moreover, the study will examine the ability of observers to extract relative and absolute features as a function of the between trial variability in the models' performance and the visual perspective of the observer, aspects not examined in previous studies employing demonstration as a training protocol for bimanual skills.

Type of Model

Research efforts incorporating an observational learning paradigm have used models with different skill levels to serve as a basis from which observers intend to learn. However, the skill level of the model (i.e. novice, intermediate, or expert) that provides the optimal demonstration protocol is still under considerable debate (Vereijken & Whiting, 1990; McCullagh & Meyer, 1997; Buchanan & Dean, submitted; Hodges & Franks, 2001). Some research has led to the conclusion that observation of an expert model allows an observer to view "correct" motion and requires only a mirror action by the observer, a process called imitation (Iacoboni et al., 1999). Other research using a discrete bimanual timing task has shown that viewing the best action strategy only leads to attempts to replicate the best strategy but not to good performance outcomes (Martens et al. 1976). How does observation of multiple strategies in a task affect learning? Will

trial-to-trial variability in terms of strategy selection benefit or hinder learning? The current study used novice and well practiced models in order to control for the skill level of the model. One purpose was to reveal the impact of the amount of trial-to-trial variability in a model's use of multiple strategies on the extraction of relative and/or absolute motion features by an observer.

Observer Perspective

Another facet of motor learning we address is that pertaining to the visual perspective from which an observer may view a model. Parsons (1987) concluded through a series of experiments using hand/foot motion judgments that during observation, a learner will mentally rotate the observed image to match his/her own physical orientation (first-person perspective), a conclusion recently supported by Maeda, Kleiner-Fisman & Pascual-Leone (2002). Although Parsons' (1987) findings suggest that a first-person perspective may contribute to the success of demonstration as a training protocol, the issue of observer viewpoint of the model has yet to be examined experimentally in an observational practice context. Al-Abood, Davids, and Bennett (2001) used a dart tossing task in which participants observed a model in the sagittal plane and showed learning by observers with regard to relative motion features of the task. Although not noted by the authors, the sagittal perspective represents a third-person point of view. Hodges et al. (2005) asked participants to observe an overhead view (first-person) of a model in which the effectors of the model were spatially identical to that of the observers relative to the body midline in a bimanual coordination task. Results

showed significant learning by observers with regard to relative motion features. Was the observers' performance dependent upon the viewing perspective the demonstrations offered in the above experiments? The current study addresses this question by investigating the impact of viewing perspective on the degree to which an observer extracts successfully relative and/or absolute motion features.

CHAPTER II

REVIEW OF LITERATURE

Social Learning: Observation and Modeling

From infancy, humans extract various types of information from the environment by visual observation and use this information to form behavioral responses (Bruner, 1981). Thorndike (1898) addressed observational learning in the late 19th century when he defined imitation as the occurrence of when humans (and other animals) from “...an act witnessed learn to do an act” (Alissandrakis, Nehaniv, & Dautenhahn, 2004). Today, skill demonstration is a common form of teaching protocol implemented by practitioners trying to elicit motor skill learning by observers (Hodges & Williams, 2007). Over the past several decades numerous empirical efforts have been directed toward understanding the theoretical and neurological processes involved in learning via observation (i.e. Piaget, 1969; Cutting & Proffitt, 1982; Bandura, 1982, 1986, 1989; Dipellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992; Hodges et al., 2007). Early theoretical attempts suggested that observational learning requires a transformation of visual information into a cognitive representation, followed by a transformation into a motor representation (Sheffield, 1961; Bandura, 1969; Carroll & Bandura, 1982). Sheffield (1961) suggested a process called cognitive orientation, which refers to a sequence of perceptual and symbolic processes wherein the extraction of visuomotor information leads to cognitive rehearsal prior to physical rehearsal. In other words, observation by a subject who has the intent to replicate the observed skill results in

mental rehearsal of the skill, a process that provides a neural “blueprint” by which the novel skill can be guided. Soon after cognitive orientation was established in the field, Albert Bandura (1977) introduced Social Learning Theory, a concept that proved to be one of the most pertinent theoretical methods from the last half-century regarding observation as a training method.

Social Learning Theory suggests that by observing others one forms an idea or cognitive representation of a new behavior and this coded information later serves as a guide for action (Bandura, 1977). Hypothetically, the newly formed cognitive representation has two basic functions. One function is to regulate behavior, while the other function is to provide a standard to compare to the response produced feedback. Although very similar to the concept of cognitive orientation, Social Learning Theory provides a more global explanation of how humans extract information from environmental events. The environment, in this context, refers to the various contexts or social actors from which an observer extracts information. The theory suggests that people observe and then model the behaviors and emotional reactions of others, especially those perceived as valuable (rewarding) in nature. Bandura (1977) explained that:

Learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them what to do. Fortunately, most human behavior is learned observationally through modeling: from observing others one forms an

idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action. (p. 22)

The development of these two basic functions of a cognitive representation for learning through observation in social contexts proved beneficial to later researchers interested in motor skill acquisition. For example, Carroll and Bandura (1987) applied the basic premises of Social Learning Theory to the problem of motor skill acquisition by using an observational learning paradigm. The task involved video observation of a model manipulating a hand-held paddle. Each observer was instructed to watch a model perform a complex sequence of movements, which incorporated nine various spatial and temporal configurations of the arm, wrist, and paddle. The initial component of the action sequence was a 5-second movement followed by eight two-second movements. For six testing trials, all participants observed the model's movement. After a rest period (26 seconds), half of the participants reproduced the action while again observing the model (concurrent group). The other participants reproduced the task from memory (separate group). Half of the participants from each group viewed a replay of their own action, with the other half of the group not given any feedback about their performance. After the second, fourth and sixth test trials, the observers performed a recognition test of the component responses and attempted to order the still images of each movement in the correct manner (pictorial-arrangement test). The tests determined if the observers had developed an explicit cognitive representation of the motor sequence. Results showed that the participants who produced the task simultaneously with observation of the

movement itself (concurrent group) were more able to accurately recall and recognize the sequence components. Results also showed that the separate condition group that did not receive feedback could not accurately produce the task. The authors concluded that visually coordinating one's performance with a reference (model or self) is crucial to the ability to reproduce an observed action. The authors further deduced that visually guided performance promotes the development of the cognitive representation, or explicit awareness, of the action components. This idea received elaboration when Carroll and Bandura (1990) used the same pictorial-arrangement test and found that increased observations led to a more accurate cognitive representation, which in turn led to a more accurate action reproduction. Verbal coding also increased recognition capability, but only when the number of observed trials increased from two to eight. The findings suggest that the coding of "movement features" facilitates reproduction of observationally learned actions. One of the primary criticisms of Social learning theory when applied to motor skill acquisition is the lack of a clear identification of the encoded movement features (Hodges et al. 2003; Scully & Newell, 1985).

Scully and Newell (1985) suggested that Bandura's Social Learning Theory, when applied to motor skill acquisition, placed too much emphasis on identifying "how" information is derived and cognitively encoded from observation, without providing any clear example on "what" type of information is extracted in this same process. In other words, if the motor system controls some aspect of a movement, e.g., timing, speed, distance, this information should be recognized and relevant to the observer without requiring a cognitive representation. Scully and Newell addressed this issue of coding by

suggesting that specific features of a movement extracted during observation do not require an independent cognitive representation prior to implementation.

Visual-Perception Perspective

Scully and Newell (1985) proposed that an understanding of the processes that support observational learning must come through the identification of “what” type of information the observer extracts from the model’s actions. To introduce this issue, the authors drew upon the visual perception literature and the distinction between common motion, relative motion, and absolute motion features (Johansson 1973; Cutting & Proffitt 1983). Common motion refers to the motion common to each element of a system in relation to the environment or to an observer viewing the action. An example of common motion might be the motion of the body while running. In this example, the entire system and its components (i.e. arms, legs, torso), are moving against the external environment in the same general direction. Relative motion refers to the motion of the different, individual elements of the system in relation to one another. In the aforementioned locomotion example, the relative motion would refer to the movement between the upper and/or lower extremities and ignore the movement against the environment. For example, the temporal relationship between the joints of the arms during running would represent a relative motion feature. Absolute motion emerges as a combination of relative and common motion features (Cutting & Proffitt, 1982). Some have interpreted absolute motion to be the overall quantitative spatial and temporal features of a movement. An example of absolute motion in this sense may be the actual

amplitude, velocity, or directional trajectory of an effector in motion. In the running example, the absolute motion may be the quantitative, kinematic measures of the systems components in space and time, such as stride length or movement time.

Scully and Newell (1985) suggest that the information extracted by an observer during observation is relative in nature. In other words, an observational learner is able to recognize the movement pattern of a system, a concept supported by research showing that humans have the ability to distinguish biological motion in point-light displays (Johansson, 1975, 1976; Barclay, Cutting & Kozlowski, 1978; Beardsworth & Buckner, 1981). Furthermore, research has shown that the salient information needed to recognize biological motion does not exist in static point-light displays (e.g. Johansson, 1973). Rather, the points must move in a coordinative fashion relative to one another for the movement characteristics to be recognized (Dittrich, 1993; Kozlowski & Cutting, 1977; Mather & Murdoch, 1994). An important feature of visual perception learning is the ability to discriminate differences between visual patterns (Gibson, 1954; Gibson & Gibson, 1955). With regard to the recognition of biological motion in point-light displays, the perceived invariance between the motions of the points allow for perceptual discrimination, and therefore, recognition of different action patterns. In other words, the visual system extracts the relative motion of the observed system points, resulting in recognition of the movement pattern (Johansson 1973). Scully and Newell (1985) proposed the visual-perception perspective based in part on this point-light research, a theory that has proven invaluable to how motor learning scientists approach the concept of learning through observation.

Research has compared the effects of observing point-light displays to observation of a human in motion in order to test certain aspects of the visual perception perspective. In Experiment I of an article by Scully and Carnegie (1998), participants observed five seconds of a dance routine in which a female dancer moved laterally and then jumped vertically (became airborne) while splitting her legs and pointing her toes downward as to create an inverted “V” shape with the lower body. Observers watched one of three types of video recording: slow motion, real time, and a chronological set of still images. When observers reproduced the movement, results showed a more accurate reproduction of the relative motion of the model’s legs when producing the “V” shape, the absolute movement time of the task, peak force on landing, and peak force on take-off, by observers who had watched the slow motion video. The authors concluded that the relative motion feature extracted by the observers was the motion of the upper and lower legs relative to one another and the trunk. The absolute motion feature extracted was the overall time of the routine (~5 seconds). Experiment II used a point-light display of the exact same action split into independent video segments from which specific body parts (knees, hips, ankles, and toes) were eliminated from the display. This provided control over the number of points defining the relative motion between the legs. Results showed that when the point-lights from the hips were removed, the replication of the action was more accurate than when point-lights from the other body components were removed. These results suggest that the relative motion between certain components holds more salient information for an observer than other points, and more specifically, that the hips (at least in this task) were of little relevance for the observer. This

conclusion was further justified with Experiment III, wherein the observers received instructions to attend to either the knees or ankles. These instructions provided a focus of attention for the observers in a hope to understand how specific components of a system may hold more or less salient information needed for task reproduction. Results showed that a more accurate reproduction of the relative motion between the legs occurred when the instructional cue directed the participant's attention to points placed on the model's ankles, the distal most points in the point-light display. The authors concluded that the end-effector (ankles) provided the most salient information for extracting the relative motion between the legs in this task. Moreover, the results suggest that the relative motion between the legs was more important than relative motion between the joints within the legs. The ability to match absolute time, however, is counter to the initial proposal of Scully and Newell (1985).

Breslin, Hodges, Williams, Curran, and Kremer (2005) incorporated direct human observation in an attempt to understand the importance of relative motion features as they pertain to learning through modeling in a total body movement task. The method required observation of a cricket bowling (pitching) task in one of four conditions: 1) multiple element (including wrist) point-light display, 2) video of actual person, 3) point-light display with a single point, and 4) no demonstration. The system components that were marked for the point-light display presentation were the models' shoulder, elbow, wrist, knee, hip, finger, ankle, toe, and forehead. The authors measured relative angular displacement between various components as the dependent variable. Angular displacement was calculated by measuring the spatial movement of one joint

relative to another. For example, wrist relative phase was measured as an intralimb coordination variable expressing the relative motion between the models right elbow and right wrist. Results showed that the relative angular displacement performance was more accurate by those who had viewed the multiple element point-light display or the video than the group who had observed the point-light display of the wrist motion alone. Results also showed no differences in performance between the observers who had viewed the video and those who had viewed the multiple-element point-light display. The authors concluded that relative motion (in the form of angular displacement) between multiple components is necessary for proper replication of an observed action. The authors did not include a measure of any absolute motion feature (i.e. movement amplitude and/or movement time). These results suggest that video observation and observation of a point-light display both allow for the effective extraction of salient relative motion features that will help an observer perform the action.

Others have used tones to test if an auditory stimulus facilitates the extraction of relative and absolute motion features of a serial motor action (e.g. Heyes & Foster, 2002). By incorporating two different 5-element timing sequences (long and short) and two sound conditions (one with auditory tone and one without auditory tone), the authors were able to investigate whether the extraction of absolute and relative timing features by observers was facilitated with the use of an auditory stimulus. In this case, the relative motion feature is the relative timing between key strikes. The absolute feature is the actual time of the entire sequence (1,000 ms or 1,600 ms). For the 1,000 ms pattern, the goal relative timing segments were 188, 312, 125, 125, and 250 ms, respectively. For the

1,600 ms sequence, the goal relative timing segments were 300, 500, 200, 200, and 400 ms, respectively. Results showed a significant benefit for both models and observers on the relative timing component of the task when the auditory tones were available. The absolute timing only improved when pairing the auditory tones with physical practice. This suggests that observation of a model performing did not elicit learning of the absolute motion feature of absolute time in observers.

Black and Wright (2000) used two experiments to test the effects of observation on error detection and movement production. Participants were paired together with one person designated as a physical practice participant and the other the observer. The task involved pressing four number keys (2, 4, 6, and 8) in three different segments on a keyboard with the index finger. The sequence of key presses contained both a relative timing component and an absolute timing component, with each component emphasized as important for successful replication to both the models and observers. The relative motion feature of the task was the relative timing between key presses (26%, 33%, and 41% of total movement time). The absolute motion feature was the total time (700, 900, and 1,100 ms) of the sequence. The practice session involved performance of the task by the physical practice participant followed by knowledge of results in the form of displaying the goal relative times and total time against the actual performance. After a 24-hour delay, the observers performed 12 trials without feedback in a retention session without the model present. After each retention trial, the participants gave an estimate of their absolute movement time (complete the sequence). Results from the retention tests showed no difference in error detection capability between the observers and physical

practice participants, a finding supported by a similar study by Black, Wright, Magnuson and Brueckner (2005). The authors did not see significant learning by the physical practice participants or observers of the relative motion feature. However, when the number of practiced trials observed increased from 72 to 108 and the retention test contained 18 trials of the same segment (experiment 2), results showed better learning of the relative timing component in the physical practice participants, but not the observers.

Buchanan et al. (2008) used a single-limb coordination task to study the concept of movement feature extraction during observation. Physical practice participants (models) generated rhythmic arm motions about the wrist and elbow in order to match specific absolute and relative motion features designated as tasks goals. The absolute motion feature goals were joint angles of 80° and 48° for the elbow and wrist while the goal relative motion feature was a relative timing (or phase) offset of 90° between the two joints. The observer's task was to watch his/her model with the intent to learn and replicate the coordination pattern the model practiced. After two days of observation, a retention test showed that the observers were better able to replicate the relative motion goal between the elbow and wrist than a control group that did not practice physically or observe a demonstration of the action. The observers did not match the performance levels of the models with regard to the absolute joint angles required. Results also showed no differences between the control group participants and the observers in the measure of the absolute joint angles. This suggests that the relative phase between the elbow and wrist was picked-up by the observers and reproduced without extensive physical practice. The observers did not match the required individual elbow and wrist

joint amplitudes, indicating a physical practice requirement to scale absolute motion features as suggested by Scully and Newell (1985). The authors conclude in agreement with Scully and Newell (1985) that observers are able to extract relative motion features without the need for physical practice.

The aforementioned literature provides extensive evidence that observers are capable of extracting relative motion features through visual-perception processes across a variety of empirical tasks. However, the extent to which observers can extract the absolute motion features of a task remains less well defined. The current study examines the extraction of relative and absolute motion features during observation and the extent to which between trial variability in the models demonstrations (novice versus expert) and observer perspective affect this extraction process.

Discovery and Expert Learning

In observational learning research, the question of how the model's skill level affects an observer's performance is an important issue in developing optimal demonstration training protocols (e.g. Landers & Landers, 1973; Lirgg & Feltz, 1991). Does the model need to be an expert performer, novice performer, or medium-skill level performer for an observer to learn optimally? Before answering this question, one must define what makes a novice and expert. The primary difference between an expert and novice performer is the extent of variability in performance across trials and possibly the number of strategies used to achieve the same goal. As an expert performer executes a skill, he/she typically does so with relatively consistent performance from trial-to-trial

and therefore consistently equal error. Thus, the overall performance typically shows little trial-to-trial variability across a demonstration session. Further, an expert performer is usually aware of the ideal method or strategy for performing a specific action and typically uses only one strategy during performance. This use of a single strategy and lack of performance improvement as a function of practice is not characteristic of performances by a novice. As an individual practices a new task, he/she typically shows learning as a function of attempts, and therefore a gradual reduction in error. In addition, he/she also may use multiple strategies or methods to perform the task in a search for the optimal solution. This funneling effect from relatively large error to low error and the search for an ideal strategy characterizes “discovery learning”. In other words, discovery learning is the process by which an inexperienced performer attempts multiple strategies in a search for the ideal method of performance (McCullagh & Meyer, 1997; Lee & White, 1990; Pollock and Lee, 1992). One question we hope to address here is how novice and expert performance levels may affect the ability of an observer to extract relative and absolute movement features.

Martens et al. (1976) were some of the first to attempt to answer this question by investigating the differences between observer groups that watched models performing the same skill at different competency levels. In a projectile skill task (experiment III), called a “shoot-the-moon” task, observers in four different conditions were tested over 50 trials. The task involved the manipulation of two rods with a goal of “shooting” a ball upward toward targets. The goal of the task was to shoot the ball to the upper-most target. The experiment consisted of four different groups, a control group that had no

observation, a correct model group in which observers viewed consistent correct performance, an incorrect model group in which observers viewed an ineffective strategy, and a learning model in which participants watched an individual improve over time. Results showed that the observers of the incorrect strategy in acquisition attempted the incorrect strategy in practice, yielding low scores. In addition, the observers who viewed a correct strategy in acquisition attempted the same strategy in practice, but did not score better than those observers that used the incorrect strategy. Thus, the demonstration biased the strategy selection processes without benefitting performance. This indicates that low trial-to-trial variability may not benefit a beginner when demonstrations are limited. The results confirm the conclusion of Bandura (1990) who suggested that more demonstration trials lead to greater learning.

Adams (1986) asked participants to observe a model manipulating a joystick in an observational practice paradigm. Models sat in a chair and moved a vertically placed joystick that stood between the participant's knees to different locations on a circular ring that surrounded the joystick. The objective of the model was to contact three specific points (25 cm away from the start position) at specified goal movement times of 2.5, 1.5, and 0.5 seconds (total movement time = 4.5 seconds). In the experiment, one group of observers received knowledge of results of the models performance in the form of an absolute error (in seconds) for each movement segment (3 per trial) and the overall goal error in seconds (OKR group). The other group of observers did not receive KR about the models performance (ONKR) even though the model did receive KR. The observers watched the model perform 50 trials before they were tested. When retention

testing was administered, the observers were also required to perform 50 trials with KR. Results indicated that early in practice (first 20 trials) the KR provided to the model assisted both observer groups (ONKR and OKR) equally well. However, after the first 20 trials, only the observers that received KR of the model's actions (OKR) showed continued error reduction. Adams (1986) proposed that observation of a learning model coupled with KR (OKR group) allowed the observer to problem-solve by comparing the observed action to the KR provided. He further concluded that the decrease in trial-to-trial performance error lead to the creation of a cognitive representation of correct performance. He suggested that during this discovery process, when error and variability tend to decrease, motor learning takes place. It was hypothesized that this gradual reduction in error lead to stable performance and allowed the observer to "pick up" on the goal of the task, therefore eliciting good physical performance with minimal physical practice. The above findings indicate that a model performing in a discovery context (as opposed to an expert or instruction context) is beneficial for an observer (Pollock & Lee, 2002; Buchanan & Dean, in press).

Vereijken and Whiting (1990) used a ski simulator task to study how prior knowledge of a task affects motor learning in novice performers. The authors compared two different groups, participants who observed an expert performer prior to practice and a group who did not observe an expert performer prior to practice. In the observation group, the observers watched an expert performer oscillate with relatively consistent motion on a ski simulator. The no-observation group participants did not observe any model and were instructed verbally how to perform the task. In both conditions however,

the participants had not physically performed the task prior to testing, allowing for discovery learning to take place. Results showed that discovery learning when combined with physical practice leads to greater learning than prior observation of an expert model combined with physical practice. In other words, demonstrations by an expert prior to practice proved to be an inferior training method compared to discovery learning.

A similar conclusion regarding the benefit of viewing the discovery learning process was reported by Mattar and Gribble (2005). The goal of the task was to move a handle from one point to another in a straight line through the horizontal plane. The handle was attached to a robotic arm and a constant force applied to the handle drove the handle away from the target position. Thus, the model had to learn to adapt to the applied force in order to produce a straight-line trajectory. In one condition, the robotic arm was always perturbed with the same magnitude of force and in the same direction as the subject tried to move the robotic arm toward the goal position. In this condition, the model gradually learned to overcome the force field and counter its effects in order to move in a straight line to the goal target. This condition showed a consistent reduction in trial-to-trial variability in the model. In another condition, the robotic arm was perturbed in a random fashion with a different force magnitude and perturbation direction from trial-to-trial. Models in this condition were not able to direct the robotic arm towards the target with a straight-line trajectory and trial-to-trial variability did not decrease. Observers watched a video of one of the two models with the intent to learn how to direct the robotic arm toward the goal position however, the observers were not aware of the force field prior to observation. Results showed that by allowing participants to

observe another individual develop a competency to overcome the same force field perturbations over time (discovery), the observers began to learn. In other words, the gradual reduction in error by the model allowed the observers to understand the need for adjusting forces to counter the force field perturbations. Conversely, participants who did not observe a consistent decrease in trial-to-trial variability throughout practice showed significantly less capability in a test that incorporated an external force on the robotic arm. Taken together, the results from Mattar and Gribble (2005), and Vereijken and Whiting (1990) suggest that the discovery process is important if the observer is to pick-up salient information that will allow them to perform the task. However, not all empirical efforts directed toward understanding discovery learning have provided evidence that observing a discovery model is superior to observation of an expert model.

Lee and White (1990) used two experiments to study the effects of unskilled (novice) models on the performance of observers. The primary purpose was to compare the effects of random versus blocked observational practice. Blocked practice refers to a systematic method of practice in which trials presented in a specific order provide relatively low contextual interference between the various conditions (e.g. Shea & Morgan, 1979; Lee & White, 1990). An example of a blocked design may be a set of 60 trials where the first 20 trials are task “A”, the second 20 trials are task “B”, and the last 20 trials are task “C”. In contrast, random practice refers to an unsystematic method of practice in which trials are organized pseudo randomly, or in such a way as to provide relatively high contextual interference between the various conditions (e.g. Shea & Morgan, 1979; Lee & White, 1990). Lee and White (1990) asked participants to play a

track and field computer game in which participants manipulated a cursor to complete three different “events”. One of the two gaming tasks involved a relative timing component (key presses) in which specific buttons needed to be pressed in the proper order relative to one another (‘x’, ‘return’, and ‘space bar’). In the other gaming task, the participant controlled a cursor as it moved on the screen by controlling its direction with four keys (absolute timing). Each of the tasks, referred to as a “game”, elicited a score after each trial. The authors did not differentiate between absolute and relative motion features in the tasks but rather based the effects of observational learning on the overall scores. Results revealed that the group of participants who observed random performances by the models (random observers) showed no score differences from participants who observed blocked (Shea & Morgan, 1979) performances by models. Results also showed a significant benefit of the aforementioned groups over the models who had practiced randomly. These results suggest that in some instances, a random design (in which error is not consistently reduced as a function of trial) is not always inferior to blocked practice (typically less trial-to-trial variability as practice continues) in an observational learning paradigm. This conclusion to some extent contradicts the presumption that viewing trial-to-trial reduction in error performance is necessary for observational learning (Mattar & Gribble, 2005).

Hodges and Franks (2001) used a bimanual coordination task to study the effects of explicit instruction and feedback on performance in an observational learning context (physical practice and demonstration combined). The goal of the task was to coordinate the hands in such a way as to produce a 90° continuous phase relationship between the

two limbs. A 90° phase relationship has proven to be difficult to perform without extensive practice (Zanone & Kelso, 1992, 1997; Lee, Swinnen & Verschueren, 1995) unless very specific experimental conditions are preset. This difficulty arises from an innate tendency of the subject to produce either an in-phase pattern (0°) or an anti-phase pattern (180°). Bimanual in-phase coordination of the fingers, wrists or forearms consists of simultaneous flexion and extension of the effectors toward and away from the body midline, while anti-phase coordination requires an alternating flexion and extension of the two limbs toward and away from the body midline. The relative phase of 90° is an intermediate phase to both the 0° and 180° coordination phases and is achieved when the right effector leads or follows the left effector by exactly $\frac{1}{4}$ of a cycle. In this case, a cycle consisted of an elbow flexion-extension oscillation in the horizontal plane, and participants oscillated their upper arms in the horizontal plane while holding manipulanda in each arm. The authors employed a variety of feedback (Lissajous and time series) and instruction techniques (verbal and demonstration) as manipulations within the observational practice context. The primary finding for the purposes of this study was that several demonstrations accompanied with explicit verbal instructions of the task by an expert did not offer a significant benefit regarding the pick-up the relative phase (relative motion feature) compared to discovery learning. The demonstration in the Hodges and Frank (2001) task was provided only a few times throughout practice. Furthermore, the demonstration did not reveal a trial-to-trial reduction in performance variability. Results therefore, do not provide valid evidence for the ability, or lack of, an

observer to extract relative features within a purely observational practice context of this bimanual task.

Hodges, Chua, and Franks (2003) used a bimanual 90° relative phase paradigm to study the extent that video demonstration by an expert would interact with video of an observer's physical performance. The authors used the same manipulandum setup describe in the aforementioned experiment (Hodges & Franks, 2001). Before approximately 30% of the practice trials, participants watched a video demonstration of an expert model performing a 90° relative phase in the same task. Participants were asked to try to correlate their peak inward movements with two flashing lights (squares) displayed on a separate monitor, consistent with what was provided to the model in the video. One practice group received video feedback of their own movements from their practice trial after the presentation of the expert's video. This allowed the participants to compare the video of the model to their own movements. The control group was not provided with feedback of their own movements, rather given a 30-second rest period. A retention test after several days was administered. Results showed that the video-feedback group performed better than the no feedback group in both acquisition and retention. Results also showed that the participants who had received video-feedback of their own movements were better able to detect error (deviation from 90°) than the no feedback group. The authors concluded that the feedback provided the observers allowed the goal relative phase to be extracted more effectively (more salient information) allowed for better perceptual discrimination of other relative phases.

In the two aforementioned studies (Hodges & Franks, 2001; Hodges et al., 2003), the authors hoped to measure how a 90° bimanual coordination task was learned through observation. However, the authors did not adequately measure the extent to which a model might allow for learning by an observer. That is, the studies always employed an observational learning context instead of an observational practice context, and manipulated the feedback and skill level of the model. Thus, it is not clear to what extent demonstration alone as training protocol influenced the extraction of the relative motion features. In both studies, the authors used expert performances in the demonstration protocol. As some research indicates, this may or may not be the optimal demonstration context. In addition, the task of oscillating the upper arms in the horizontal plane allows for only two possible solutions to producing the goal phase (left hand lead or right hand lead). How will instructions and/or different modes of demonstration (expert or discovery) affect learning in observers? Will instructions hinder learning (Hodges and Franks, 2001) if more solutions to the task are available?

Buchanan and Dean (in press) also used a bimanual task to address in more detail the importance of trial-to-trial variability when using demonstration as a training protocol. The authors used a bimanual coordination task in which participants were required to trace 10 cm diameter circles with a 90° continuous relative phase (Φ) pattern between the arms. The goal of the task was to perform a 90° relative phase between the two limbs while tracing two circles (achieved by using any one of eight different strategies; fig. 1). To achieve the 90° relative phase, the two circles can be traced with both arms moving either clockwise (C) or counter-clockwise (CC), or with each arm

rotating in the opposite direction of the other. These multiple combinations of limb motion indicate that there are four different rotation strategies (fig. 1) linked to tracing a pair of circles. However, in order to produce a 90° relative phase, one hand must lead the other by $\frac{1}{4}$ of a cycle, meaning that the goal phase of 90° can be produced with any one of eight different strategies (2 hand leads x 4 rotation directions).

Direction / Lead Strategies

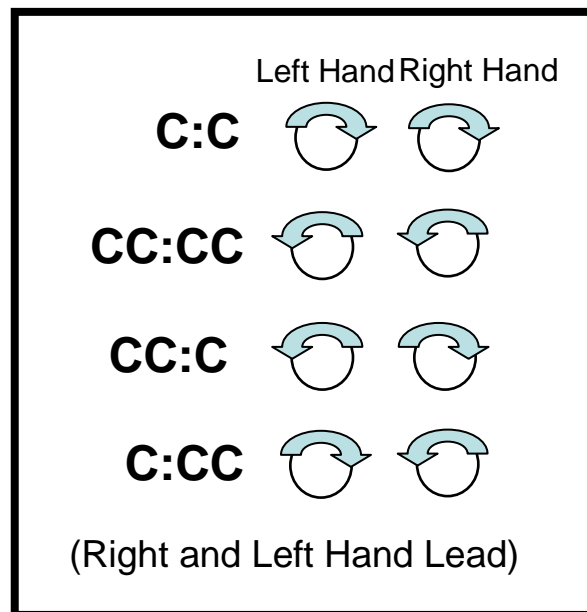


Figure 1. Direction / Lead Strategies. A table of the direction/lead strategies available to a participant performing a 90° relative phase between the two limbs in the Buchanan and Dean (in press) study.

In the experiment, participants participated in pairs (model and observer) and the pairs divided equally into two groups - verbal instruction and discovery learning. The

verbal instruction group pairs received specific instructions that directed the models to one of the eight strategies: tracing the circles with a clockwise rotation of the left hand and a counter-clockwise rotation of the right hand (C:CC, fig. 1), with a right hand lead. The discovery learning group pairs did not receive any specific instruction that would provide a bias toward any one strategy. In the discovery condition, the models were forced to discover a solution (settle on a specific strategy), which resulted in slower error reduction as a function of trial. Across six of the discovery models, each of the four rotation directions and hand lead strategies emerged at least once across the two days of practice, including the strategy provided to the instruction models.

Results indicated that the verbal instruction models performed significantly closer to the goal relative phase than the discovery models during acquisition and in a 24-hour retention test. These results contradict those of Hodges and Franks (2001) who found that detailed verbal instruction hindered performance. This difference can be attributed to one or more differences between the two studies. First, the verbal instructions in the Buchanan and Dean study reduced the number of strategies used by one group of models (from eight possibilities to one) during the acquisition phase. Thus, the verbal instructions reduced the amount of trial-to-trial variability in the model's performance during the learning process, whereas the lack of instructions created high trial-to-trial variability in the discovery model's practice sessions. Another difference between the two studies is the number of degrees of freedom required (biomechanical and methodological). Hodges and Franks (2001) and Hodges et al. (2003) used a paradigm in which the participants were required to oscillate their arms about the elbow

and manipulate two levers. Since each lever had only one degree of freedom (left or right), the bimanual design had only two degrees of freedom. However, Buchanan and Dean (in press) asked subjects to trace two circles on a table surface (two dimensions) with elbow and shoulder motion (four biomechanical degrees of freedom) to drive the end-effector. This difference in degrees of freedom between the two tasks may have accounted for the different results.

Unexpectedly, the same verbal instructions that assisted the one group of models seemed to hinder learning by the observers of those models. The observers who viewed the discovery learning models performed better on a retention test than the observers that were privy to the verbal instructions given to their model partner (reduced strategies). Buchanan and Dean (in press) note two key findings from the experiment. The first is that the discovery condition facilitated the observers' ability to extract the required relative phasing between the limbs. This suggests that when a model is not capable of performing a skill correctly early in practice and is forced to move through a discovery process, the corresponding observer develops a representation of the skill. In other words, the tasks cognitive representation contains a closer approximation to the task goal as the result of viewing a variety of strategies. The second key finding was that verbal instructions and viewing a model perform a single strategy combined to bias the observers to the same direction strategy as their corresponding model, but failed to facilitate the extraction of the required relative phase. This leads to the conclusion that verbal instruction and discovery processes may enhance the extraction of different movement features. The verbal instructions designed to assist learning for both models

and observers only benefited the model. In this case, the instructions provided a single strategy to achieve the required relative motion feature (relative phase; “1/4 of a cycle”) with a template to represent the absolute motion feature (movement amplitude; “trace the circles”). When paired with physical practice, the single strategy produced rapid performance changes in the model, but without physical experience did not benefit the observer. This indicates that demonstration contexts benefit the observer more when extensive trial-to-trial variability in strategy selection processes is present in the model. One last possible explanation of why the verbal instructions assisted the model and not the observer is that the explicit instructions may have caused the observers to focus less attention on the model, an issue addressed in the current experiment. The authors also suggest that perhaps a random versus blocked practice effect may have taken place. However, as mentioned earlier, observation of a model within random and blocked practice contexts does not always yield similar results as found in those who physically practice under random and/or blocked practice (Lee and White, 1990).

These conclusions suggest that the same instruction may not equally affect learning by a model and an observer. The current study examines this presumption by providing a model with different instructions compared to a group of observers. Independent instructional sets for observers and models will allow for greater control of trial-to-trial variability in the demonstration protocol with regard to strategy selection. Control of trial-to-trial variability provides an opportunity to examine the impact of novice versus expert demonstrations on observers that are not aware of the performance level of the model.

Perspective

Aside from investigating the extent that relative motion feature extraction by an observer depends on a model's skill level, another topic addressed with the current experiment is the observer viewing perspective. Some researchers have shown that viewer perspective has an impact on motor skill production, both imaged and physical (Starek & McCullagh, 1999; Anquetil & Jeannerod, 2007; Stevens, 2005; Maeda et al., 2002). Here, we manipulate the spatial orientation of the model to the observer in an attempt to reveal any impact that viewing perspective may have on the extraction of relative and absolute motion features during observation.

Some insight into the role of viewing perspective on observational learning comes from Maeda et al. (2002) who asked observers to watch video clips of three different right-hand finger movements from different perspectives. The finger movements were thumb abduction-adduction, index finger abduction-adduction, and index finger extension-flexion movements. Motor-evoked potentials (MEPs) induced by transcranial magnetic stimulation (TMS) were recorded from various muscles in the hand. The *away* perspective was an orientation of the observer to the model such that a natural hand-orientation was present (right on right and left on left). In other words, the left hand of the model spatially correlated to the left hand of the observer in reference to the body midline. The *toward* perspective gave a view opposite of the model (right on left and left on right). The *away* perspective may be defined as a first-person perspective, while the *toward* perspective may be defined as a third-person perspective. Results showed that MEP facilitation was significantly greater in conditions in which the

observer viewed the corresponding movement from the *away* perspective. In other words, motor actions are affected at the neurological level by the angle at which a skill is observed. More specifically, maximization of the MEP signals occurred when the observed action corresponded to the orientation of the observer. This provides evidence that the neurological system responds differently to, or recognizes, different angles of observation. This suggests that viewing angle may influence learning when demonstration acts as a training protocol.

Sebanz, Knolich and Prinz (2003) addressed the issue of viewing perspective when they used a spatial compatibility reaction time task to test whether or not motor skill observation results in the development of functionally identical motor representations for the observer. The perspectives of the observers were similar to those incorporated by the previously discussed study (Maeda et al., 2002). The authors used three conditions (2-choice condition, paired go-nogo condition, and an individual go-nogo condition) wherein subjects reacted to a digital image of a finger pointing toward or away from a target, similar to the Maeda et al. (2002) study. Results showed a “joint compatibility” effect with the participants reacting faster to the compatible, away stimulus (first-person perspective).

Anquetila and Jeannerod (2007) used a motor imagery prehension paradigm to study the different effects of first-person and third-person viewpoint perspectives. A first-person perspective (1P) exists when the right side of the model’s body spatially correlates with the right side of the observers’ body. Conversely, a third-person perspective (3P) occurs when the model faces the observer providing a mirror image of

the model to the observer across the body midline. The authors used a reaching task in three conditions: 1) imagery of another person reaching (3P), 2) imagery of actual reaching (1P), and 3) actual reaching (1P). In each of the perspective conditions, the difficulty level was controlled. The stylus for which the participants reached (imagined or actual) was oriented at either 45° or 0° in reference to the hand's position. The 45° orientation was labeled as "easy" as it allowed for a comfortable wrist angle upon grasping. However, the 0° orientation angle forced the participant to dorsiflex the wrist considerably upon grasping, resulting in an uncomfortable endpoint position. Therefore, the 0° angle condition was labeled as "hard." Movement time estimations were recorded and used as the dependent measure. Although the difficult orientation angle (0°) required more time to grasp than did the easy angle (45°) in all three conditions, no differences in movement time emerged between the 1P and 3P imaged conditions. The authors conclude that participants kept the same egocentric representation of the action for both visual perspectives. This, in turn, suggests that the same motor representation emerges from both a first-person and third-person perspective in over learned motor skills.

Stevens (2005) administered four experiments to examine how motor and visual imagery are utilized during the mental representation of human movement. Participants imagined themselves walking from two different perspectives, a "primary" location and an "opposing" location. The primary location was similar to a first-person perspective in that participants used motor imagery to view themselves initiating walking from where they stood. The opposing condition was similar to a third-person perspective in that participants used motor imagery to view themselves initiate walking from an alternate

point within the path walked. Results showed that participants were more capable of estimating accurate movement times when imaging themselves in the first-person perspective in comparison to the third-person perspective.

Taken together, the above tasks do not support the conclusion that viewing perspective has no impact on motor imagery; instead, the data suggest that the ideal viewing angle for a model is dependent upon the task itself (context dependent). In addition, all of the aforementioned studies incorporated common, over-learned skills as the task to observe (either imagined or real). How will viewing perspective influence the learning of a novel motor action? Hodges et al. (2003) showed that observers can "pick up" relative features in a bimanual coordination task from a first person perspective. The Hodges et al (2003) first-person perspective task is quite different from the method used in the Buchanan and Dean (in press) study that placed observers directly in front of the model, a third-person perspective. In this position, the observer had essentially a mirror picture of the subject's performance (the observer's right arm lined with models left arm and vice versa). Viewing angle has received little if any study within the observational learning literature. The imagery research indicates that viewing angle contributes to performance outcome differently as a function of the task. This raises the issue of the role of viewing perspective in demonstration protocols and its impact on observational learning of a novel task and the impact that viewing angle has on the extraction of relative and absolute motion features.

Coordination Dynamics

Why is the “what” question asked by Scully and Newell (1985) such an important question? The importance of identifying what information an observer extracts through observation provides an opportunity to identify how perception and action are linked on both concrete (application) and abstract (theoretical) levels. Kelso (1994) addressed this linked between perception and action by stating that self-organizing dynamical systems are themselves, informational structures. This information suggests that perception and action are linked through self-organizing coordination dynamics on the level of relative phase. Within this context, relative phase is the relation among the components of a system independent of the nature of the actions themselves (Kelso, 1997). This support for relative phase as an informational variable emerges from work on phase transitions in bimanual coordination, stability changes in bimanual learning tasks, and perceptual judgment studies of bimanual coordination tasks reviewed below.

The dynamical systems theory, sometimes referred to as the coordination dynamics theory (Kelso, 1984; Haken, Kelso, & Bunz, 1985; Schönner & Kelso, 1988a, 1988b; Turvey, 1990), refers to motor patterns as behavioral states that can be quantitatively defined in terms of the system’s level of order or the stability of different states (Kelso, 1995; Jirsa & Kelso, 2004). The theory proposes that a phenomenon referred to as self-organization allows a system to self-stabilize due to innate system characteristics (Zanone & Kelso, 1992, 1997; Kelso & Zanone, 2002; Buchanan, 2004; Hurley & Lee, 2006). A main premise of the coordination dynamics approach is to map the observed motor patterns on to attractors of a non-linear equation of motion as a

means to explain how the human body adapts to environmental constraints. This adaptation occurs when common skills such as walking, running, or talking are stressed by certain variables that lead to spontaneous phase transitions between these states (e.g. Kelso, 1984; Kelso & Scholz, 1985; Kelso, Bressler, Buchanan, DeGuzman, Ding, Fuchs, & Holroyd, 1992; Jirsa, Fuchs, & Kelso, 1998; Vereijken, Whiting, & Beek, 1992). The transition is triggered by a loss of stability in the system after a control parameter has driven or pushed the system to a point of increased variability among the various degrees of freedom (df) within the system (Turvey, 1990). The stability of the different states of a system may be determined by analyzing movement variability in the system's order parameters. An "order parameter" provides a quantitative measure of the systems' current coordinative state and the stability of that coordinative state. An example of an order parameter from human motor skill research is the relative phasing between two oscillating effectors such as the hands.

Kelso (1984) was one of the first researchers to investigate empirically for the existence of phase transition phenomenon in human actions. These shifts from one state to another were identified by having participants oscillate their hands in the horizontal plane while grasping vertical handles. Participants attempted to maintain an anti-phase relationship (180°) between the hands as movement frequency increased. Kelso noted that at a critical point the anti-phase pattern of movement shifted to an in-phase pattern (0°). This shift occurred because the continuous scaling of movement frequency resulted in instabilities that destabilized the anti-phase coordination pattern (Schöner, Haken, &

Kelso, 1984; Kelso, Scholz, & Schöner, 1986). At such “critical points”, new more stable and possibly more energetically efficient patterns emerge (Kelso, 1984).

The phenomenon of these state transitions has been captured with a potential function model (Haken, Kelso, Bunz, 1985), $V(\Phi) = -a \cos\Phi - b \cos 2\Phi$. The variables a and b are coupling parameters that are designed to capture the impact of constant and increasing movement frequencies on bimanual coordination. For values of $b/a \geq 1$, two minima emerge in the potential landscape at $\Phi = 0$ and $\Phi = \pm\pi$ (Fig. 2A), a finding consistent with stable in-phase ($\Phi = 0$) and anti-phase ($\Phi = \pm\pi$) bimanual coordination for slow movement frequencies (Kelso, 1984; Scholz & Kelso, 1985; Buchanan et al. 1996; Carson et al. 1997). A key feature of the HKB model is that it captures the differential stability between the 0° and 180° coordination patterns found in so many experiments (e.g. Schöner & Kelso, 1988b; Haken et al., 1985). This may be seen in the deeper well associated with $\Phi = 0$ compared to $\Phi = \pm\pi$. For values of the ratio $b/a \leq .25$, the minima at $\Phi = \pm\pi$ is eliminated and only the minima at $\Phi = 0$ remains (fig. 2C). This is consistent with transition phenomenon from anti-phase to in-phase bimanual coordination as movement frequency increases (Kelso, 1984; Scholz & Kelso, 1985; Buchanan et al. 1996).

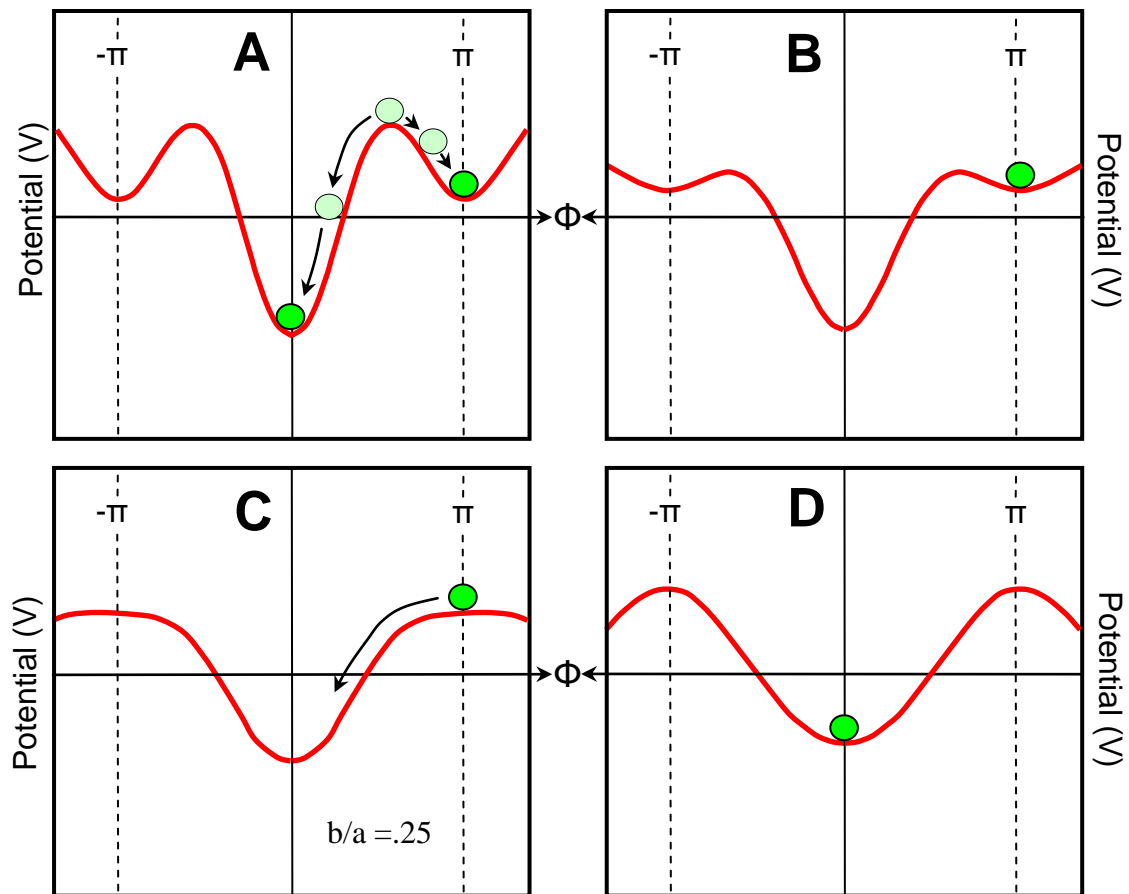


Figure 2. HKB Model. The potential landscape of the HKB model of bimanual coordination for four values of the ratio of b/a is shown in A to D. The shaded ball represents the state of the system. The x-axis represents the relative phase (Φ) of the system's components, with in-phase coordination represented by the well centered on $\Phi = 0$ and anti-phase coordination represented by the well centered on $\Phi = \pm\pi$.

For the current study, an important feature of the model is that the 90° relative phase lies directly in between the stable 0° and 180° relative phases and is characterized in the HKB model as a repeller (crest in fig. 2A, middle ball). The 90° relative phase value is referred to as a repeller because attempts to perform such a coordination pattern often lead to shifts to the more stable in-phase and anti-phase states. Zanone and Kelso (1992) asked participants to oscillate their index fingers in time with two light emitting

diodes (LEDs). Subjects practiced the 90° relative phase for five days and then tested on the 90° pattern and other phase patterns. Results showed that the relatively difficult coordination pattern of 90° was learned through extensive practice, but that the stability of the pattern was still not equal to the stability of the innate patterns of 0° and 180° . The participants learned to incorporate a perceptually defined pattern into a stable motor pattern, which provides evidence of a link between perception and action. Therefore, relative phase is shown to be (at least in this case) an informational variable within a motor skill-learning context.

Bingham, Schmidt, and Zaal (1999) investigated the visual perception of relative phase to examine further the link between perception and action capability. In experiment 1, participants had to “judge” subjectively the coordination (1-10) of oscillating pendulums presented as dots on a computer screen. In two different conditions, the dots oscillated in either the sagittal, or frontal plane relative to the observers. Results showed that judgments of the most stable coordination occurred when the dots were moving at the 0° and 180° relative phases. In addition, as the relative phase between the two dots moved away from the two “stable phases”, the motion of the dots was viewed as less coordinated and less stable. In other words, the perception of relative phase mimicked exactly the inherent tendencies of human coordination suggested by the HKB model. This led the authors to conclude that relative phase is a “perceptual property” and that this perception is most evident at the more stable phases (Bingham, et al. 1999; Zaal et al. 2000).

This link between the production and perception of relative phase in bimanual coordination tasks indicates that relative phase carries information regarding the relative motion between components as well as information on the stabilities of the pattern between components (Bingham et al., 1999; Zaal et al. 2000; Buchanan et al., 2008). The ability of observers to establish the link between perception and action regarding the informational structure of relative phase was shown in a single limb multijoint coordination task (Buchanan et al., 2008) and to some extent in several bimanual tasks (Hodges et al., 2007; Hodges and Williams, 2007). However, the extent to which (1) the model's skill level and (2) the viewing perspective of the model by the observer will influence this informational link still needs examination.

Experimental Hypotheses

As mentioned before, the present experiment addresses three issues still debated in observational learning literature. One objective is to determine more definitively the extent to which the relative and absolute motion features of a movement are extracted by an observer watching a model perform a bimanual coordination task. The observers will watch the models manipulate two styli and trace two circles in order to provide demonstration protocol for extracting salient information (Jansson et al., 1994; Hodges et al., 2007). Similar to Buchanan et al. (2008), the absolute motion feature will be movement amplitude. However, unlike Buchanan et al., the movement amplitude will be a two dimensional planar motion rather than one-dimensional joint angles. Based on previous work (Scully and Newell, 1985; Jansson et al., 1994; Al-Abood et al., 2001;

Breslin et al., 2005) we predict that a relative feature will be extracted by an observer, specifically the relative phase relationship between the hands (e.g. Bingham, Schmidt, & Zaal, 1999; Hodges et al., 2003). We also postulate that the absolute feature (amplitude) will not be extracted during observation and thus not reproducible.

A second objective of the current study is to identify the role of trial-to-trial variability in the demonstrations offered to an observer. We postulate that a model that gradually reduces error (learns) during practice will provide information that is more salient to an observer than a model that has consistent error across trials (expert model and instruction model). Thus, based on work by Matter and Gribble (2005) and Buchanan and Dean (in press), it is predicted that observation of reduced error and variability over time, a characteristic of discovery learning, will elicit the greatest learning from observers. Furthermore, performance differences between observers of an “expert” model and observers of an “instruction” model will not emerge, because these models offer less trial-to-trial variability in performance solutions.

Lastly, an attempt to answer the question of what perspective of the model is optimal for learning by the observer, a first-person perspective or a third-person perspective, is undertaken. Based on the limited research that has addressed similar questions, we predict that the perspective of the observer in which the right and left sides of the body are spatially similar to that of the model (first-person perspective) will elicit greater motor learning. Conversely, due to the processing requirements suggested by mental rotation, we predict that a mirror image of the model in which the effectors are on

opposite sides of the body midline (third-person perspective) will prove less effective in providing the salient information required for optimal skill production from observation.

CHAPTER III

EXPERIMENT

Method

Subjects

College students (N=52) received academic credit for participation in the experiment. All participants had no prior familiarization with the experimental task and were not aware of the study purpose. Participants were right-hand dominant, as determined by a self-report, prior to the experiment. Informed consent approved by the IRB for the ethical treatment of experimental participants at Texas A&M University was obtained prior to participation in the experiment (45 CFR 46).

Protocol – Models

Four male subjects trained on the task to serve as models in the experiment. The purpose of the models participation was to create digital videos of performance, which would serve as a demonstration tool for observers. The models data collection protocol was as follows.

The task used was a circle-tracing task involving both hands (Carson, Thomas, Summer, Walters, & Semjen, 1997). A tracing template of two equal size circles (10 cm in diameter and 5 cm apart) was fixed 15 cm from the edge of a table. The model sat in a height adjustable chair in front of the table with their body midline centered between the two circle templates. To the left of the model, a computer monitor displayed a target template and the model's hand motion as feedback. The models traced the circle

templates with wooden styli (1.2 cm square and 15 cm long) held in the hand like a pen. An Optotrack 3020 camera system was used to collect kinematic data from infra-red light emitting diodes (IREDS) placed at the distal ends of the two styli, and on the participants elbows and shoulders (fig. 3A). The IREDS provided spatial information (location) of the prospective joints in all three axes, and were sampled at 100 Hz.

A function generator (Sony Tektronix, AFG320) provided digital templates that defined asymmetric (180°) and symmetric (0°) coordination, the goal relative phase of 90° (Fig. 3B). Symmetric tracing of the two circles (Fig. 1, C:CC and CC:C), accomplished by tracing the two circles with a 0° relative phase in relation to the body midline, is represented as a positive sloped diagonal line in the Lissajous plot. Asymmetric tracing of the two circles (Fig. 1, C:C and CC:CC), accomplished by tracing the two circles at a phase relation of 180° in relation to the body midline, is represented as a negative sloped diagonal line. The tracing the two circles with any of the eight possible strategies at the goal phase of 90° relative phase, is represented as a circle in the Lissajous plot. Performance feedback was provided by showing a single trace representing the circle tracing movements of both the left and right hands in the Lissajous plot. The x-axis of the Lissajous plot represented the x-axis motion of the right hand and the y-axis of the Lissajous plot represented the x-axis motion of the left hand. The required circle diameter of 10 cm was represented in the Lissajous plot, in that tracing exactly around the digital circle template could only be done by producing a 10 cm diameter circle with each hand.

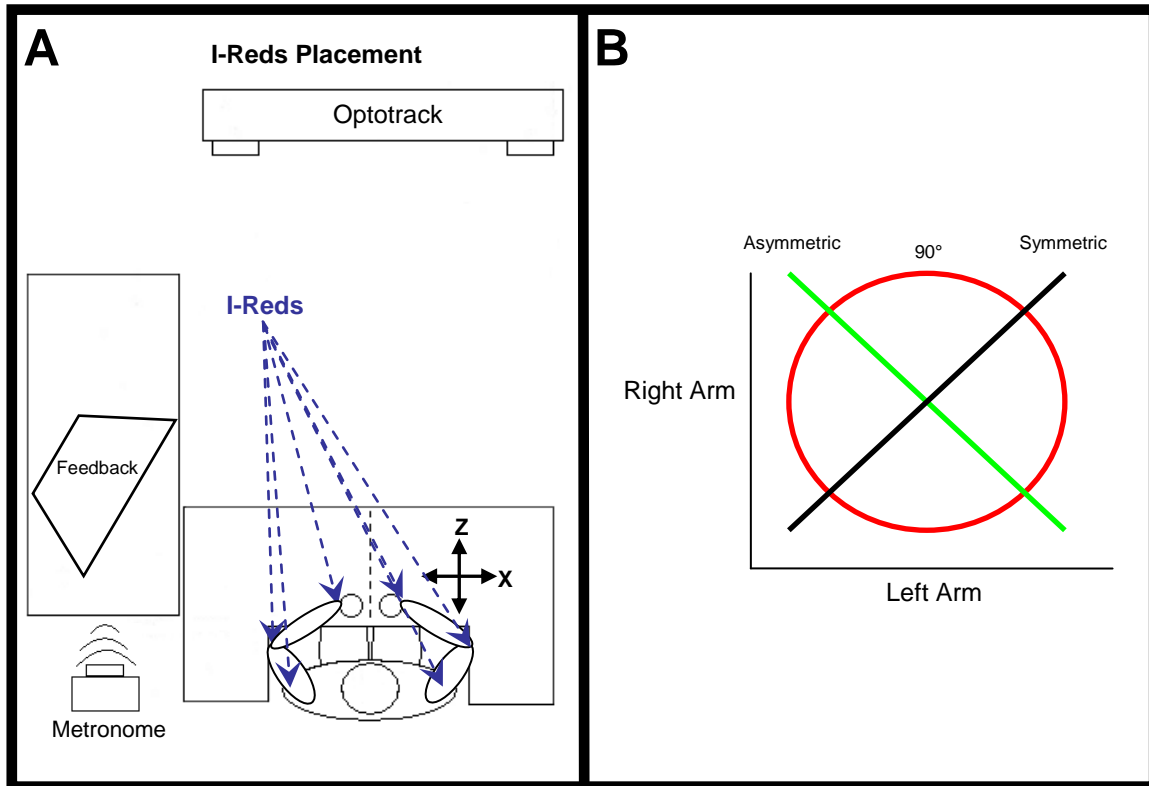


Figure 3. I-Red Placement and Lissajous Plot Feedback. Portrayed in (A) is an overhead view of the experimental setup for the models during the training phase. The arrows point to IRED placement locations. B) An image of the digital templates in the form of the Lissajous plot provided to the models during practice.

Two digital video cameras were set at two different locations to record the tracing movements of the models. The first camera recorded the model from directly overhead (fig. 4A). This video recording represents the first-person perspective (1P) camera because it provided a performer's viewpoint of the templates. A second camera positioned two meters in front of the model provided a third-person perspective (3P) (fig. 4B).

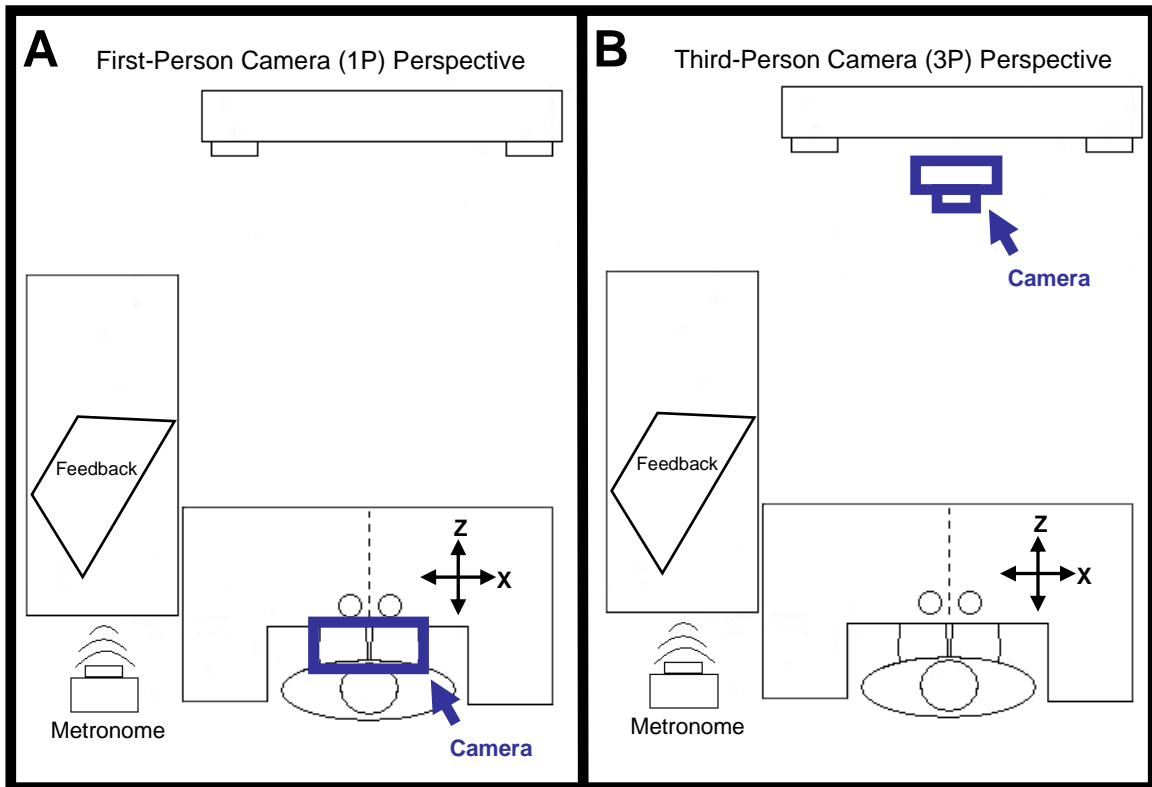


Figure 4. First-Person and Third-Person Camera Perspectives. The positioning of the camera mounted above the model that provided the 1P perspective is portrayed in (A), while the positioning of the camera providing the 3P perspective is shown in (B).

The models sat up straight in a height adjustable chair and grasped the two tracing styli. The models were instructed to use elbow-joint and shoulder-joint movements only to trace the circles and to complete one trace of the circles in time with an auditory metronome beeping at 1 Hz. The models were also instructed not to sway the trunk during performance. There were 16 beeps of the metronome per trial. Verbal instructions provided to the models described symmetric circle tracing as rotating the left hand clockwise and the right hand counterclockwise while maintaining symmetry of

movement about the body midline (fig. 1, C:CC). The asymmetric pattern was described as tracing both circles in a clockwise direction (fig. 1 C:C) with both hands while keeping the two hands spatially identical relative to their position on the circles. These initial asymmetric and symmetric trials familiarized the participant with the task and allowed them to understand the presentation of the feedback. For the first six trials, the models produced the symmetric and asymmetric patterns without feedback in blocks of three trials. These trials ensured the participants understood the task of tracing the circles and demonstrated how the goal pattern was unique, as all participants received instructions that the goal phase was distinct from the symmetric and asymmetric coordination patterns. Before exposing the models to performance feedback related to the target relative phase, the models attempted three trials at the goal relative phase of 90° without feedback.

After the pre-practice trials were completed (nine total trials), one of the four models was selected to serve as the “instruction” model (I_{Mod}). The I_{Mod} was provided with specific verbal instructions of how to achieve a 90° relative phase while tracing the two circles. The instructions read: “In order to correctly match the circle in the Lissajous plot, the tracing of one circle must lead or lag the other by exactly $\frac{1}{4}$ of a cycle. We want you to trace the right-hand circle counter-clockwise and the left-hand circle clockwise. The left hand must be $\frac{1}{4}$ of a circle behind, or lag, the spatial location of the right hand.” These instructions were the same instructions used by Buchanan and Dean (in press) and specified the direction strategy C:CC (fig. 1) with a right hand lead. In the Buchanan and Dean (in press) study, the instructions had prevented an elaborate discovery process for

the model during the acquisition phase and reduced the number of strategies attempted from eight to one.

The other three models did not receive the instructions provided to the I_{Mod} . These three models were labeled “discovery” models (D_{Mod}). The D_{Mod} had to find a strategy that would elicit a circle on the Lissajous plot. This made available to these models eight different possible solutions during the acquisition phase.

After two days of practice, one of the three discovery models began to consistently use a strategy similar to the one used by the instruction model (left hand clockwise, right hand counter clockwise, right hand lead). The video of that D_{Mod} provided the discovery video for this observational experiment. This allowed all the observer groups to view the same direction/lead strategy over the models third practice day. After three days of practice, with 32 trials per day, two digital videos each from the 1P and 3P cameras were created for both the I_{Mod} and D_{Mod} . The first video contained all the practice trials from session one and the first half of the practice trials from session two. The second video contained the second half of the practice trials from session two and all the practice trials from session three, with chronological trial order maintained across the two videos. The resulting four videos were labeled D_{Mod} -1P, D_{Mod} -3P, I_{Mod} -1P, and I_{Mod} -3P, representing the four combinations of model and perspective. For example, the D_{Mod} -1P references the first-person perspective video of the model that learned through discovery.

A third pair of videos, labeled the “expert” videos (E_{Mod}), were composed of a random order of the ten least variable and most accurate trials from the instruction

models 1P and 3P perspectives. The expert videos were labeled E_{Mod-1P} and E_{Mod-3P} . All ten trials in the expert video averaged within 5° of the 90° degree continuous relative phase goal with an average within trial variability of 18.6° . All videos (Expert, Discovery, and Instruction) retained the audio recording of the model's trials in order to provide the auditory beats of the metronome to the observers.

Protocol - Observers

Forty-eight participants served as observers in the experiment. Prior to sitting through the observational learning protocol, each observer performed the same nine pre-practice trials (3 trials of symmetric, 3 trials of asymmetric and 3 trials of the target phase of 90°) just as the models. Up to this point, the task explanation was similar between models and observers. After performing the pre-practice trials, the IREDs placed on the observers for the pre-practice trials were removed and the observational learning protocol initiated.

All observers watched a video of one of the models while sitting in the same location as the models during their acquisition phase. The table, circle templates, and feedback monitor (turned off) were placed in the same location as when the model's data was collected and visible by the observer. During the observation sessions, the observer sat and watched the training performance of the models while sitting in a chair that sat approximately two meters from a 28" television (Toshiba; Model #27A41). The observers ($N = 48$) were randomly divided into two observer perspective groups, the first-person perspective and the third-person perspective groups. Each perspective group

was subsequently divided into three different groups (8 subjects per group), the discovery observation group (D_{Obs}), the instruction observation group (I_{Obs}), and the expert observation group (E_{Obs}). This resulted in six different observer groups (D_{Obs} -1P, D_{Obs} -3P, I_{Obs} -1P, I_{Obs} -3P, E_{Obs} -1P, and E_{Obs} -3P), representing the six combinations of model and perspective. For example, the D_{Obs} -1P references a first-person perspective video of the model that learned through discovery.

All observers were instructed to watch their corresponding videos (instruction, discovery, or expert), watching one video per day, for two days. All observers were provided with an instruction reading prior to watching the video in order to effectively and consistently provide the observer with their objective. The before observation paragraph read: “You will be asked to sit and watch a video of a person tracing two circles with hand held styli. The model’s goal was to produce a 90° relative phase template on the monitor, which you may or may not see. The model in the video was told to ‘lock’ his wrists, and use the shoulder and elbow joints to trace the circles. Your objective is to observe the motions of the model with the intent to learn the coordination pattern needed to elicit the circle on the monitor. After two days of watching the video demonstration, you will attempt to perform the goal coordination pattern achieved by the model in the video. If any of these instructions are unclear please ask a question so that I may clarify the instructions for you.” After answering any questions, the day 1 observational learning video was shown.

Every other pair of trials was combined with the correlating terminal feedback in the form of a Lissajous plot. This was done by using the monitor placed to the left of the

observer to play the Lissajous feedback of the trial previously watched on the television. Therefore, both the model and observer were provided with terminal feedback on the same trials. After observing the first 24 trials on a video, the observers received a 10-minute break. After the midway point, the observers returned to watch the remaining 24 trials on the video. This same protocol occurred during the two observational sessions, with the discovery and instruction observer groups viewing the last 48 trials of their corresponding model on the second day. On day three, the observers from all groups read a set of instructions for the retention test: “You were asked to sit and watch a video of a person tracing two circles with hand held styli. The goal of the model in the video was to coordinate their hands in a manner as to elicit a circle on the monitor that represented the task goal of a 90° relative phase pattern. Your objective was to observe the movement with the intent to learn and replicate the coordination pattern needed to elicit the circle on the monitor. Today you must trace the circles in such a way as to produce the target relative phase. Be sure to lock your wrists and use only elbow and shoulder movements to trace the circles.” The observers then performed the symmetric pattern for three trials and asymmetric pattern for three trials without feedback. Following these six trials, the participants were asked to perform the “goal phase” (90°) for four trials, without feedback. Following these four trials, the observers were provided with pair-alternating feedback (Lissajous plot) for eight more trials. After these eight trials, the circle templates sheet was replaced with a blank sheet of white paper under the Plexiglas. Twelve more trials were attempted with the same feedback protocol used in the first 12 attempts at the goal phase, four trials without feedback followed by eight

trials alternating concurrent and terminal feedback. The reason for the template removal during the last 12 trials of the day 3 retention test was to allow for a measure of the difference in tracing circle diameter. This would therefore provide evidence for whether or not the absolute feature of movement amplitude was extracted during observation. The entire observer protocol is listed in Table 1 below.

Table 1. Observer Protocol. The pre-practice, observation, retention, and practice protocol for observers.

<p>Observer Protocol:</p> <p>Day 1</p> <ul style="list-style-type: none"> - Pre-Practice of 0°, 180°, and 90° (3 trials each) - Observe 24 trials (Alternating terminal feedback every 2 trials; Lissajous plot) - Rest Period (10 minutes) - Observe 24 trials (Alternating terminal feedback every 2 trials; Lissajous plot) <p>Day 2</p> <ul style="list-style-type: none"> - Observe 24 trials (Alternating terminal feedback every 2 trials; Lissajous plot) - Rest Period (10 minutes) - Observe 24 trials (Alternating terminal feedback every 2 trials; Lissajous plot) <p>Day 3</p> <p>Block 1 - Post-Practice of 0° (3 trials)</p> <p>Block 2 - Post-Practice of 180° (3 trials)</p> <p>Block 3 - Test 4 trials (no feedback)</p> <p>Block 4 - Test 8 trials (alt. terminal/concurrent fdb every 2 trials)</p> <p>Block 5 - Test 4 trials (no feedback, no template)</p> <p>Block 6 - Test 8 trials (alt. terminal/concurrent fdb every 2 trials, no template)</p>

Data Analysis

The x and z time series from the IREDs attached to the wooden styli were filtered (Butterworth, 10 Hz cutoff, dual pass) prior to computing any dependent measure. All dependent measures were computed with Matlab 7.0 (Mathworks, Inc.).

Continuous relative phase (Φ_C). The temporal coordination between the two hands was analyzed with a continuous relative phase (ϕ_c) measure. The x and z time series from the IREDs on the styli were used to compute a continuous tangential angle (θ_i) for motion around the traced circle for the left-arm and right-arm. The x-axis displacement trajectory of the stylus held in the left-arm was multiplied by -1 before computing the tangential angle. The x, z displacement trajectories were then mean centered for each circle pair in a trial and a three-point central difference algorithm was used to derive the continuous tangential angle for each hand for each circle-pair. The magnitude of the obtained vector corresponds to the instantaneous tangential velocity and the vector of the angle represents the tangential angle (Carson et al., 1997). The continuous phase measure is then just the signed difference in degrees between the tangential angle of the left-arm (θ_l) and right-arm (θ_r) circle trace, $\phi_c = \theta_r - \theta_l$. Circular statistics (Mardia, 1972) were applied to the individual ϕ_c values before computing the observed mean relative phase (ϕ_{obs}) (Burgess-Limerick, Abernethy, & Neal, 1991) and a measure circular variance (CV) for each trial. The mean relative phase for each practice trial was subtracted from the required relative phase (ϕ_{req}) of 90° to create a relative phase error score that was used to evaluate performance, $\phi_E = |\phi_{req} - \phi_{obs}|$.

Circular variance. Circular variance (CV) values range from 0 to 1, with 1 representing perfect uniformity (i.e., no variation) between oscillating components, and a uniformity value of 0 representing maximum dispersion (extensive variation). The CV is the inverse of the ordinary sample standard deviation (Carson et al., 1997; Peper et al., 2008) and characterizes the stability of the coordination patterns produced by the motion

of the two end-effectors, with larger CV values representing more stable coordination. The individual trial CV values were transformed (TCV) to the range 0 to ∞ as follows, $TCV = -2 \log_n (1 - CV)^{0.5}$, in order to submit the circular variance values to inferential tests based on standard normal theory (Mardia, 1972). The transformed circular variance values are reported in the text.

Movement amplitudes. The diameter of each individual circle produced by the left and right arms was computed to ascertain the spatial accuracy of the tracing motions. A peak picking routine located the points of maximal and minimal displacement in the x and z axes time series. These points were used to compute two, half-cycle circle diameters for x and z motion per cycle for each arm. The x and z half cycle circle diameters were averaged separately and the resulting means were used to compute an estimate of circle diameter $CD_H = ((x_{mn} + z_{mn}) / 2)$ for each hand. A spatial measure of the movement circle diameter was taken from the IREDS placed at the elbows as well. This was calculated by using the movement of each IRED in all three axis (x , y , and z) to find the relative distance from 0 using the Pythagorean Theorem where $Amp_E = \sqrt{(x^2 + y^2 + z^2)}$. The 1P perspective videos did not show a full, superior plane view of the model's shoulders while the 3P perspective videos did not consistently show the model's shoulders above the axillary region. Additionally, the verbal instruction provided the observers prior to observation directed the attention of the observers to the model's hands and emphasized a stationary trunk during performance. Therefore, information from the IREDS placed on the shoulders was not used in the study.

Statistics. The ANOVAs (SAS) used to analyze the practice, pre-practice and post-practice data sets each contain different factors and are reported in each section. Simple effects tests and post-hoc comparisons using Tukey's HSD test ($\alpha = 0.05$) were conducted when appropriate.

Model Results

Pre-Practice Performance

Relative phase. The pre-practice data of the two models was analyzed in a 2 group (instruction, discovery) x 3 pattern (0°, 180°, and 90°) ANOVA. As expected, a pattern effect for Φ_E was shown ($F_{(2,12)} = 706.56, p < 0.0001$). Post-hoc tests showed significantly greater Φ_E in the goal phase condition compared to the symmetric and asymmetric conditions (Fig. 5A). No other significant effects were found.

Analysis of the TCV data also showed a pattern effect ($F_{(2,12)} = 5.63, p < 0.05$; figure 5B). Post-hoc tests showed that TCV values from the goal phase trials were significantly smaller than the TCV values from the symmetric trials (Fig. 5B). Unlike the Φ_E , no differences in TCV were found between the asymmetric pattern trials and goal phase pattern. No other significant effects were found.

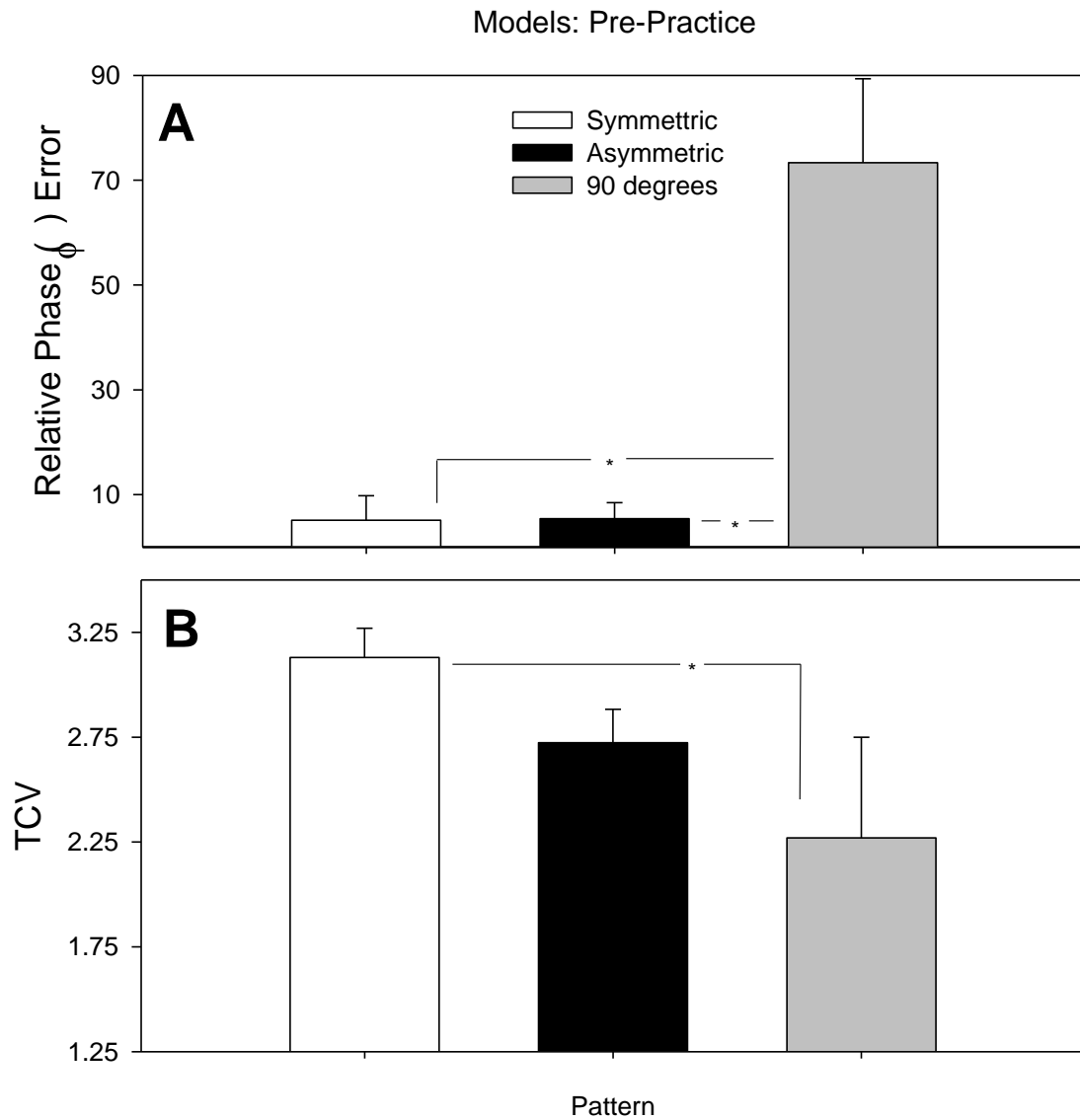


Figure 5. Models: Pre-Practice. **A**) Bar graph of the continuous relative phase error (Φ_E) of the models pre-practice performance. The “*” represents a significant difference between means. **B**) Bar graph of the models TCV data from the pre-practice session.

Movement amplitude. The CD_H and AMP_E data were analyzed in 2 group x 3 pattern x 2 arm ANOVAs with repeated measures on pattern and arm. The CD_H data showed a significant effect of group ($F_{(1,24)} = 6.57$, $p < 0.05$), pattern ($F_{(2,24)} = 4.37$, $p < 0.05$), arm ($F_{(1,24)} = 21.58$, $p < 0.001$), and group x arm ($F_{(1,24)} = 8.30$, $p < 0.05$). Post-hoc tests of the pattern effect showed no differences in CD_H between the symmetric ($CD_H = 9.69$ cm) and asymmetric ($CD_H = 9.37$ cm) conditions. There were also no differences between the asymmetric condition and the goal phase condition ($CD_H = 9.27$ cm). However, the CD_H of the symmetric pattern was significantly greater than the goal phase pattern. Tests of the group x arm interaction showed that the discovery model produced significantly larger tracing circle diameters with the left arm (mean = 10.04 cm) compared to the right arm (mean = 9.15 cm). The left arm of the discovery model (mean = 10.04 cm) produced significantly larger circle diameters than the left-arm of the instruction model (mean = 9.4 cm). No other significant effects were found.

The Amp_E data showed a significant effect of group ($F_{(1,24)} = 100.75$, $p < 0.0001$), pattern ($F_{(2,24)} = 7.45$, $p < 0.005$), arm ($F_{(1,24)} = 53.25$, $p < 0.001$), and pattern x arm ($F_{(1,24)} = 6.30$, $p < 0.005$). The discovery group had significantly greater elbow amplitudes ($Amp_E = 5.91$ cm) than the instruction group ($Amp_E = 4.82$ cm). Tests of the Amp_E data for the pattern x arm interaction showed that the left arm elbow diameter was significantly larger compared to right arm elbow diameter in both the goal phase (left $Amp_E = 5.98$ cm, right $Amp_E = 4.75$ cm) and asymmetric patterns (left $Amp_E = 5.54$ cm, right $Amp_E = 4.69$ cm). The Amp_E for the symmetric pattern did not differ between the

two arms (left $Amp_E = 5.77$ cm, right $Amp_E = 5.48$ cm). No other significant effects were found.

Practice

Acquisition performance: coordination and amplitude variables. The Φ_E , TCV, CD_H , and Amp_E data for both models changed significantly across the three practice sessions (Fig. 6). The data for the expert model does not show any change in performance characteristics across days or blocks. The data of the expert model was not included in the statistical analysis. The Φ_E and TCV data were analyzed in an ANOVA with group (I_{Mod} , D_{Mod}), block (B1 – B5), and day (1, 2, 3) as factors with repeated measures on day and block in order to examine the models' acquisition performance. For the Φ_E data, a group effect ($F_{(2,168)} = 24.29$, $p < 0.0001$), day effect ($F_{(2,168)} = 24.29$, $p < 0.0001$), block effect ($F_{(3,168)} = 10.98$, $p < 0.0001$), group x day effect ($F_{(2,168)} = 17.41$, $p < 0.0001$), and a group x block effect ($F_{(3,168)} = 2.93$, $p < 0.05$) was shown. Post-hoc tests of the group x day interaction found that Φ_E was larger in the discovery model ($\Phi_E = 57.69^\circ$) compared to the instruction model ($\Phi_E = 26.65^\circ$) only on day 1, and not days 2 and 3 (Fig. 6A). The discovery model showed a significant decrease in Φ_E during each day of practice (day1 = 57.69° , day2 = 24.37° , day3 = 10.41°). However, the instruction model only showed a significant reduction from day 1 ($\Phi_E = 26.65^\circ$) to day 2 ($\Phi_E = 17.07^\circ$). For the group x block effect, post-hoc tests showed a significant decrease in Φ_E from block 1 ($\Phi_E = 43.16^\circ$) to block 2 ($\Phi_E = 34.63^\circ$), and from blocks 2 and 3 to block 4 ($\Phi_E = 15.45^\circ$) for the discovery model. The instruction model only showed a reduction

in error from block 1 ($\Phi_E = 26.51^\circ$) to block 2 ($\Phi_E = 17.96^\circ$). The first three blocks of the discovery model ($\Phi_E = 43.16^\circ$, 34.63° , and 30.06°) were significantly greater than the first three blocks of the instruction model ($\Phi_E = 25.61^\circ$, 17.96° , and 15.57°). No other significant effects were found.

In the TCV analysis, a significant day effect ($F_{(2,168)} = 29.64$, $p < 0.0001$), day x block effect ($F_{(6,168)} = 3.63$, $p < 0.005$), and a group x day x block effect ($F_{(6,168)} = 2.74$, $p < 0.05$) were found. Post-hoc tests of the day x block effect showed a gradual increase in the TCV values through practice (day 1 = 2.24, day 2 = 2.39, day 3 = 2.66). The 3-way interaction occurred because the discovery model had an initial decrease in TCV values from block 1 to blocks block 2, 3, and 4 during the day 1 session (fig. 6B). In the day 2 session, the discovery model showed a significant increase in TCV across blocks. The discovery model showed no differences in TCV values on day 3. The TCV values of the instruction model increased significantly in sessions 2 and 3 compared to session 1. No other significant effects were found.

Movement amplitude. The CD_H and Amp_E data were analyzed in 2 group x 3 day x 2 arm ANOVAs with repeated measures on day and arm. In the CD_H data set, a group effect ($F_{(1,360)} = 37.63$, $p < 0.0001$), day effect ($F_{(2,360)} = 5.22$, $p < 0.005$), block effect ($F_{(3,360)} = 2.95$, $p < 0.05$), group x day effect ($F_{(2,360)} = 12.88$, $p < 0.0001$), and a day x block effect ($F_{(6,360)} = 3.09$, $p < 0.005$) were shown (Fig. 6C). Post-hoc tests of the group x day effect found that the discovery model produced larger tracings ($CD_H = 9.99$ cm) on day 1 than the instruction model ($CD_H = 9.35$ cm), with no differences on days 2 and 3. The instruction model showed no differences in CD_H as a function of day. Post-hoc

tests of the day x block effect showed that day 1 had significantly greater CD_H values in blocks two ($CD_H = 9.83$ cm) and three ($CD_H = 9.84$ cm) than in blocks one ($CD_H = 9.42$ cm) and four ($CD_H = 9.60$ cm). Days two and three did not differ from one another. No other significant differences were found.

In the Amp_E data set, a group effect ($F_{(1,360)} = 809.14$, $p < 0.0001$), day effect ($F_{(2,360)} = 21.82$, $p < 0.0001$), and group x day effect ($F_{(2,360)} = 7.5$, $p < 0.0005$) were shown. Post-hoc tests of the group x day effect found that the discovery model produced larger movement diameters ($Amp_E = 6.22$ cm) on day 1 than the instruction model ($Amp_E = 4.68$ cm), with no differences between the models on days 2 and 3. Both models showed a significant decrease in Amp_E between day one and day two however, the instruction model (day 1 = 4.68, day 2 = 4.46, day 3 = 4.59 cm) showed an increase from session two to session three that was not present in the discovery model (day 1 = 6.22, day 2 = 5.76, day 3 = 5.69 cm).

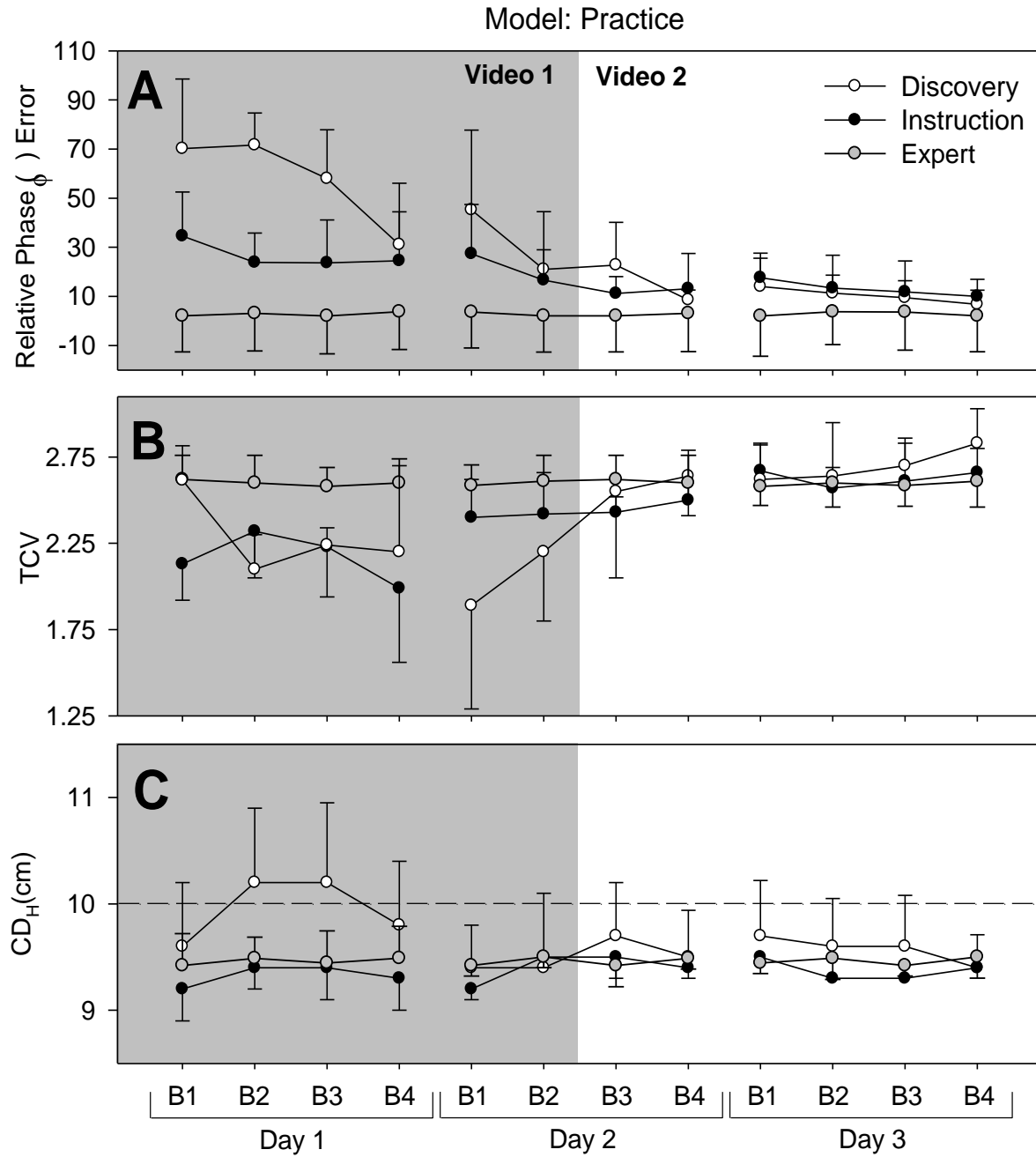


Figure 6. Models: Practice. The Φ_E (A), TCV (B), and CD_H (C) data are plotted as function of day and block for the discovery, instruction, and expert models. The error bars represent ± 1 standard deviation around the mean. The dashed line in C represents the required circle diameter of 10 cm. The labels video 1 and video 2 represent the demarcation of the three practice sessions in to the two videos that the observers watched on day 1 (video 1) and day 2 (video 2).

Acquisition performance: discovery process. As expected, the instruction model showed no signs of “searching” for a correct strategy. The instruction model used only the instructed rotation strategy (C:CC) and hand lead (right hand) during the three days of practice. However, throughout the first two days of practice the discovery model used three different rotation strategies (C:CC → 47 trials, CC:CC → 6, and C:C → 11 trials) (Fig.1). The discovery model did not use the CC:C rotation strategy at any point during practice. Data also showed that the discovery model changed rotation strategies from trial to trial twelve times on day 1 and four times on day 2 of practice. The discovery model also changed hand lead within seven trials (right lead to left lead) and changed movement rotation strategy within four trials. On day 3 of practice, the discovery model used only one direction strategy (C:CC) with a right-arm lead. These movement characteristics show that the discovery model was searching through a variety of strategies before selecting one strategy. These changes indicate a discovery processes in the current model that is consistent with discovery models in the Buchanan and Dean (in press) study.

Summary of Results

The models’ performance of the goal phase (90°) during pre-practice showed a significantly greater error compared to the asymmetric (180°) and symmetric (0°) patterns (fig. 5A). Analysis of the TCV data showed similar results, with the TCV values of the goal phase significantly less than the symmetric and asymmetric phases in pre-practice (Fig. 5B). Analysis of the model’s movement circle diameter showed no effects

across pattern (0° , 180° , or 90°) or group (instruction or discovery) in the pre-practice data but did show tracing circle diameters less than the template diameter of 10 cm in both hands. These pre-practice results demonstrate that the two individuals who served as models did not show any pre-practice differences regarding the symmetric and asymmetric patterns or any biases with regard to the required goal relative phase and required movement circle diameters.

The greatest difference in performance measures between the two models occurred within the first practice session, with the instruction model performing with smaller Φ_E , and slightly larger than required movement circle diameters compared to the discovery model. Coordination stability, however, seemed to be very similar for day 1 trials. Within the second session and throughout the third session the performance measures for the discovery and instructional model were not statistically different. The differences in the models performance would have been most notable in the first video session compared to the second video session, indicating that discovery observers viewed more trial-to-trial variability in their first session compared to the instruction observers. The expert observers viewed the least amount of trial-to-trial variability in both video sessions compared to the discovery and instruction observers (see fig. 6).

Observer Results

Pre-Practice Performance

Relative phase. An ANOVA with group (I_{Mod} , D_{Mod} , E_{Mod}), pattern (0° , 180° , 90°) and perspective (1P, 3P), as factors was run in order to examine the observers pre-

practice performance based on the Φ_E and TCV data. A significant difference in pattern was found in Φ_E ($F_{(2,84)} = 794.54$, $p < 0.0001$). Post-hoc tests showed significantly greater Φ_E in the goal phase condition compared to the symmetric and asymmetric conditions (fig. 7A). No other significant effects were found.

Analysis of the TCV data from the pre-practice trials for the observers showed a pattern effect ($F_{(2,84)} = 96.13$, $p < 0.0001$). Post-hoc tests showed that TCV values were significantly different between all three groups (goal phase TCV = 2.63, symmetric pattern TCV = 3.13, asymmetric pattern TCV = 2.87; fig. 7B). No other significant effects were found.

Movement amplitude. The CD_H and Amp_E data were analyzed in 3 group x 3 pattern x 2 perspective x 2 arm ANOVAs with repeated measures on pattern and arm. A pattern effect was shown in the CD_H data ($F_{(2,84)} = 17.28$, $p < 0.0001$). Post-hoc tests showed that all three patterns significantly differed from one another (Fig. 7C), with the largest tracing circle diameter in the goal phase pattern and the smallest tracing circle diameter in the symmetric pattern. No other significant effects were found.

A pattern effect was also shown in the Amp_E data ($F_{(2,84)} = 4.91$, $p < 0.05$). Here, the elbow diameter for the symmetric pattern ($Amp_E = 5.27$ cm) differed significantly from the other two patterns. The asymmetric ($Amp_E = 5.43$ cm) and goal phase patterns ($Amp_E = 5.46$ cm) did not differ. No other significant effects were found.

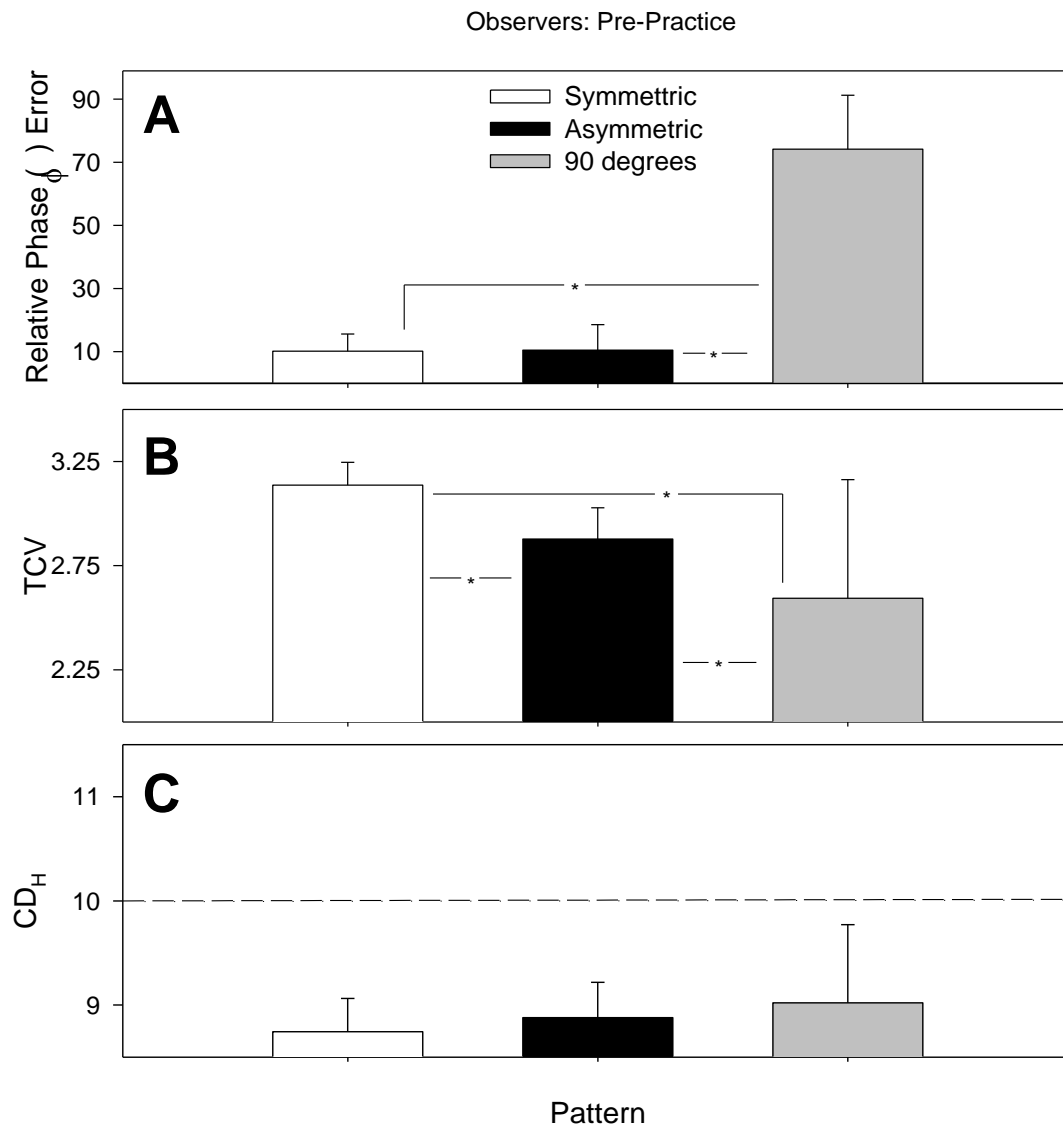


Figure 7. Observers: Pre-Practice. **A**) The bar graph displays the continuous relative phase error (Φ_E) in the observer's coordination performance before the video demonstration. **B**) The bar graph displays the TCV data representing the stability of the observer's coordination performance before the video demonstration. The * in each plot represent a significant difference between means. **C**) The observers CD_H data plotted as function of required coordination pattern. The error bars represent ± 1 standard deviation around the mean.

Pre-Practice versus Post-Practice: 0° and 180°

Relative phase. The first six trials in session three for the observers consisted of three trials of the symmetric pattern (0°) and three trials of the asymmetric pattern (180°). An ANOVA with group (I_{Obs} , D_{Obs} , E_{Obs}), pattern (0° and 180°), and day (1 and 3) as factors was run on the Φ_E and TCV data. Results of the Φ_E analysis showed a day effect ($F_{(1,21)} = 9.31$, $p < 0.01$), with a small reduction in error for both patterns from day 1 ($\Phi_E = 10.35^\circ$) to day 3 ($\Phi_E = 8.52^\circ$). No other significant effects were found.

The analysis of the TCV data showed a pattern effect ($F_{(1,21)} = 234.96$, $p < 0.0001$) and a day x pattern effect ($F_{(1,21)} = 6.45$, $p < 0.05$). Post-hoc test showed a significant difference between the symmetric pattern (TCV = 3.13) and the asymmetric pattern (TCV = 2.87) on day 1, however no differences were found between the two patterns on day 3 (symmetric pattern = 3.12, asymmetric pattern = 2.91). No other significant effects were found.

Movement amplitude. The CD_H and Amp_E data were analyzed in 3 group x 2 day x 2 perspective x 2 arm ANOVAs with repeated measures on day and arm. An analysis of CD_H showed a significant pattern effect ($F_{(1,21)} = 11.54$, $p < 0.005$) and day effect ($F_{(1,21)} = 10.23$, $p < 0.005$). CD_H was significantly greater in the asymmetric pattern ($CD_H = 8.92$ cm) compared to the symmetric pattern ($CD_H = 8.80$ cm). In addition, CD_H was significantly greater on day 3 ($CD_H = 8.89$ cm) compared to day 1 ($CD_H = 8.81$ cm). No other significant effects were found.

An analysis of Amp_E data showed effects of day ($F_{(1,21)} = 5.89$, $p < 0.05$), pattern ($F_{(1,21)} = 10.00$, $p < 0.005$), and group x day ($F_{(2,21)} = 5.51$, $p < 0.05$). The elbow diameter

in the symmetric pattern ($Amp_E = 5.32$ cm) was significantly less than the elbow diameter in the asymmetric pattern ($Amp_E = 5.46$ cm). Post-hoc tests of the group x day interaction showed a significant increase in elbow diameter from session 1 ($Amp_E = 5.27$ cm) to session 3 ($Amp_E = 5.51$ cm) in the discovery observers. The instruction and expert groups showed no differences between days. The instruction group showed a significantly larger Amp_E on day one (5.49 cm) compared to the expert (5.29 cm) and discovery ($Amp_E = 5.27$ cm) observers. On day 3, the expert group showed a significantly smaller Amp_E (5.29 cm) compared to the instruction (5.50 cm) and discovery (5.51 cm) observers. No other significant effects were found.

Pre-Practice versus Post-Practice: 90°

Following the 0° and 180° trials, the observers completed four trials in which they attempted to perform the goal relative phase (90°) without feedback. These trials represent the “retention” test since the observers attempt to perform the goal relative phase, post observational practice.

Relative phase. An ANOVA with group (I_{Obs} , D_{Obs} , E_{Obs}), day (1 and 3), and perspective (1P and 3P) as factors was run on the Φ_E and TCV data in order to compare the pre-practice trials of 90° to the last three 90° trials of the retention block. This allowed for an analysis of the impact of observational practice as a training protocol on performance. Results showed a group effect ($F_{(2,42)} = 6.83$, $p < 0.005$), day effect ($F_{(1,42)} = 86.27$, $p < 0.0001$), group x perspective effect ($F_{(2,42)} = 5.66$, $p < 0.01$), and group x day effect ($F_{(2,42)} = 5.59$, $p < 0.0005$). Post-hoc tests of the group x perspective

interaction showed a significantly greater error in the 1P discovery observers compared to the expert and instruction 1P observers (fig. 8A). In the 3P perspective, both the discovery and instruction observers showed greater Φ_E than the expert observers (fig. 8A). Results also showed that Φ_E for the 1P discovery group was larger than the 3P discovery group. The instruction group however, showed an opposite effect with greater error found in the 3P view compared to the 1P view. For the experts, differences in perspective did not emerge in the Φ_E data. Post-hoc tests of the group x day interaction found no significant difference in Φ_E between groups in the day 1 pre-practice trials (Fig. 8B). However, on day 3, all three groups differed from one another, with the discovery group showing the greatest Φ_E and the expert group showing the lowest Φ_E (Fig. 8B). Post-hoc tests of the group x day interaction showed that all three groups had a significant reduction in Φ_E from pre-practice to post-observational practice.

The analysis of the TCV data showed only an effect of day ($F_{(1,42)} = 6.39$, $p < 0.05$). Results showed a significant increase in the TCV data from day 1 (TCV = 2.43) to day 3 (TCV = 2.59). The analysis revealed no differences between the three groups in the TCV data, however it should be noted that the perspective x day interaction approached significance ($F_{(1,42)} = 4.01$, $p = 0.052$; fig. 8C). No other significant effects were found.

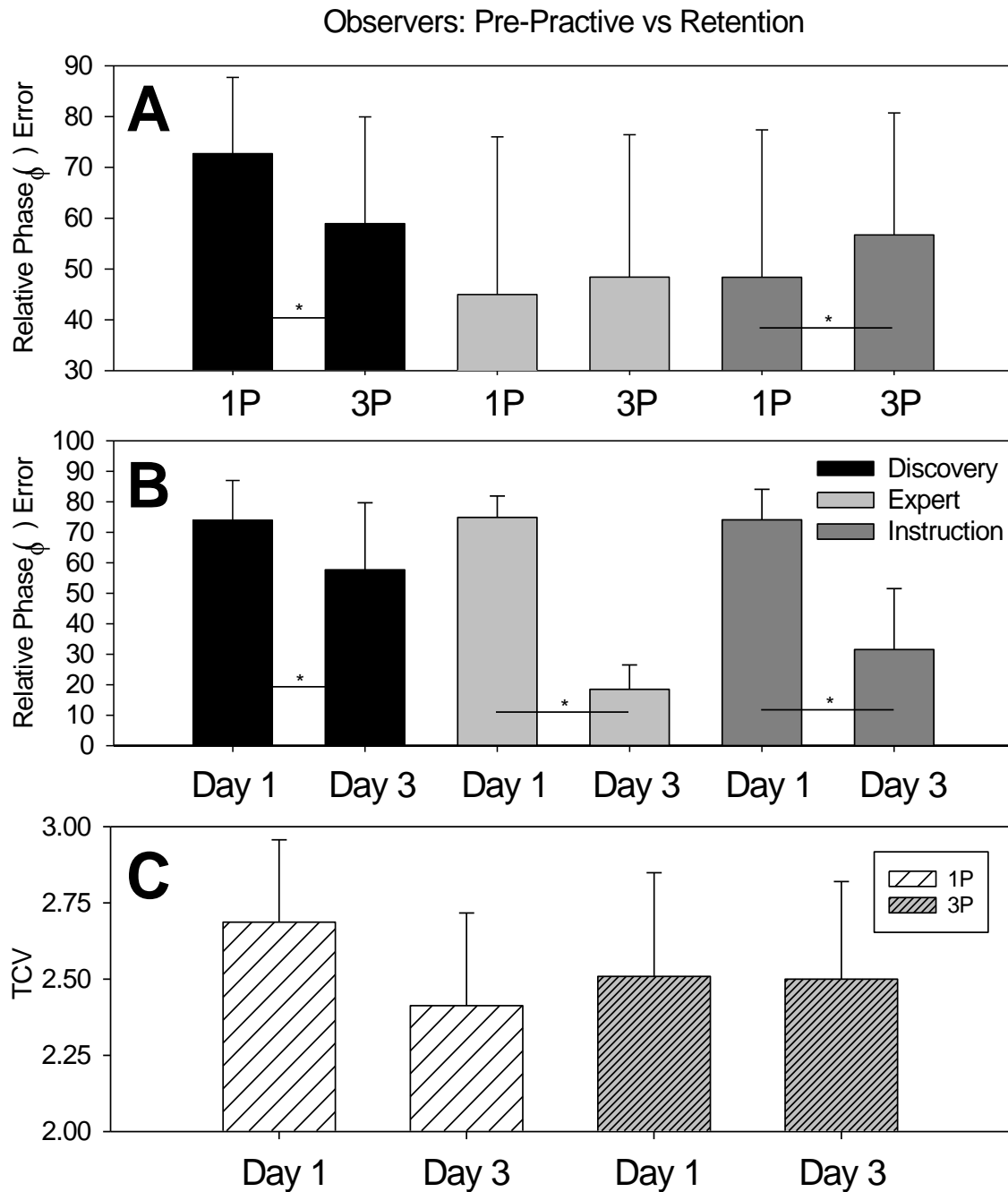


Figure 8. Observers: Pre-Practice vs Retention. Φ_E means representing performance in the pre-practice and post-observational retention trials plotted as a function of group and perspective in A), and a function of group and day in B. C) TCV values plotted as a function of day and viewing perspective. The asterisks represent significant differences between means.

Movement amplitude. For CD_H , results showed a significant day effect ($F_{(1,42)} = 4.37$, $p < 0.05$), with tracing circle diameter increasing from day 1 ($CD_H = 9.02$ cm) to day 3 ($CD_H = 9.20$ cm). No other significant effects were found.

Results of the Amp_E data showed an effect of group ($F_{(2,42)} = 3.90$, $p < 0.05$). Post-hoc tests showed a significantly greater elbow diameter in the instruction observer group ($Amp_E = 5.66$ cm) compared to the discovery and expert observer groups (Discovery $Amp_E = 5.36$ cm, Expert $Amp_E = 5.38$ cm). No other significant effects were found.

Retention Performance

Relative phase. An ANOVA of the relative phase data from the retention block trials alone, with group (I_{Mod} , D_{Mod} , E_{Mod}) and perspective (1P and 3P) as factors, showed a significant group effect ($F_{(2,174)} = 54.33$, $p < 0.001$) and group x perspective effect ($F_{(2,174)} = 13.76$, $p < 0.001$) in Φ_E . Post-hoc tests of the group x perspective interaction showed that the 1P and 3P perspectives differed in all three of the observer groups. For the instruction and expert groups, the 1P perspective yielded a lower Φ_E compared to the 3P perspective (fig. 9A). However, for the discovery group, the 3P perspective yielded the lowest error scores. The Φ_E scores from both the 1P and 3P perspectives of the expert observer group were significantly less than the error scores of the discovery observer group. In the 1P perspective, the discovery observer group differed significantly from the instruction group, and in the 3P perspective, the expert

observer group differed from the instruction observer group (Fig. 9A). No other significant effects were found.

Analysis of TCV in the retention block showed an effect of group ($F_{(2,174)} = 11.72$, $p < 0.001$) with the instruction and expert observer groups (Instruction TCV = 2.56, Expert TCV = 2.52) showing significantly greater TCV scores than the discovery observer group (TCV = 2.26).

Movement amplitude. The CD_H and Amp_E data were analyzed with a 3 group x 2 perspective x 2 arm ANOVAs with repeated measures on arm. The analysis of CD_H showed a significant group effect ($F_{(2,21)} = 4.53$, $p < 0.05$; fig. 9B), with each group significantly different from one another. No other significant effects were found.

Analysis of Amp_E data showed an effect of group ($F_{(2,42)} = 3.90$, $p < 0.05$), with the instruction group ($Amp_E = 5.66$ cm) oscillating the elbows with significantly greater diameter than the discovery group ($Amp_E = 5.36$ cm), with the expert group not different from the other two groups ($Amp_E = 5.34$ cm) . No other significant differences were found.

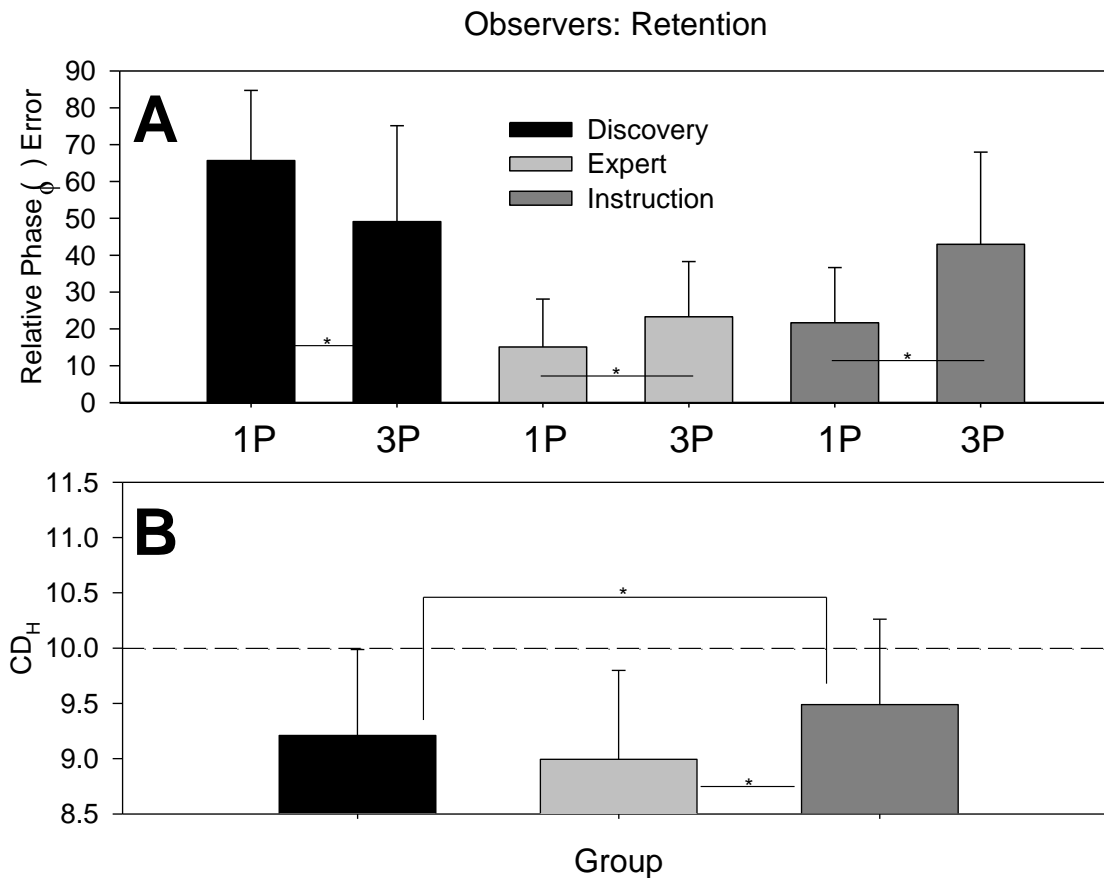


Figure 9. Retention. **A)** Φ_E values for the observers are plotted as a function of model and perspective.. **B)** Circle diameter plotted as a function of observer group.

Strategy selection. The tracing direction and predominant hand lead was recorded from each trial in the retention block. The expert model and instruction model videos portrayed a right-hand lead on every trial and the discovery model video portrayed a right-hand lead on every trial over the last half of the second video. The expert model and instruction model videos always portrayed a C:CC strategy and the discovery model video portrayed the C:CC strategy over the last half of the second video. Shown in Table

2 are the percentages of right-hand and left-hand leads as a function of observer group, and the percentage of trials performed with the C:CC as a function of observer group. Overall, the Instruction observers produced a higher number of trials with a right-hand lead in both the 1P and 3P conditions compared to the expert observers and discovery observers. Both the discovery observers and expert observers produced more left-hand leads in the 3P compared to the 1P conditions. Results showed that in the 1P condition, two participants that observed the expert video led with the left hand during all four retention trials, while the other six expert observers led with the right-hand. Seven of the eight participants in the 3P condition that observed the expert video, however, led with their left hand on all four retention trials. One participant in each of the other two 3P conditions (discovery and instruction) led with the left hand on all four retention trials. All expert observers and instruction observers rotated their hands in the same rotational direction as in the video (C:CC). In the 1P perspective, six of the eight discovery observers rotated their hands in the same direction as the model, and in the 3P condition, four of the eight discovery observers traced the circles in the same direction as the model.

Table 2. Observers: Direction/Lead Data. Percentage of hand leads and C:CC strategy usage as a function of observer group and viewing perspective for the four retention test trials.

1P	Hand lead		C:CC rotation strategy?	
	Left Lead	Right Lead	Yes	No
Discovery	25%	75%	75%	25%
Expert	25%	75%	100%	0%
Instruction	6%	94%	100%	0%

3P	Left Lead	Right Lead	Yes	No
	Discovery	47%	53%	50%
Expert	94%	6%	100%	0%
Instruction	28%	72%	100%	0%

Across Block Analysis

Following the retention trials, the observer attempted the goal relative phase pattern under three other conditions (blocks 4, 5, and 6, Table 2). Block 4 (physical practice) consisted of trials that provided the observers' with alternating concurrent and terminal feedback every two trials in the form of a Lissajous plot and circle template representing the relative phase and movement circle diameter parameters. Block 5 (circle diameter retention) removed the two circle templates representing the 10 cm circles traced in the previous trials without providing visual feedback of performance in the form of the Lissajous plot. Block 6 (circle diameter practice) consisted of trials with the two circle templates not presented, but the participants received visual feedback in the same manner as in block 4.

Relative phase. A 3 group x 2 perspective x 4 block analysis (ANOVA) was performed on the Φ_E and TCV data sets from blocks 3 through 6. For Φ_E , results showed a group effect ($F_{(2,39)} = 11.93, p < 0.0001$), block effect ($F_{(3,117)} = 3.79, p < 0.05$), and a significant group x block interaction $F_{(6,47)} = 2.50, p < 0.05$). Post-hoc tests of the group x block interaction showed rather elaborate results. The discovery observer group significantly differed from the expert and instruction observer group in all four blocks, and the expert observer group differed from the instruction observer group in all but the fourth block (physical practice with template) (Fig. 10A). For the discovery and instruction observer groups, Φ_E values decreased significantly from block three (retention) to block four with no difference between blocks 4, 5, and 6. For the expert observer group, the block means were not significantly different. No other significant effects were found.

A group effect in the TCV data set was shown ($F_{(2,39)} = 3.41, p < 0.05$) as well as a block effect ($F_{(3,117)} = 5.49, p < 0.005$) and a group x block interaction ($F_{(6,117)} = 2.20, p < 0.05$). Post-hoc tests of the group effect showed that each group significantly differed from one another (Fig. 10B). The fifth block (no template, no feedback) TCV values (TCV = 2.45) were significantly different from the fourth (TCV = 2.33) and sixth (TCV = 2.35) blocks. The TCV values of the retention block (TCV = 2.44) also differed from block 4. No other significant differences were found.

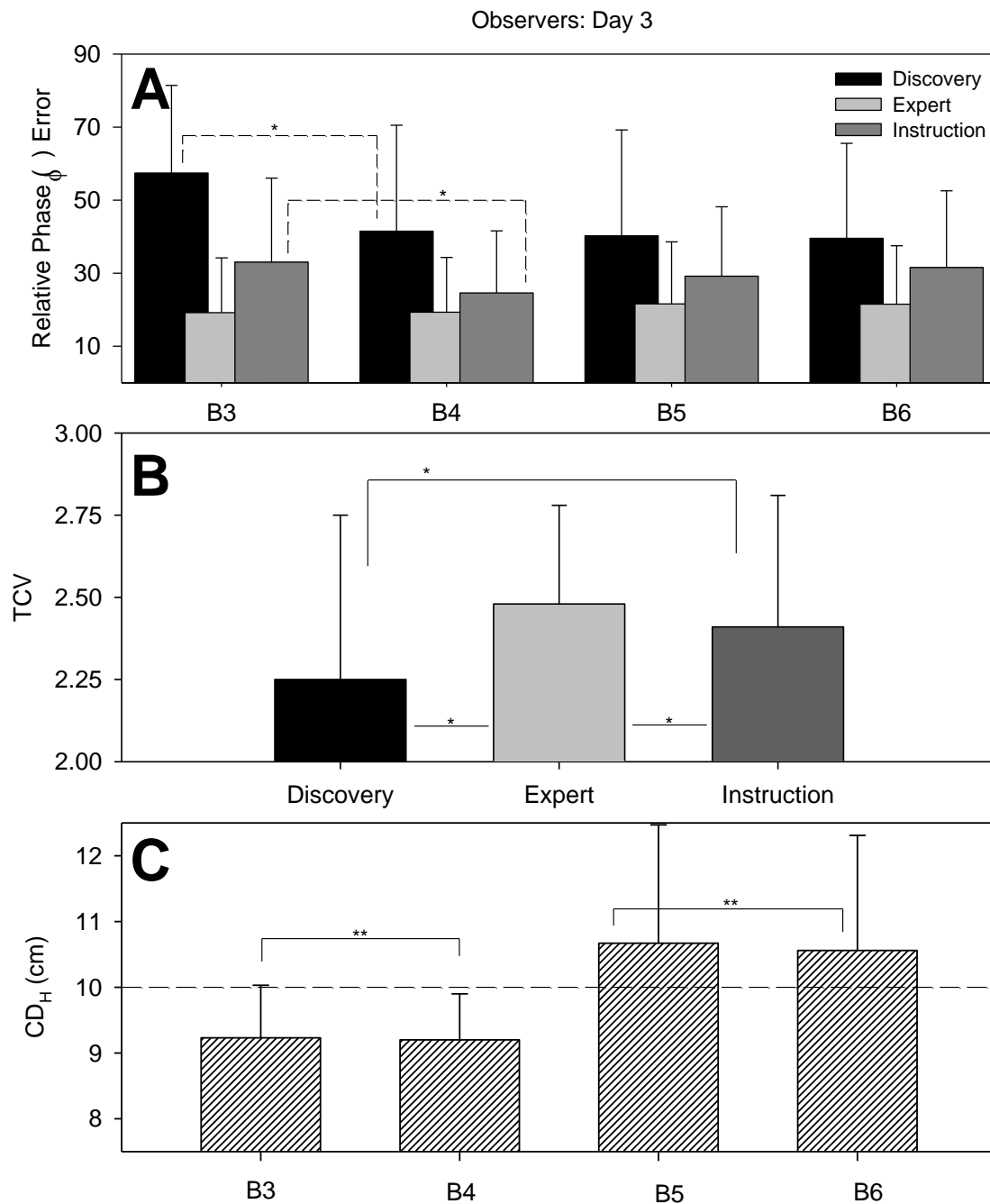


Figure 10. Observers: Block Analysis. **A**) Φ_E values for the observers plotted as a function of group and post-practice block. **B**) TCV data plotted as a function of observer group. **C**) Circle diameter plotted as a function of block with the circle templates removed in B5 and B6.

Movement amplitude. The CD_H and Amp_E data were analyzed in 3 group x 2 perspective x 4 block x 2 arm ANOVAs with repeated measures on block, and arm. A block effect of CD_H was shown ($F_{(3,117)} = 50.78$, $p < 0.0001$; fig. 10C), along with an arm effect ($F_{(1,39)} = 80.28$, $p < 0.01$) and block x arm interaction ($F_{(3,117)} = 9.53$, $p < 0.0001$). Results showed that the two blocks in which the two circle tracing templates were removed, blocks 5 and 6 had significantly larger CD_H values compared to blocks three and four with the circle templates present. No other significant differences were found.

Results of the Amp_E data also showed a block effect ($F_{(3,126)} = 16.28$, $p < 0.0001$) and arm effect ($F_{(1,117)} = 33.33$, $p < 0.0001$). Similar to CD_H , post-hoc tests showed that the two blocks in which the tracing template was removed ($B5$ - $Amp_E = 6.05$ cm; $B6$ - $Amp_E = 5.96$ cm) had significantly larger Amp_E values compared to the two blocks in which the movement template was available ($B3$ - $Amp_E = 5.50$ cm; $B4$ - $Amp_E = 5.51$ cm). The post-hoc tests also showed that the left elbow amplitude ($Amp_E = 5.99$ cm) was significantly greater than the right elbow amplitude ($Amp_E = 5.51$ cm). No other significant effects were found.

Summary of Results

Observers: pre-practice, retention, and practice. The goal coordination of 90° relative phase in pre-practice proved difficult for all observers, with attempts characterized by larger errors in relative phase compared to the asymmetric and symmetric coordination patterns. TCV values showed that the attempts at the goal

pattern were less stable than the attempts at asymmetric and symmetric coordination patterns. No significant differences emerged in circle diameter tracing across all groups; however, the tracing diameter mean was slightly less than the template diameter of 10 cm. These results of the observer pre-practice data show that the observers were equally capable of performing the 0° and 180° phase patterns (symmetric and asymmetric) and equally incapable of performing the goal phase prior to observation/practice. Unlike Hodges et al. (2005), participants did not show a detriment if performing the 180° pattern post-practice of the goal phase. In fact, observers showed a decrease in Φ_E from the day 1 pre-practice trials to the day 3 post-practice trials for the stable phases of 0° and 180° .

Overall, the observers of the expert videos showed the greatest learning. All of the participants who observed the expert videos performed with a relatively low mean relative phase error across all blocks. The observers of the instruction model showed significantly greater learning than those who observed the discovery model. Fourteen observers of the instruction model video performed an average under 45° in the retention block. Conversely, only three of the sixteen participants who watched the discovery video performed under 45° relative phase error in the retention trials. Unexpectedly, the viewing perspective affected the groups differently. For the discovery observers, Φ_E was lower in the 3P perspective. However, for the instruction and expert groups, the best performances occurred in the 1P perspective.

The expert observers showed no decrease in Φ_E as a function of block on day 3. Further, the instruction and discovery observers showed improved performance because

of the eight physical practice trials in block 4 on day 3. However, performance did not improve after block 4 on day three for any group. Both circle diameter measures did however, show an effect of template, as the two blocks in which the template was removed (blocks 5 and 6) resulted in larger diameter circles and larger elbow diameters. The TCV data values were lower for the discovery group across all blocks on day 3.

CHAPTER IV

GENERAL DISCUSSION

This study manipulated the variability in strategy selection and viewing perspective of a model to determine the degree to which these factors influenced the extraction of relative and absolute motion of the action by observers. Manipulation of the models' training protocol led to the development of two novice model videos and one expert model video. One model showed learning through discovery and attempted six of eight viable strategies for achieving the task goal. The video of this model had high trial-to-trial variability regarding strategies used during practice. Verbal instructions constrained the other novice model to practice a single strategy for achieving the goal. The video of this model had low trial-to-trial variability regarding strategies attempted during practice. The expert model consisted of the ten best trials of the verbal instruction model's practice sessions. Thus, the expert video had low trial-to-trial variability in performance as well as low within trial performance variability. For each model, an observer group watched the video of the model from either a first or third person perspective. Overall, trial-to-trial variability in strategy selection and viewing angle interacted significantly to influence the extraction of the relative motion features of the task, but not the absolute motion features.

Movement Features: Relative or Absolute

Scully and Newell (1985) suggested that relative motion features between a system's components can be picked-up through visual perception processes and then used to generate a motor action consistent with those relative features. Within the current study, the pre-practice and post-observational analysis showed that the relative phase relationship of 90° between the two hands (relative motion feature) was extracted (at least to some degree) by all observers. Observers that watched demonstrations with low trial-to-trial variability in strategy selection (expert and instruction videos) showed the greatest improvement in performance post-observation, while observers of a discovery model exhibiting high trial-to-trial strategy variability in 2/3 of the practice attempts showed the least amount of improvement in post-observation performance. Therefore, differences in the trial-to-trial variability in the models performance led to differences in the degree to which the relative motion feature (relative phase) of the bimanual task was extracted. After testing the performance on the goal relative phase of 90° in a retention block without feedback and allowing practice with feedback, the circle templates were removed. Results showed an increase in circle diameter tracing across all groups. This change in amplitude has two possible interpretations. First, an analysis of the absolute error found no difference between blocks with the templates present and blocks without the templates. This analysis suggests the possible extraction of the absolute feature. Second, an analysis of the actual diameters reveals a two cm difference between the trials with the templates and those without the templates. Without the templates, the observers produced larger than required circles, this suggests to some extent that the

absolute feature was not extracted since the models on average produced circles less than the required 10 cm.

Previous research has shown that observers adopt the coordination strategy (movement direction and hand lead) practiced by the model they observe (Buchanan et al. 2008; Buchanan and Dean, in press; Martens et al. 1976). The rotation direction strategy (feature) is an absolute motion feature. This is evident in the fact that the rotation direction of one hand (i.e. left hand moving clockwise) does not affect the direction (label) of the opposite hand. In other words, the labeling of one hand, with regard to direction, is not dependent upon the rotation direction of the other hand. In the current task, all of the observers that watched the expert and instruction videos consistently used the rotation strategy observed (C:CC). In the discovery condition, most of the observers consistently used the rotation strategy observed when the model settled onto the C:CC strategy during the day three practice session. The characteristic of hand lead in this task receives is labeled as a relative movement feature because the hand lead is dependent upon the relationship between the two hands. In other words, no matter what direction a hand might be rotating (i.e. left hand moving clockwise), the variable hand lead is only be defined by comparing the spatial feature (location on template) of one hand to the other hand. In the 3P perspective of the expert model, seven of the eight observers used a consistent left hand lead in retention, opposite of that observed. This is particularly interesting, as we had hypothesized the use of mental rotation by all those in the 3P perspective, an occurrence that would lead to the use of the same lead strategy observed. Why did seven of eight observers of the expert 3P video not extract the

relative movement feature of hand lead? It is possible that the lack of trial-to-trial variability in the strategy process prevented the observers from presuming that hand lead was important for success in the task. Therefore, when the observers linked perception to action, the 3P perspective allowed for what appeared to be a left hand lead. In other words, since hand lead never changed in the expert model and error (both in strategies used and relative phase error) was low, the observers of the 3P video did not use mental rotation to align the model's arm motions to their own first person perspective. This finding suggests that under certain circumstances viewing perspective influences the pick-up of some but not all relative movement features. In other words, mental rotation was not necessary to extract the relative phasing relationship within a low error demonstration context. The current findings support Scully and Newell's idea that demonstration as a training protocol makes available to the observer a variety of the important relative motion features of a task (relative phase), with viewing perspective interacting with the variability in the demonstration context (i.e. hand lead).

Model Mode: Discovery, Instruction, or Expert

Conclusions from research investigating the effects of model performance on observational learning are inconsistent to say the least. Some researchers have shown that observation of relatively poor performance by a model can hinder learning (Kay, 1951). Others have shown a benefit from observing novice performers (Vereijken & Whiting, 1990; Buchanan & Dean, in press; Pollock & Lee, 1992; McCullagh & Meyer, 1997). Recent research in observational learning has tended to agree largely with the

later finding, suggesting that the reduction in error seen in novice performers over time allows an observer to perceptually narrow attention processes or direct attention to the movement characteristics required for correct performance (e.g. Vereijken & Whiting, 1990; Mattar & Gribble, 2005; Pollock & Lee, 2002; Buchanan & Dean, in press). Interestingly, however, the present results suggest less than optimal learning when observing the discovery process. This less than optimal performance may have to do with the amount trial-to-trial variability in strategies viewed with regard to a reduction in error towards the target goal.

Of the three model conditions, observation of the expert video provided the least amount of between trial and within trial variability for observers. These results are somewhat unexpected, as the Buchanan and Dean (in press) study showed a benefit for a group of observers viewing discovery models with high between trial and within trial variability over that of an instruction model with low between trial and lower within trial variability. Why did the discovery models in the current task not have the same advantage as in the Buchanan and Dean (in press) study? This difference may reside in three key differences of the current study compared to the earlier study. First, the observers in the current task viewed 48 trials of terminal feedback, with no concurrent feedback of the models actions. This is vastly different from the Buchanan and Dean protocol in which the observers saw both concurrent and terminal feedback of the models performance. The lack of concurrent feedback in the present study may have reduced the amount of salient information passed to the observer, and with greater trial-to-trial variability in the demonstration protocol the loss constrained observational

processes. A second, and perhaps more viable, explanation of why observation of the expert model resulted in the greatest learning is attributed to the number of solutions viewed in the discovery video. The discovery model did not settle on a single direction strategy until day three, and did not settle on a consistent hand-lead until the end of practice session two. Therefore, unlike the expert and instruction observers who observed a consistent rotation strategy and hand-lead for the entire duration of observation, the observers of the discovery models viewed approximately 40 trials (less than half the total) in which the model used a consistent rotation direction and hand-lead strategy. Thus, this difference in observation of low between trial variability in practice attempts resulted in the benefit of the expert video for observation. If this is so, it explains the learning differences in relative phase between the discovery models as compared to the expert / instruction models. A third possible explanation for why the instruction observers in the present study did not show learning similar to those of the Buchanan and Dean study is the difference in instructions provided to the observers. The “instruction observers” in the Buchanan and Dean study were labeled so because they heard the model receive the explicit instructions laying out what strategy to practice with. However, the “instruction observers” in the present study did not receive any more, or less, verbal instruction than the discovery and expert observers. That is, they did not know that the model they viewed would only use a single strategy. What defined them as instruction observers is that they watched a model that received verbal instructions on a single strategy. The instruction observers did view slightly more variability in Φ_E than the expert observers did and significantly less Φ_E than the discovery group. Therefore,

the performance difference of the instruction observers, while not expected, has several possible explanations that open up several issues for future research.

Observer Perspective: 1P or 3P

No research, to the best of our knowledge, has examined the impact of viewer perspective relative to the model in the learning of a novel bimanual coordination pattern. We addressed this void by comparing a first-person perspective to a third-person perspective in a bimanual circle-tracing task. The results of other studies that are indirectly related to the present protocol have found contradicting results (Gentilucci, Daprati, & Gangitano, 1998; Grezes, Fonlupt, Bertenthal, Delon-Martin, Segebarth, & Decety, 2001). Maeda et al. (2002), for example, showed activity in difference brain regions based on the perspective angle of the observer to the model. Sebanz et al. (2003) found that reaction times to a single stimulus were faster when the reaction stimulus (hand) is spatially similar. However, Anquetila and Jeannerod (2007) showed no difference in estimated movement times in a motor imagery task comparing different viewing perspectives.

A review of the direction-rotation strategy data and hand lead data show a dramatic difference in lead preference based on which angle the expert model was viewed. All observers of the expert model traced the circles in the same direction strategy observed (C:CC). Six of the expert observers in the 1P condition traced the circles with the same hand lead strategy observed (right hand lead). However seven of the eight expert observers in the 3P condition traced the circle with a left hand lead. This

shows that although the perception of rotation direction was unaffected by observer perspective, the difference in perspective of the expert model did have an effect on hand lead perception. Why did these differences occur? It is possible that focusing on the extraction of the relative phase did not allow enough attention to be devoted to mental rotation. Another possibility is that the information present in relative phase is vulnerable to effects of the perspective angle at which the coordination is perceived. This idea makes sense, as a reduced angle of view can minimize the absolute features of a coordination task (i.e. movement amplitude), forcing the relative coordination to be more difficult to recognize. This could have been the case here, as the 3P perspective showed smaller amplitudes on the 2-dimensional plane (television screen) than did the 1P perspective. However, if this is the reason for the lack of lead extraction by those in the 3P perspective condition, how is the extraction of the relative phase information through observational processes explained? Is it possible that information embedded in hand lead is not as easily perceived under specific observational parameters (circumstances)? Future investigations need to explore further these issues.

Coordination Dynamics and Observational Learning

Some of the observer groups in the present study showed considerable ability to produce a coordination pattern of 90° relative phase between the two hands without considerable physical practice. This shows, theoretically, that observers are able to distinguish a 90° relative phase from the more stable relative phase states of 0° and 180° following observational practice. The observational learning that occurred in the present

study, when approached from a dynamical systems perspective, suggests that the observers were able to extract the information carried in the relative phasing between the models' limbs (Kelso, 1994). Furthermore, the observation allowed for the non-stable phase, or repeller, to be converted into an attractor over time. Why did the observers in the present study develop the most stable attractor via observation of an expert model? Why did Buchanan and Dean (in press) find that the development of a stable attractor via observation occurred to a greater extent when the model was performing in the discovery process?

Research has shown observation facilitates the learning of simple motor skills, while observation of multifaceted motor skills is less beneficial (Schmidt & Lee, 2005). Performing 90° relative phase coordination between two effectors has traditionally been categorized as a relatively difficult skill. Bingham and colleagues (Bingham et al. 1999; Zaal et al. 2000) found that participants were not capable of recognizing differences in the variability of a 90° relative phase, even though they could distinguish it as a unique pattern. After the authors noted that subjects in other studies failed to show the ability to produce unstable relative phases without practice (Kelso, 1995; Kelso et al, 1987), it was hypothesized that a person who cannot perceive a specific relative phase would fail in their attempts to produce that same phase.

Buchanan and Dean (in press) found that allowing an observer to receive the same specific verbal instructions as the model they watched led to relatively poor performance by the observer, results similar to those by Martens et al. (1976). When an observer was not provided specific instruction in this same paradigm, the discovery

model was found to serve as the best model. However, in the current study, a model provided with specific instruction proved superior to a discovery model for observational learning. One reason for this difference may be the difference in the protocol of the discovery models between the two studies. The discovery model of the Buchanan and Dean study was labeled so because he/she had not been provided specific instructions on how to perform the goal phase ($\Phi = 90^\circ$), forcing the model to physically search for the correct strategy. Therefore, the correlating observer also did not receive instruction. The observer had to recognize, or “pick-up”, on this search in an effort to learn the correct coordination. For each trial (60 trials over two days), feedback was provided either terminally or concurrently for both the model and observer. In the present study, more trials were provided to the observer (96 trials over three days); however, no concurrent feedback of the goal phase was provided. The discovery model of the present study did not settle on a single direction strategy (C:CC) until day two, meaning that the models had only one day of performance in which the models observed consistent direction performance. This may have forced too much variability within the model’s performance, resulting in limited learning. If this is true, then the trial-to-trial variability in strategy selection limited the amount of information that could be extracted during observation. It is plausible that observing many strategies made it more difficult to discriminate perceptually a single strategy required for production of the goal phase. Therefore, observation of the conditions in which a single strategy was consistently used (expert and instruction) allowed for discrimination of the required coordination. In other

words, the inconsistency in the models' performance hindered the ability of the observer to pick-up the information needed for effective reproduction of the task.

Mental Rotation and Mirror Neurons

Recent research involving brain-imaging studies has investigated the concept of mirror neurons (e.g. Iacoboni et al., 1999; Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2006). These neurons fire during the observation of a motor action and during the production of the same motor action. It has been suggested that during observation of hand movements (with intent to learn), observers will mentally rotate their own hand until it corresponds to the perspective of the observed hand (Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000; Gentilucci et al., 1998; Parson, 1987). However, our results suggest that mental rotation does not allow for all aspects of a movement to be "rotated". In fact, it may transfer only specific features of a movement. However, if this is true, what features need to be mentally rotated to benefit performance? Anquetil and Jeannerod (2007) showed that in a prehension paradigm, the 1P and 3P perspective share a common representation. However, Stevens (2005) used a motor imagery paradigm and showed more accurate movement time estimations by those in a 1P perspective. However, the task used by Stevens was a walking task. It is possible that the differences found between the two studies are a result of the differences in skills used (discrete vs. cyclical). These conclusions suggest that the role mirror neurons take in developing a motor representation from observation alone is largely dependent on the task itself. Therefore, the effectiveness of mental rotation (information

extracted from observation) is very much context dependent, with the contextual variable not only representing different tasks, but perhaps different perspectives of the same task, as in the present study. It is concluded that in the present study, the relative phase is picked-up by an observer as a relative motion in this bimanual demonstration context.

CHAPTER V

CONCLUSIONS

Summary

Regarding one of the original questions of what movement features are extracted during observational learning two primary conclusions can be made. First, in agreement with Scully and Newell's original hypothesis, the movement feature of relative phase can be extracted from observation. This is possible because the information embedded in relative phase when coordinating the limbs also allows for the perception and discrimination of different relative phases and differences in the stability of the in-phase coordination pattern (Bingham et al., 1999; Zaal et al., 2000; Kelso, 1994). A second conclusion regarding movement features in observation is that the absolute feature of circle diameter is not extracted easily through observation. This conclusion is made because all the models showed an increase in circle tracing diameter when the reference template was removed. Although not included in the original hypothesis of movement feature extraction, two other movement characteristics (hand lead and rotation direction) were analyzed. Data showed that the absolute feature of rotation direction was extracted by most observers, but not all. The extraction of the relative motion feature, hand-lead, was influenced by the 3P perspective when viewing the expert model. The results are explained in terms of how mental rotation may allow for transfer of specific types of information.

Another objective of the present study was to better understand how trial-to-trial variability in movement strategy affected observational learning. This was tested by

manipulating the performance level (mode) of the model, which the observers watched. The present results suggest that an expert model better serves as a basis from which to gather learning via observation. Thus, the increase in trial-to-trial variability concerning strategy selection in the discovery model may have prevented observers from extracting the key feature required for successful skill execution (90° relative coordination).

Another objective of the present study was to understand how viewing perspective (1P and 3P) interacted with the variables of feature extraction and model mode. Results showed that differences did arise based on perspective. We attempt to explain these results through aspects of mental rotation, but the definitive reason for these differences is unknown. The results provide justification for future studies addressing the importance of the role of viewpoint perspective and mental rotation in observational learning contexts.

In conclusion, the extent to which observational learning takes place in novice observers seems to be more dependent on the explicit information that the observer is given in relation to achieving the task goals. In other words, the cognitive representation of a task, as provided by verbal instruction, may significantly affect the amount of information that can be extracted from skill observation. Hence, the type and specificity of instructions provided to an observer prior to practice can significantly improve or inhibit learning. This is an important aspect of observational learning and practitioners should consider how different methods of informing a subject might affect learning. The present results, combined with those of Buchanan and Dean (in press), suggest that withholding cognitive aspects of a movement may allow for greater learning through

observation. Thus, issues related to information withholding require further investigated within observational learning paradigms.

Reflection

During my time as a graduate student at Texas A&M University, I have come to understand that the human motor system, and subsequently the human body, is unfathomably complex. So much so, that attempts to understand its dynamic tendencies, although necessary, seems an impossible and otherwise fruitless war. Additionally, the information in the field of motor neuroscience is just as dynamic as the motor system itself.

However, my attempt to explain motor actions through neural phenomenon has been enlightening in a less traditional way. I now have no doubt of the existence of a “greater intelligence”. Although stating such may seem radical, unjustified, or even conservative, there is nothing of which I am more certain. The idea that a complex and dynamic system like the human body could arise from mud, water, lightning, and a few million years seems laughable. I thank God for the time I have spent here. Not because of the diminutive prestige that comes with a doctorate, or the praise sometimes offered to graduates of Texas A&M University, or even the spiteful joy that comes from successfully exiting the gauntlet that is Motor Neuroscience, but because God has used this exhausting process to further show his infinite power, and more importantly, his undying love. We are not but creations of the only existing infinite wisdom, thus our many questions will be answered only when they matter not.

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VITA

Noah J. Dean, Ph.D.

Texas Lutheran University
 Department of Kinesiology
 Tschoepe 234
 Seguin, TX 77843
 Office: (979) 845-2857
 Fax: (979) 847-8987
 E-Mail: NDean@tlu.edu

EDUCATION

<u>Institution</u>	<u>Degree</u>	<u>Date</u>	<u>Area</u>
Texas A&M University	Ph.D.	2009	Motor Neuroscience
Angelo State University	M.S.	2005	Kinesiology
Angelo State University	B.S.	2003	Kinesiology

JOURNAL PUBLICATIONS

- 1) Buchanan, J. J. & Dean, N. J. (In Press). Specificity in practice benefits learning in novice models and variability in demonstration benefits observational practice pattern. *Psychological Research*.
- 2) Dean, N. J., Kovacs, A., & Shea, C. H. (2008). Transfer of movement sequences: Bigger is better. *Acta Psychologica*, 127, 355-368.
- 3) Buchanan, J. J. & Dean, N. J. (submitted). Assembling reciprocal aiming actions from different motor primitives: Transitions between units of action.