

THE EFFECT OF ENVIRONMENTAL CONTEXT ON PERFORMANCE OUTCOMES
AND MOVEMENT COORDINATION CHANGES DURING THE LEARNING OF
COMPLEX MOTOR SKILLS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Kinesiology

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May 2003

ACKNOWLEDGEMENTS

I would like to give thanks to my family who has supported me over the years as I continued my education instead of going out into the ‘real world.’ I would also like to thank my father for his assistance in editing the dissertation chapters. He did not quite understand everything, and I did not allow him much time, but he helped with what he could indicating where I needed additional reviewing. I would also like to give a special thanks to Carl for the support he has given me during the last few years, putting up with me in times of high stress and little sleep. Now that I will have some free time, I will have to come up with a new excuse as to why he should continue cooking dinner.

I would also like to thank Dr. Magill for sharing his knowledge and experience as I prepared for a career in academia. His assistance in developing a clear line a research, developing experimental protocols, and editing my papers throughout the years, has prepared me for a successful career. I would also like to thank Dr. Li for sharing some of his knowledge to increase my understanding and application of biomechanics. I would also like to thank Dr. Li for his time and brain power during our late afternoon and early morning meetings as I progressed through the stages of kinematic data reduction and analysis. I am also grateful for the comments, questions, and suggestions provided by my committee during the various stages during my journey to the ‘real world.’

PREFACE

This dissertation contains four chapters and five appendices. The format of this dissertation is to include two separate manuscripts, with one chapter emphasizing on the performance outcome results (chapter 2), and one chapter emphasizing the movement kinematics (chapter 3). The concluding chapter focuses on the implications on the learning processes when comparing both the outcomes and kinematics, as they relate to motor learning and coordination changes (chapter 4). More specifically, in chapter two the focus is on the outcome scores resulting from the three days of practicing a dart-throwing skill. This chapter looks at each of the four experiments separately identifying what changes occurred throughout practice within each environmental context. The task and attentional demands within each environmental context were compared to the performer outcome scores during training. This chapter concludes with a comparison of the four experiments. Chapter three focuses on the kinematic data measuring the changes in the movements that occurred throughout practice. The analyses focused on the behavior of each of the participants and how the changes in their movements related to the hypotheses that have been put forth in the literature and those given by myself. Chapter four synthesizes what was observed in both the kinematics and outcomes as they related to each other, and what was hypothesized to occur. In addition, emphasis was placed on providing explanations and implications for what was observed. These four chapters allowed for the experimental methods, data analysis, and observations to be discussed fully for a complete understanding of what was tested, what was observed, and what was concluded from the four dissertation experiments. The task used in each of the four experiments was a manipulation of the skill of dart throwing, and although the four tasks can be categorized in one of the four boxes, this is not a statistical based

identification. This grouping was based on the descriptions of the skill characteristics and so each manipulation of the environmental context was performed in a separate experiment. The appendix includes a literature review on movement coordination changes as a result of skill learning, the approval given prior to data collection from the Institutional Review Board for human research, the instructions read by each participant in their respective experiments, a link to the program (written using the Labview software and hardware) used to perform the four experiments, and the statistical results performed on the pilot data collected to test the reliability of the radial error outcome measure.

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ABSTRACT

Four experiments presented here investigated the task demand relationship of intertrial variability (IV) and regulatory conditions (RC), on the outcome and movement changes that occurred with dart throwing practice. The four tasks included: (1) a stationary target with one location (closed w/no IV), (2) a stationary target with five possible locations (closed w/IV), (3) a moving target with one movement pattern (open w/no IV), (4) a moving target with five possible movement patterns (open w/IV). After each throw, the X, Y coordinates of the dart and the target were recorded to calculate radial error (RE). Kinematics was recorded using an eight-camera motion system with markers on the upper body, throwing arm, and dart. Novice participants performed 160 throws on each of 3 days. Results for all four tasks indicated that the RE decreased significantly ($p < 0.05$) across trial blocks, at a different magnitude and rate for each task. The displacement patterns of the wrist, elbow, and shoulder indicated changes in movement coordination as novices practiced their respective tasks. During the three days of practice, learners became more consistent in the pattern used. The displacement at the elbow was significantly different from the shoulder and wrist for the two consistent tasks, while the variable tasks revealed the elbow and wrist to be similar. Analysis of the joint-linkage cross-correlations showed the elbow-wrist linkage to be significantly different from the elbow-shoulder and the shoulder-wrist linkages, for all four experiments. These observations suggested that the subject controlled the degrees of freedom at the shoulder, while the elbow and wrist remained linked throughout practice. Closer analysis of the magnitude of the changes indicated an inverse relationship between the movement coordination and outcome changes. Large changes in the movement pattern resulted in small

changes in the outcomes and vice versa. The results of these experiments provide evidence that environmental context (EC) affects how one performs, and what changes occur in the outcome scores and movement coordination, but the magnitude of these changes presents differing information regarding skill acquisition. Overall, the results indicated the amount of IV in the EC had the greatest effect on the performance.

CHAPTER 1. INTRODUCTION TO CHANGES IN PERFORMANCE OUTCOMES AND MOVEMENT COORDINATION PATTERNS DURING MOTOR SKILL LEARNING

Introduction

A majority of research studies in motor learning base the assessment of learning on performance outcomes without observing the coordination pattern of the movement produced. Performance outcomes provide information related to how close the performer came to the performance goal, measured by comparing the result of the skill performance with the outcome goal (i.e. the golf ball stopped 4 cm to the left of the hole). To assess the learning of a complex motor skill, it is important to compare the outcome of the learner's performance with the intended goal; however, this information is incomplete because it ignores the coordination changes that occur during the learning of the skill. Thus, for a more complete picture of motor skill learning, both the outcome of the movement and the coordination pattern of the movement should be assessed. Focusing on changes in the movement coordination produced over time provides information about how skills are learned at the movement level and the strategies the performer uses to learn the skills. Specifically, measuring the joint or segment angles of the coordination pattern of the movements used helps determine the relationships among all the joints involved and how these relationships change as the person acquires the skill. It is then critical to compare changes observed in the outcomes to those observed in the movements to assess completely how motor skills are learned and what variables affect this learning.

The Effect of Environmental Context on Skill Learning Performance

The environmental context of the skills being learned has been hypothesized to have an effect on both the performance outcomes and the movements used during skill acquisition.

Gentile (1972, 2000) proposed the environmental context as a combination of the regulatory conditions (stationary vs. in motion) and the absence or presence of intertrial variability (similarity of skill and/or environmental characteristics from one trial to the next). If the environmental context changes as the skill is performed, and this movement influences the movements used to perform the skill, then the regulatory conditions are considered “in motion,” and the skill is categorized as “open.” An example of an open skill would be catching a thrown ball or walking through a crowded hallway. In both situations the environmental context affects the movements used to perform the skill, because the movement of the ball directs where you go to catch the ball, and the people direct where you go so that you will not run into anyone. When the environmental context is stable, and does not change as the movement is performed, the regulatory conditions are labeled as “stationary,” and the skill is categorized as “closed.” An example of a closed skill would be walking in an empty room or shooting a free throw in basketball, because both skills can be initiated by the performer and the movements used are not influenced by the environmental context.

According to Gentile (1972), the second factor related to the environmental context is intertrial variability. This intertrial variability can either be absent or present over a series of trials, and is determined by the similarity of the skill characteristics from trial to trial. If the regulatory conditions (stationary vs. in motion) are the same every time the skill is performed and no other skill characteristics are changed, then there is no intertrial variability. However, if skill characteristics change from trial to trial, such as the distance walked, the weight of the ball, or the speed of the object, then intertrial variability is present. Changing the aspects of

the skill from one trial to the next is hypothesized to affect both the movements used to perform the skill and the outcome performance of the skill.

Gentile, Higgins, Miller, and Rosen (1975), developed a skill taxonomy representing how motor skills can be categorized into one of four categories based on the regulatory conditions in which the skill is performed and the absence or presence of intertrial variability (Table 1.1). By changing either the regulatory conditions or the absence or presence of intertrial variability the skill will fall in one of the four cells of the taxonomy. As the skills are classified from the upper left-hand corner to the lower right-hand corner of Table 1.1, skills become more complex and/or more difficult to perform. In the motor learning context, complexity is defined as the number of component parts of a skill, and not the difficulty of the skill (Magill, 2000). As more parts are added to the skill the complexity increases; however, the addition of components does not automatically make the skill more difficult. If the additional components of the skill also increase the attentional demands of the skill, the task is considered both more complex and more difficult.

If the skill components also involve specific timing characteristics to achieve the rhythm of the movement (i.e. the timing of the step, hop and jump in the triple jump), and/or the external timing of the movement is based on the action of the object (i.e. catching a moving object), the more complex skill also becomes a more difficult skill (Gentile, 2000). Both the presence of intertrial variability, and regulatory conditions in motion create an environmental context that is more complex than an environmental context with stationary regulatory conditions and no intertrial variability. The timing constraints of the skill to be learned place additional demands on the information processing and the timing of movement

initiation, resulting in a more difficult skill to perform successfully due to the increase on the attentional and task demands.

Table 1.1. A representation of the environmental context manipulations creating four skill conditions based on the regulatory conditions (stationary vs. in motion), and the absence or presence of intertrial variability (IV).

<i>Environmental Context</i>		<u>Intertrial</u>	<u>Variability</u>
		Absent (Consistent)	Present (Variable)
<u>Regulatory Conditions</u>	Stationary (Closed)	Closed task – w/ no IV	Closed task – w/ IV
	In Motion (Open)	Open task – w/ no IV	Open task – w/ IV

It has been hypothesized that the environmental context affects the movements used to perform the skill, and the outcome performance scores, during skill acquisition. During the learning of both closed and open skills, the absence or presence of intertrial variability affects: 1) the demands placed on the attentional processes, 2) how the movements are organized, and 3) how the skill is represented in memory (Gentile, 2000). When there is no intertrial variability the amount of information processing needed for movement preparation is minimal. The learner knows what is going to happen next so limited visual scanning of the environment usually provides enough information for the learner to be successful. With practice, a learner is able to attend to critical cues needed to perform the skill using a functional movement pattern. Once this movement pattern is learned, which successfully achieves the action-goal, limited effort is given to change the movement organization.

Instead, the performer refines the movement until a successful movement pattern is performed consistently, which has been referred to as 'fixation' (Gentile, 1972). Both the movement coordination and the outcome scores are observed to become consistent during practice of these skills due to the predictability of the skill and environmental context. Attentional demands are also decreased when intertrial variability is absent because the learner begins to 'automatically' produce the same movement based on the internal model developed in memory (Gentile, 2000).

On the other hand, when intertrial variability is introduced, demands on the attentional processes are increased, the movements must be organized to adapt to the unpredictable environmental context, and the memory representation of the skill must be flexible enough to adapt to the changing environmental context. This presence of intertrial variability in the environmental context increases the attentional demands because the learner is unaware of where the target may appear, the speed or trajectory of the object to be caught, or other changes in the skill characteristics. This intertrial variability results in the learner needing to continuously monitor the environment to detect the regulatory conditions affecting the skill performance, while identifying the non-regulatory conditions that should be ignored. With practice the learner is able to attend to critical cues needed to perform the skill in various situations.

As the learner focuses the attention on critical aspects of the skill, he or she is able to determine which movements result in the best outcome performance. When learning skills with intertrial variability a flexible movement pattern, which can adapt to the changing task characteristics and/or regulatory conditions, has to be learned to successfully achieve the variable action-goals. This unpredictable environmental context leads to changes in the

movement organization because the learner must adapt his or her movements to match the changing environmental context. This movement pattern adaptability has been referred to as ‘diversification’ (Gentile, 1972). The additional demands to the system increase the information processing occurring during skill acquisition of these skills, which increases the variability of their performance.

Changes in Coordination at Individual Joints during Learning

Coordination is the relationship of two or more joints, segments, limbs, etc. at any specific point in time, or how the joints are positioned in relation to one another, at an exact moment in time. With practice, changes in the coordination occur as the learner develops a more effective and efficient way of performing the skill. By comparing the movement patterns during different stages of skill acquisition, coordination is observed to change over time. This adaptation of specific components of the limbs, throughout the learning of a complex motor skill describes the changes in coordination observed in the present studies. When identifying the coordination patterns of a movement, it is critical to evaluate how coordination changes temporally. These changes in coordination provide information about how the movements are produced, which can then be related to the factors in the environmental context affecting these changes. As the learner determines how to perform a skill, changes in the coordination pattern occur. Identifying these coordination changes from one point in time to the next provides critical information concerning how the learner adapts movements to produce a skilled activity. Bernstein (1967), and others, (Gesell, 1929; Gentile 1972, 2000; Newell, 1985; and Kugler, Kelso, & Turvey, 1980) observed changes in coordination and provided hypotheses of the coordination changes that can be expected during the course of learning a complex motor skill. In addition, they have provided

descriptions of the changes in coordination associated with early and later stages of the learning process (Bernstein, 1967; Kugler, et al., 1980; Newell, 1985; & Gentile, 1972, 2000).

Changes in Coordination between Joints during Learning

These changes observed in the movement coordination during skill acquisition involve the “process of mastering redundant degrees of freedom of the moving organ,” (Bernstein, 1967, p.127). One of the reasons that skills, which involve changes in the movements used to achieve the action goal and/or timing constraints of the movements, are more difficult is because of the ‘degrees of freedom’ problem. This problem occurs during initial learning due to the difficulty in simultaneously controlling multiple, independently moving body parts (Schmidt & Lee, 1999). This problem of coordinating all the necessary body parts to successfully achieve the goal of a skill was first noted by Bernstein (1967) and was termed the “degrees of freedom problem.” Learners are observed “rigidly, spastically” (Bernstein, 1967, p. 108) fixing the number of joints or limbs involved when initially performing a skill to reduce the number of degrees of freedom. When a beginner initially performs a skill, he or she must “utilize all roundabout methods” (Bernstein, 1967, p. 107) before deciding which coordination pattern produces the best outcome. When first learning to kick a ball, knowing the correct timing of when to flex and extend the hip, knee, and ankle, and the correct range of motion to move each joint is difficult. To ‘solve’ this degrees of freedom problem the learner will ‘freeze’ his or her knee and ankle and only change the angle of the hip. This strategy of movement organization results in a straight leg kick, which is easier for the novice to perform, but does not allow the control of the movements needed for a skilled kick.

This “freezing” of degrees of freedom at the initial stages of learning is followed by an “unfreezing” of degrees of freedom toward the later stages of learning. These changes in the

relationship of the degrees of freedom used over time has been observed in a number of complex skills including sharp shooting, kicking, handwriting, basketball dribbling, and dart throwing (Arutyunyan, Gurfinkel, & Mirskii, 1968, 1969; Newell & van Emmerik, 1989; McDonald, van Emmerik, & Newell, 1989; Anderson & Sidaway, 1994; Broderick & Newell, 1999; Verijken, van Emmerik, Whiting, & Newell; 1992). During this progression of skill learning, the degrees of freedom are released gradually, allowing the learner to use and/or control more degrees of freedom as the skill level increases and the movement coordination changes. As the degrees of freedom are released, the performer is able to independently control the degrees of freedom used during the movement. For example, early in practice you may observe the performer trying to kick a ball ‘freezing’ their leg to move as one unit and only producing the movement from the hip joint. However, with practice the performer will begin to ‘release’ the degrees of freedom by moving the hip joint independently of the knee joint, and moving the knee joint independently of the ankle joint. These changes in the relationship of the degrees of freedom provide insight to how the performer changes his or her movement coordination during skill acquisition.

Directional Patterns of the Changes in Coordination

The direction in which degrees of freedom are released, and greater control is gained, is hypothesized to occur from the more proximal joints initially, to the more distal joints later in practice, as this has been observed for many skills. Gesell (1929) reported that as infants learn to grasp, the changes in coordination of the movement pattern occur in a proximal-to-distal trend. For instance, when reaching toward an object, the infant will produce the movement from the shoulder joint and push the arm forward. As the infant becomes more skilled in this movement, he or she will begin to utilize elbow and wrist joints to accomplish

the action. Eventually, the fingers themselves will be “freed” to reach and grasp. The proximal-to-distal strategy observed in the development of skills has also been observed during the skill acquisition of some skills. In dart throwing and handwriting, learners have been observed producing the arm movements from their shoulder early in practice, followed by an increase in wrist movement later in practice (McDonald, van Emmerik, & Newell, 1989; Newell and van Emmerik, 1989). However, this strategy has not been observed for all motor skills (Arutyunyan, Gurfinkel, & Mirskii, 1968, 1969; Broderick & Newell, 1999). In studies observing skilled and unskilled basketball players dribbling and sharpshooters shooting, the wrist joint was observed to be constrained or locked during the movement, while the movement variability was observed to occur at the shoulder joint. This strategy was interpreted by the authors to contradict the proximal to distal strategy. Had these findings been attributed to the constraints of the skills, the proximal to distal direction for the release of the degrees of freedom would have been supported. To successfully perform both the basketball dribbling and the sharpshooting, one must decrease the movement variability at the wrist joint to assure control of the ball or gun. The increased variability at the shoulder joint provides this control and stability at the wrist joint. If the task constraints had been taken into consideration, this change in the control of the joints and their relationship to each other would have indicated a proximal to distal direction for the control of the degrees of freedom.

Experiments

Four experiments were conducted in which the skill of dart throwing was practiced in four distinct environmental contexts. This allowed the researcher to observe the changes that occurred during the learning of the four tasks. The tasks practiced in each of the four

experiments were based on the taxonomy presented in Table 1.1, which categorizes skills based on their regulatory conditions and the absence or presence of intertrial variability (Gentile, et al., 1975). By manipulating the regulatory conditions and the amount of intertrial variability, the demands on the performer change. During the learning of a closed task with no intertrial variability, there are few demands placed on the learner both in the amount of attention needed to learn the task and the difficulty of the task itself. When the environmental context is such that the learner practices an open task with intertrial variability, the demands increase greatly both in the attention needed to learn the skill and the difficulty level for the performance of the skill. These effects were expected to be observed in both the movement pattern changes and the outcome performance scores during the three days of practice.

Outcome Performance

For each of the four tasks, the performance outcomes were measured by calculating the radial error between the dart and the target for every trial. This distance was calculated from the location of the dart on the dartboard to the center of the intended target. These radial error values were then averaged in blocks of 20 trials to assess both the magnitude of the performance improvements during the three days of practice, and the rate of these improvements. It was hypothesized that the participants would show a negatively accelerated curve during practice, due to the greater performance improvement initially, followed by a lesser rate of improvement and/or a plateau later in practice. This type of curve is typically observed of novices during skill learning. Both the rate of performance improvements and the variability (measured as within subject standard deviation) of the performance were used to test the effects of the environmental context on performance. The attentional demands of the task were hypothesized to affect the magnitude of the standard deviations as well as the slope

of the changes overtime. Greater attentional demands were expected to result in greater standard deviations during practice due to the increased difficulty of learning tasks with intertrial variability.

Movement Coordination Performance Changes

The movement coordination used to perform the tasks was assessed by calculating the joint angles (shoulder, elbow, and wrist) and the joint-linkages (Elbow-Wrist, Shoulder-Elbow, and Wrist-Shoulder) across time. The movement patterns were used to assess how the performers adapted their movements within each environmental context. The measurements at the joints allowed for the fixation and diversification predictions of Gentile (1972) to be tested by evaluating movement consistency, and movement adaptability. It was hypothesized that performance on the two tasks without intertrial variability would show a consistent movement pattern developing by the third day of training, while performance on the two tasks with intertrial variability would show a variable movement pattern at the end of practice to adapt to the changing target locations.

How the joint-linkages correlated with one another indicated to how the degrees of freedom were controlled as the movement was produced. In the four experiments, participants learning to throw the dart were expected to release their degrees of freedom during the three days of practice, resulting in greater control of the three joints of the arm. This release in degrees of freedom was expected to occur from the shoulder and move towards the elbow and wrist as the participants learned to throw the dart with greater control. A decrease in the range of motion at the shoulder would indicate increased control at this joint. An increase in range of motion at the wrist would also indicate greater control at this joint as the learners begin to use the wrist more in the throwing of the dart.

Questions investigated throughout the following three chapters include: What was the effect of the environmental context on the rate the learners improved their performance? What was the effect of the environmental context on the essential changes in the pattern of movements that occurred during the acquisition of a skill? What was the effect of the environmental context on the relationship between the movement and performance outcomes? Collecting both outcome scores, by measuring where the dart lands in relation to the target position, and kinematics of the upper body, by measuring the movement coordination of the shoulder, elbow, and wrist, allowed these questions to be answered.

The following two chapters address the hypotheses and concepts for the outcome and kinematic data individually. Each chapter identifies how the environmental context was changed for each experiment and how those changes affected the learners' performance. Chapter 4 provides a general conclusion of how the outcomes and kinematics related to each other and how these findings enhance our current knowledge of motor learning, including how these findings will direct future research.

CHAPTER 2. EFFECT OF ENVIRONMENTAL CONTEXT ON LEARNING DART THROWING TASKS

Introduction

Researchers have identified skills based on their environmental context and skill characteristics and classified the skills using both one-dimensional continua (e.g. discrete vs. continuous, gross vs. fine, closed vs. open) and two-dimensional taxonomies. Once the skills are classified, researchers can predict which skills may be more difficult to learn or perform due to the muscular power, endurance, or control, and/or mental ability needed for the learning of these skills. What is unknown about these continua and taxonomies is whether performance during skill learning follows the predictions based on these classifications.

Gentile has been at the forefront classifying skills based on their environmental context using two-dimensional taxonomies (Gentile, 1972; 2000). One-dimension of the environmental context is based on the regulatory conditions during practice, while the second dimension is based on whether these conditions change from one attempt to the next (Gentile, 2000). Regulatory conditions are those features in the environment affecting how the performer moves to achieve the action goal (e.g. distance to target, speed of a ball in motion, size of a cup, etc.), while non-regulatory conditions are those environmental features in the background, which may distract the learner (e.g. color of the ball, crowd noise, etc.), but do not directly affect the movements used to achieve the action goal. When the regulatory conditions are stationary, and do not change as the skill is performed, the environmental context is labeled as “stationary” and the skill is categorized as “closed.” An example of this would be walking in an empty room or shooting a free throw in basketball. The performer has the flexibility to decide when to begin the movement in this situation. However, in

certain instances the environmental context determines when and how the performer must initiate and/or perform the skill. This occurs when the regulatory conditions are “in motion” as the skill is performed. In this situation the skill is categorized as “open.” When performing an open skill the changing environmental context influences the performer and influences how and when the skill is performed. An example of this would be catching a thrown ball or walking through a crowded hallway. In both situations, the environmental context (moving ball or people) affects the skill performance because the ball directs where the person must go to catch the ball, and the people direct where not to go so you will not run into anyone.

According to Gentile (2000), skills can be categorized into one of four distinct categories based on the environmental context in which the skill is performed, open versus closed, and the absence or presence of intertrial variability (see Table 2.1). The absence or presence of intertrial variability is determined from the similarity of the regulatory conditions from trial to trial. If the regulatory conditions (closed vs. open) remain the same every time the skill is performed, and no other skill characteristics are adapted (e.g. location, size, or speed of an object), then there is no intertrial variability. However, if skill characteristics change from trial to trial such as the distance walked, the weight of the ball, the speed of the object, then there is intertrial variability, because aspects of the skill are changed from one trial to the next. When no intertrial variability is present the environmental context is consistent, while the presence of intertrial variability generates a variable environmental context. Table 2.1 provides a representation of the four categories classifying the skills in a two-dimensional format; however, these four classifications have also been placed along the skill continuum of closed to open skills based on their environmental context (Magill, 2000).

Table 2.1. A representation of the four skill conditions based on environmental context (closed vs. open) and the absence or presence of intertrial variability (IV).

<i>Environmental Context</i>		<u>Intertrial</u>	<u>Variability</u>
		Absent (Consistent)	Present (Variable)
<u>Regulatory</u>	Stationary (Closed)	Closed task – w/ no IV	Closed task – w/ IV
	In Motion (Open)	Open task – w/ no IV	Open task – w/ IV

Stationary w/ No IV	Stationary w/ IV	In motion w/ No IV	In Motion w/ IV
Consistent environmental context	Variable environmental context	Consistent environmental context	Variable environmental context

Figure 2.1. Representation of the four components on a skill continuum systematically based on their environmental context (stationary or in motion, with or without intertrial variability (IV).)

The skills are placed along the continuum systematically as they progress from completely closed to completely open (Figure 2.1). As the skill continuum progresses from closed to open, the skills become more complex and more difficult to learn and perform. This increase in difficulty is due to the demands placed on the motor control system, throughout the movement selection process and the execution of the movement.

During the learning of both closed and open skills, the absence or presence of intertrial variability affects: 1) the demands placed on the attentional processes, 2) how the movement is organized, and 3) how it is represented in memory (Gentile, 2000). When there is no intertrial variability the amount of information processing needed for movement preparation is minimal. The learner knows what is going to happen next so limited visual scanning of the environment usually provides enough information for the learner to be successful. Once a movement pattern is learned, which successfully achieves the action-goal, limited effort is given to change the movement organization. Instead, the performer refines the movement until a successful movement pattern is performed consistently, which has been referred to as fixation (Gentile, 1972). Attentional demands are also decreased when intertrial variability is absent and the learner begins to ‘automatically’ produce the same movement.

The decreases in information processing, movement organization and attentional processes observed when intertrial variability is absent, increase when intertrial variability is introduced. The variability of the environmental context increases the attentional demands because the learner is unaware of where the target may appear, the speed or trajectory of the object to be caught, or other changes in the skill. This intertrial variability results in the learner continuously monitoring the environment to detect the regulatory conditions, while identifying the non-regulatory conditions to ignore. The intertrial variability in the

environmental context also leads to changes in the movement organization because the learner must adapt his or her movements to match the environmental context. This increase in the complexity of the skill to be learned places additional demands on information processing and results in a more difficult task to be learned. Both the presence of intertrial variability and regulatory conditions in motion increase the skill complexity (Gentile, 1972; 2000).

Skills performed in a closed environmental context assert limited demands on the performer with respect to the onset, duration, and offset of the movements; however, those skills performed in an open environment are controlled temporally and spatially by the regulatory conditions (Gentile, 1972). The timing and spatial location of the movement is determined by the environment, not the learner, during the execution of an open skill. This single-handedly creates a more difficult skill for the learner to perform. However, not only is the timing of the object or moving environmental context a factor, but also the timing delays inherent in the internal processing and execution by the performer (Gentile, 2000). The performer must factor these delays into the timing of the initiation and speed of the movement as the skill is performed. When learning how to successfully intersect with moving objects, the movement must be organized based on both extrinsic and intrinsic information. What has to be learned is where to direct attention to receive crucial information based on the trajectory and path of the environmental context or object acted upon as the skill is performed. The learners must also discern the non-regulatory conditions from the regulatory, and begin to direct their attention to those essential features that will ultimately guide them to perform the action-goal successfully and consistently. The environmental context of the skill will ultimately determine how the movements must conform for success.

The present experiments observed the performance curves of novices learning the skill of dart throwing in four different environmental contexts. The skill performance of novices learning dart throwing during practice was then compared to the environmental context in which the learner trained. This comparison was used to observe whether the outcomes provided the same distinction as the conceptual classification. If the stability and/or variability of the environmental context affected how the learners performed, the outcome scores would show the same systematic progression as the skill continuum predicts. Overall, the results of the four tasks were not as clear as the continua and taxonomies predict; however, some of the predictions were supported.

The tasks learned in the four experiments in the present study were each based on one cell from the 2 X 2 skill matrix in Figure 2.1. The experiments individually investigated open and closed skills, both with and without the addition of intertrial variability. The first experiment tested the learning of a closed task with no intertrial variability. Here the participants practiced throwing darts at a stationary target, which was projected in the center of the dartboard for each trial (closed task with no intertrial variability). For the second experiment, participants practiced a closed task, with intertrial variability. The stationary target was randomly projected in one of five locations on the dartboard for each trial (closed task with intertrial variability). For the last two experiments the target was moving at a constant speed (0.05 Hz) as the participant attempted to land the dart within the target circle. For Experiment 3, the target appeared on the left-hand side of the dartboard, moved horizontally across the board to the far right side, and reversed direction until it returned to its starting location. The pattern of movement was the same for each trial providing an environmental context that was in motion with no intertrial variability (open task with no

intertrial variability). For the fourth experiment, the learners practiced hitting a moving target, which randomly appeared in one of five locations and moved across the board and back to its starting location in a linear pattern (open task with intertrial variability).

To assess how the participants were performing during the practice trials for their respective tasks, a radial error score was calculated for every trial. This radial error score was calculated as the hypotenuse between the dart and the intended target. Within each experiment it was hypothesized that the amount of error would decrease with practice as the participants learned to hit the target with the dart. This decrease in the radial error should follow a negatively accelerated curve pattern, which is typically observed in skill learning of novices. The size of the error and the slope of the curves were hypothesized to differ for each task, based on the environmental context in which the learners trained and the demands on the motor control system each task required. The error was hypothesized to be smaller for the closed tasks than the open tasks. In the two open tasks, the expected result was larger and more variable radial error scores, due to the difficulty in hitting a moving target and the changing environmental context. The performance scores should decrease quicker for the two consistent tasks (no intertrial variability) when compared to the results of the two variable tasks (with intertrial variability). It was also hypothesized that the slopes of the two consistent tasks would have similar slopes to each other, as would the two variable tasks; however, these two slope patterns would be different from each other. This was hypothesized because the rate of learning should be easier for the consistent tasks because there are less attentional demands on the learners, compared to the variable tasks.

The within-subject variability was calculated using the standard deviation of the radial error across the blocks of 20 trials. It was hypothesized that there would be high variability

observed in the standard deviation scores early in practice; however, this variability would decrease over the three days as the participants became more consistent in their throws. The two consistent tasks (no intertrial variability) were hypothesized to have smaller standard deviations that decreased with practice due to the low attention demands of these tasks. The two variable tasks (with intertrial variability) were hypothesized to have larger standard deviations that decreased later in practice due to the high attention demands in these tasks. The within-subject variability was also expected to be smaller for the closed tasks when compared to the open tasks. This expectation was because it is harder to hit a moving target than a stationary target. The outcome scores were expected to show a clear distinction based on their environmental contexts. The participants learning the closed task with no intertrial variability should have the smallest errors, those learning the closed task with intertrial variability would have slightly larger errors, followed by an increase in the errors from those in the open task with no intertrial variability, while the participants in the open task with intertrial variability should have the largest errors. Table 2.2 presents the demands of each task and the hypothesized results of the performance outcomes. The four experiments were performed to test the effects of the environmental context on the performance outcomes during the three days of practice.

Experiment 1 - Closed (Closed Task with no Intertrial Variability)

The dart throwing task was performed in a completely closed environment. The target appeared in the middle of the dartboard and remained stationary as the learner threw the dart. These conditions were the same for every trial indicating no intertrial variability was present in this experiment. This environmental context provided low task demands because the target

was stationary and low attention demands because the target appeared in the same location each trial. It was hypothesized that the participants would start out with small radial errors,

Table 2.2. Representation of the demands of each task and the expected results for each of the four experimental tasks, based on the changes in the Radial Error (RE).

	Environmental demands = expected changes in RE	Environmental demands = expected changes in RE	
<p>Closed Task with no IV →</p>	<p>Low task demands = small mean radial error</p> <p>Low attention demands = consistent standard deviation scores</p>	<p>Low task demands = small mean radial errors</p> <p>High attention demands = variable standard deviation scores</p>	<p>Closed Task with IV ←</p>
<p>Open Task with no IV →</p>	<p>High task demands = large mean radial errors</p> <p>Low attention demands = consistent standard deviation scores</p>	<p>High task demands = large mean radial errors</p> <p>High attention demands = variable standard deviation scores</p>	<p>Open Task with IV ←</p>

which would decrease during the three days of practice. The greatest decrease in error was hypothesized to occur on day one and by day three, the errors should stabilize due to the low task demands. This trend would be consistent with the power law of practice stating larger amounts of improvement are observed early in practice, followed by a slowing in the rate of change later in practice. This trend would also be consistent with the negatively accelerated curve typically observed of novices during skill learning (Magill, 2000). Because of the low attentional demands of the task, it was also hypothesized that the standard deviations of the radial error scores would decrease over time as the participants became consistent in their outcome scores.

Method

Participants

Eight volunteers participated in this experiment. Participants (7 females and 1 male with a mean age of 22.57 years) were recruited from undergraduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The dartboard was made of a 1.22 X 1.22 m sheet of insulation Styrofoam suspended from the ceiling. A wooden bookcase was placed with its back against the back of the dartboard to stabilize the board after each throw, minimizing the sway of the target for each trial. An X Y grid was printed in centimeters on a 0.91 m X 1.22 m sheet of white bond paper with coordinate (0,0) in the center of a paper. The paper was then centered on the Styrofoam

and the grid was used to calibrate the target location prior to data collection and to measure the X, Y coordinates of the dart's location after each throw. The target was a red circle (14½ cm in diameter) projected to the dartboard, with the bull's-eye placed at coordinate (0,0) for each trial (Figure 2.2). The target appeared using a program (written in Labview, see Appendix D) projected through a projector (Infocus) onto the target board. The participant stood 3 m from the board and just to the right of the projector (Figure 2.3).

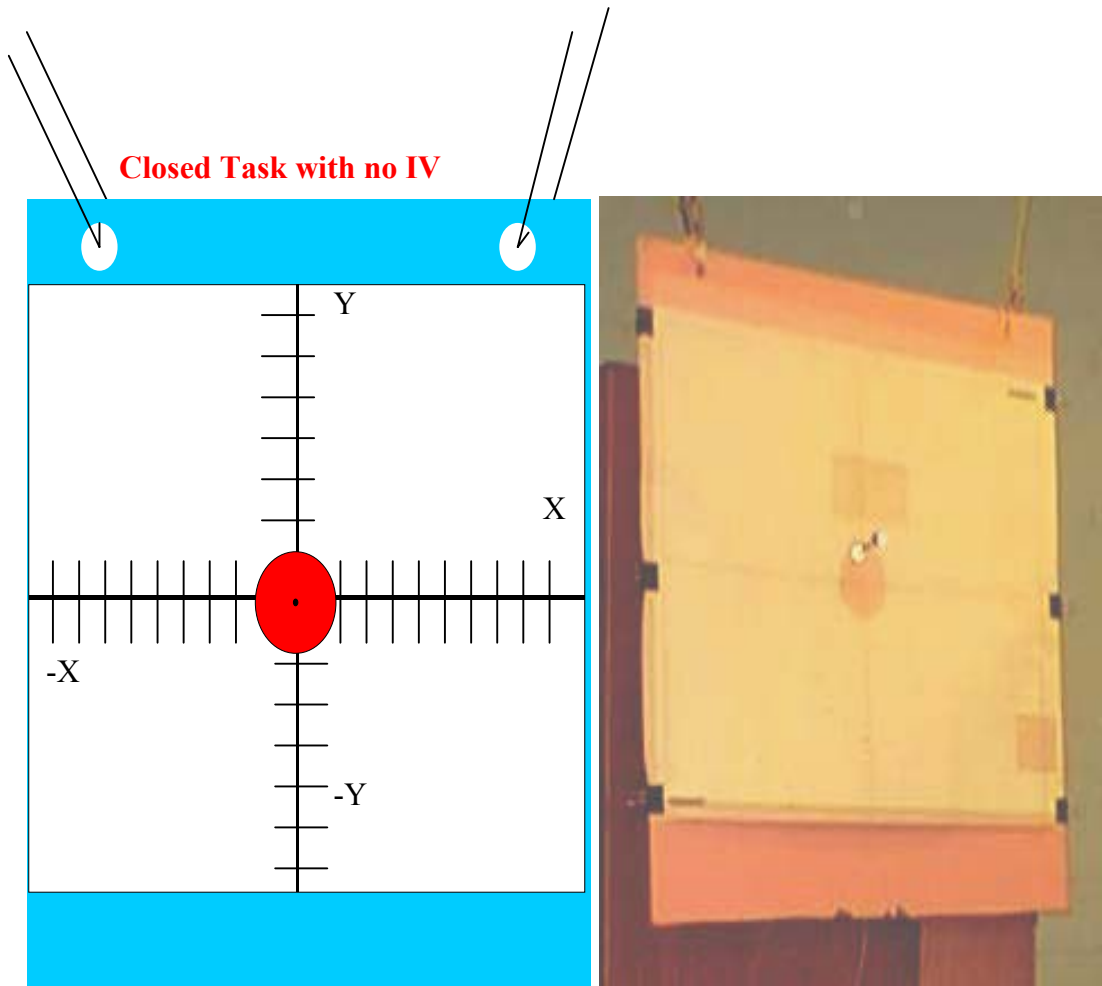


Figure 2.2. Diagram (left) and photograph (right) of target and board, suspended from the ceiling.

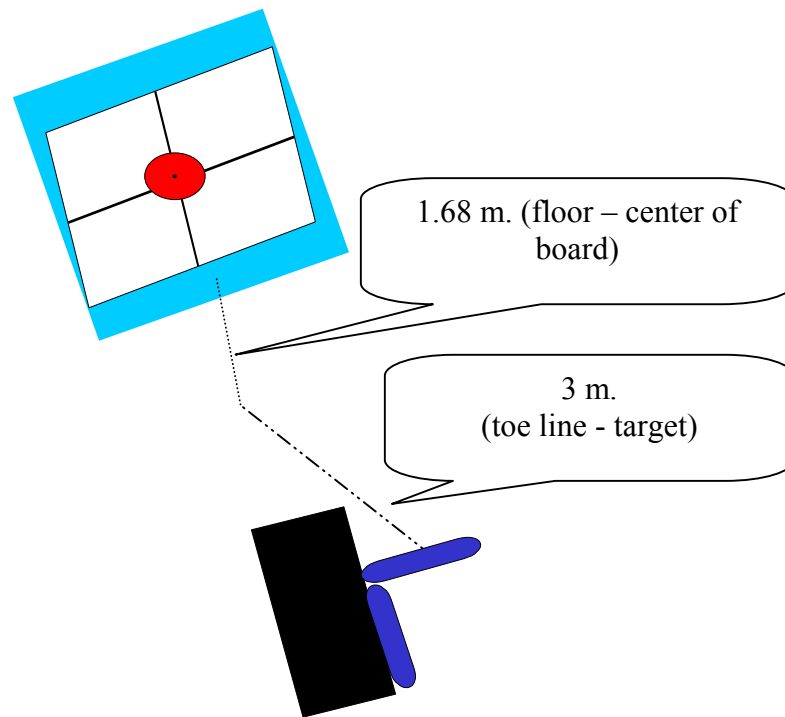


Figure 2.3. Diagram of the projector stand and location of the toe line and dartboard.

Procedure

After reading the written instructions, the participant was shown the target projected on the dartboard as an indication of the size of the target, and data collection began if there were no questions. For each throw, participants started with their throwing arm at a 90° angle prior to the target being presented. They were told to begin their throw soon after the target appeared on the dartboard. After the throw, the participant walked to the dartboard, measured the X, Y coordinates of the dart using the preprinted coordinate grid on the dartboard, and read aloud the X, Y position of the dart to the experimenter, who manually recorded these values into the computer.

The participant then removed the dart from the board and returned to the same start location to prepare for the next trial. Markings on the floor assured the participants returned

to the same start location for each trial. The participant raised his arm to 90° to indicate he was ready for the next throw, the board was cleared of any projected images, and the target reappeared for the next throw. The participants trained for approximately one hour each day performing 160 trials each day for three days, and \$20.00 was awarded to the participant scoring the lowest radial error at the end of the experiment.

Results and Discussion

The radial error score for each throw was calculated to assess learning across the three days. Learning was inferred based on the improvements observed, across trial blocks, in the radial error scores calculated from the position of the dart in relation to the position of the target for each throw. This score was calculated using the X and Y coordinates of the target and the dart for each throw. Radial Error = $\sqrt{[(x_d - x_t)^2 + (y_d - y_t)^2]}$ where d = dart and t = target (Hancock, Butler, & Fischman, 1995). The significant differences level for all analyses was set at $p \leq 0.05$. Although there were no retention or transfer tests, comparing the mean of the first block of 20 trials on the second (and third) day to the performance at the end of the first (and second) day indicated the participants were learning since the mean radial errors were similar. This indicated that the performance improvements observed the day before were retained, since their error scores did not increase when they returned for their subsequent day of practice.

Mean radial error for blocks of 20 trials across the three days of practice are displayed in Figure 2.4, with the standard error bars indicating the variability between participants. Results were analyzed using a 3 X 8 (day X trial block) analysis of variance, repeated measures design performed on the radial error scores in mean blocks of twenty trials. This analysis revealed a significant main effect for day, $F(2,14) = 8.21$; $p < 0.005$. Post-hoc

analysis (Tukey-Kramer) revealed day 3 to be significantly different from both day 1 and day 2. The majority of the changes occurred during the first two days. By day 3, the participants began to plateau in their rate of decrease in radial error. These results also indicated that although there are significant improvements in the radial error scores as the participants plateau, the participants have not yet mastered the task at hand. The changes that occurred during training are in the direction of mastering the task; however, these results show the participants are still in the earlier learning stages because they are not consistently hitting inside of the target. The radial error scores are larger than 7.5 cm indicating they are landing outside the target on average.

Within-subject standard deviations of the means calculated for each block of 20 trials are displayed in Figure 2.5 with the standard error bars representing the variability between subjects. These values were used to show how consistent the participants became as they practiced the task. Results were analyzed using a 3 X 8 (day X trial block) analysis of variance, repeated measures design performed on the standard deviations of the mean radial error scores in blocks of twenty trials. This analysis revealed a significant main effect for day, $F(2,14) = 4.52$; $p < 0.05$. Post-hoc analysis (Tukey-Kramer) revealed day 3 to be significantly different from day 1. The greatest change occurred on day 1 followed by a plateau of the standard deviation values.

The main effects observed in the analyses of the radial error means and standard deviations, indicated that the performance error was decreasing over time as well as becoming more consistent. There was a decrease in radial errors, as participants were getting closer to the target with practice. By day three they were consistently landing within 6 cm of the target. This improvement was based on the rate of decrease in radial error scores, and the

Closed Task with no IV

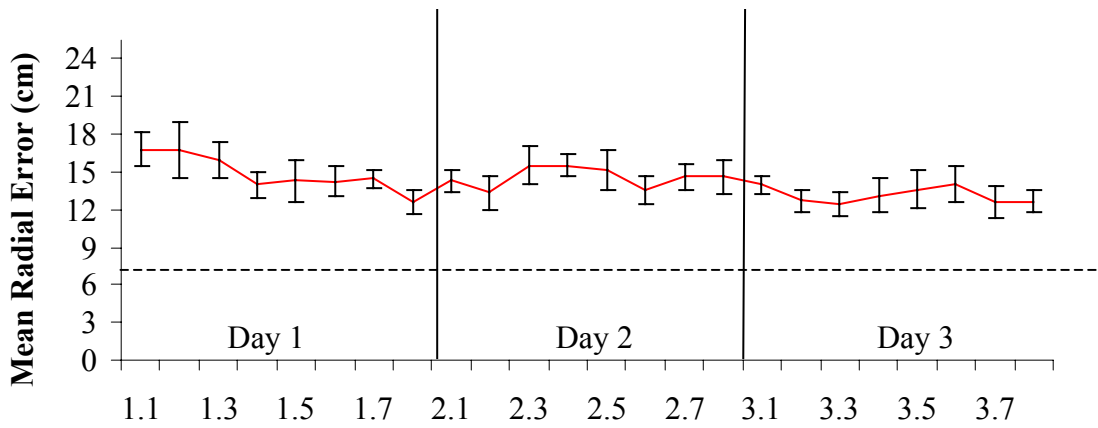


Figure 2.4. Mean radial error (in cm) across the three days of practice (blocks of 20 trials). A mean score inside the target occurs at less than 7.25 cm (dashed line).

Closed Task with no IV

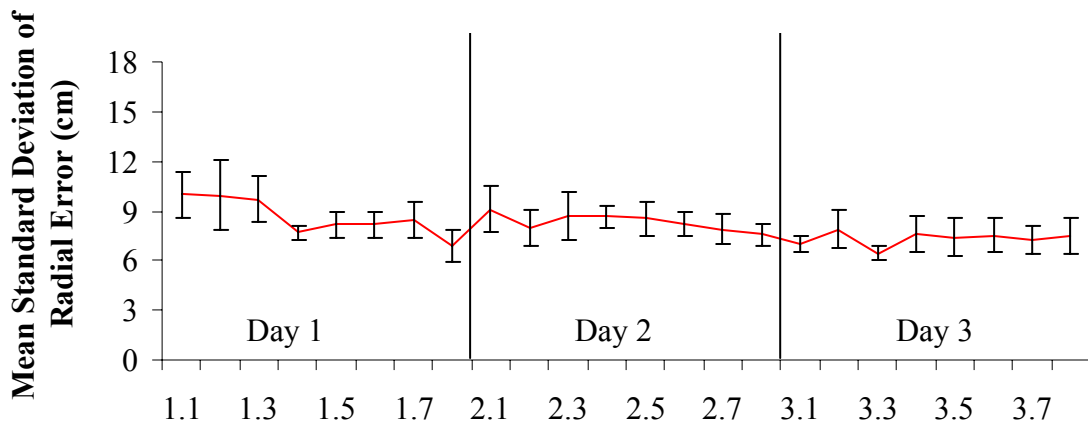


Figure 2.5. Standard deviation of the radial error (from mean blocks of 20 trials) across the three days of practice (within subject -intertrial variability)

variability of these outcome scores. The logarithmic trend lines indicated that the majority of the improvement occurred on the first day followed by a plateau on days two and three. This negatively accelerated curve is consistent with what was hypothesized and with what is observed with novices during performance of a novel skill.

Comparison of Accuracy of Early and Late Practice Trials

The decrease in radial error indicated that with practice the participants began to get closer to hitting the target consistently. Figure 2.6 shows where the participants were landing the dart on day 1, early in practice (top graph) and how their accuracy changed with practice by day 3 (bottom graph). This figure helps to understand the changes observed in the radial error and to see where the participants' outcomes were focused and how their accuracy improved with practice. Participants were observed favoring the right side of the dartboard early in practice. This trend could be due to the fact that all the participants preferred their right hand for throwing, and they stood just to the right of the center of the dart board. With practice, participants are observed to gravitate closer to the middle of the board, where the target is located resulting in an increase in their accuracy and a decrease in the radial error scores.

Experiment 2 (Closed) (Closed Task with Intertrial Variability)

The dart throwing task was performed in a closed environmental context with intertrial variability. The target appeared in one of five locations on the dartboard and remained stationary as the learner threw the dart. Each of the five target locations was presented 32 times each day in a random pattern. This environmental context provided low task demands because the target was stationary, with high attentional demands because the participant did not know where the target would appear each trial. It was hypothesized that the participants

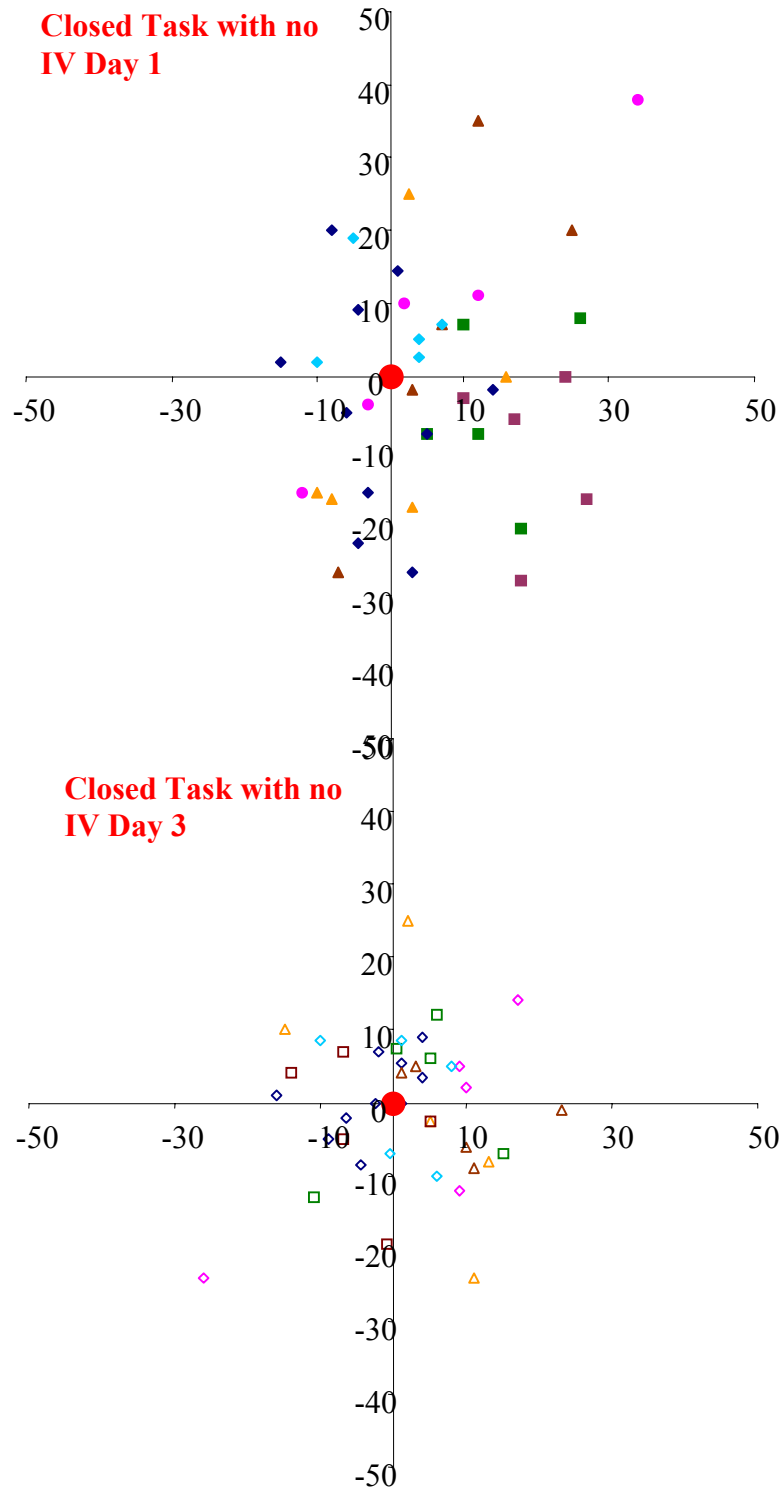


Figure 2.6. The first 5 trials from each participant on day 1 (top) and the last 5 trial from each participant on day 3 (bottom), for each target location in the closed task with no intertrial variability.

would start out with small radial errors that would decrease during the three days of practice. Due to the low task demands, the greatest decrease in error was hypothesized to occur on days 1 and 2 and by day 3 the errors would plateau. This trend is consistent with the power law of practice and the negatively accelerated curve typical of novices during skill learning (Magill, 2000). Because of the high attentional demands of the task, it was also hypothesized that the standard deviations of the radial error scores would not decrease until day three because of the time it would take for the participants to learn the task and become consistent in their outcomes. The standard deviation was hypothesized to remain high during practice due to the high attentional demands of the task.

Method

Participants

Eight volunteers, who had not participated in the first experiment, participated in this experiment. Participants (6 females and 2 males with a mean age of 20 years) were recruited from undergraduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The same apparatus described in Experiment 1 was used; however, the stationary target appeared in one of five locations on the dartboard each trial, in a counterbalanced-random order (Figure 2.7). The target disappeared before each trial and reappeared similar to Experiment 1, however the participant did not know where it would appear each time.

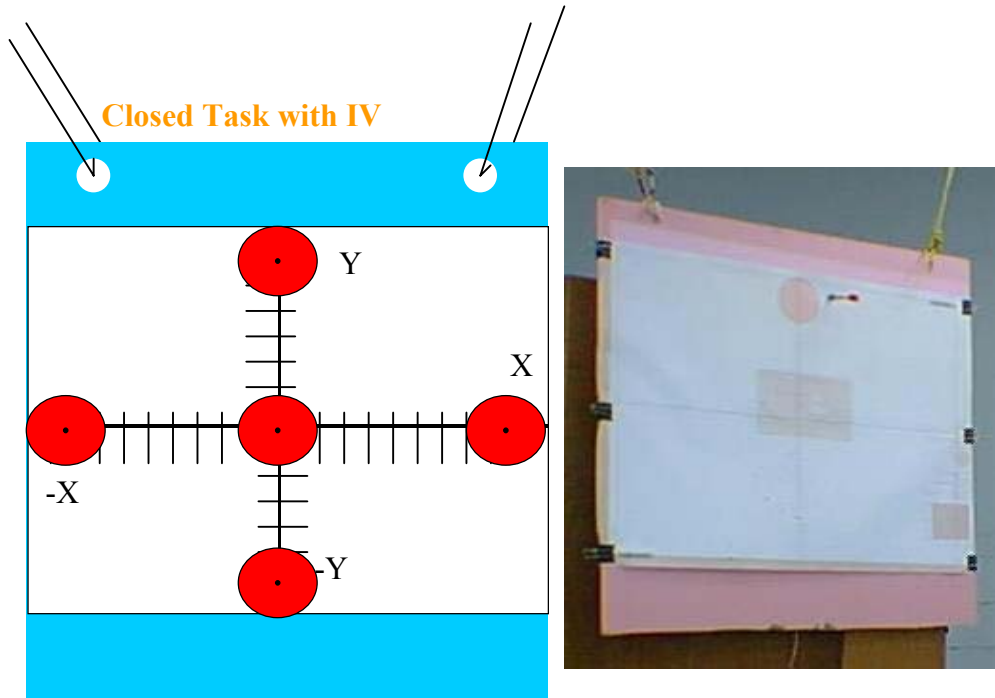


Figure 2.7. Diagram of target and board, suspended from the ceiling (left) Photograph of target in the top position (right).

Procedure

After reading the written instructions, the participant was shown the target projected on the dartboard and data collection began after all questions were answered. The data were collected, calculated, and analyzed using the same procedures described in Experiment 1.

Results and Discussion

Mean radial error for the blocks of twenty trials across the three days of practice are displayed in Figure 2.8. A 3 X 8 (day X trial block) analysis of variance, repeated measures design was performed on the radial error scores in mean blocks of twenty trials. This analysis revealed significant main effects for both day and trial blocks: day, $F(2,14) = 12.39$; $p < 0.005$; trial blocks, $F(7,49) = 3.73$; $p < 0.005$. Post-hoc analysis (Tukey-Kramer) revealed day 1 to be significantly different from both days 2 and 3. The greatest rate of change occurred during

day 1; however, this improvement continued into day 2. By day 3, participants began to plateau in their outcome performance. These results indicated that although there were significant improvements in the radial error scores, the participants had not yet mastered the task at hand. These results indicated the performers could not just refine their movements to produce an outcome, but had to adapt to the various locations where the target appeared. This adaptation could be observed in a change in the shoulder angle position or the orientation of the forearm during the throw to adapt to the position of the target each time.

Standard deviations of the means were also calculated, for each block of 20 trials across practice, and are displayed in Figure 2.9. A 3 X 8 (day X trial block) analysis of variance, repeated measures design was performed on the standard deviations of the mean radial error scores in blocks of twenty trials. This analysis did not reveal a significant main effect for day, $F(2,14) = 2.8$; $p > 0.05$ because of the large variability of the standard deviation scores on day one. The increase in the variability during practice indicated the demands on the attentional processes of the participants did result in a difficult task to learn, as was hypothesized. This increase in attentional demands created a task that was difficult to learn due to the variability of the target location. This difficulty was observed in the large and variable standard deviations across the practice blocks.

The main effects observed in analysis of the radial error means, indicated that the performance error was decreasing over time. There was a decrease in radial error as participants were getting closer to the target with practice. Although the analysis did not reveal significance for the standard deviations, Figure 2.9 shows the participants became more consistent throughout practice. Figures 2.8 and 2.9 show that the majority of the improvement occurred on day one followed by a lower rate of improvement on days two and

three. The logarithmic trend lines indicated the mean radial error and the standard deviation values followed a negatively accelerated curve, which is consistent with what was hypothesized. These trends were also consistent with what is typically observed with novices during skill acquisition.

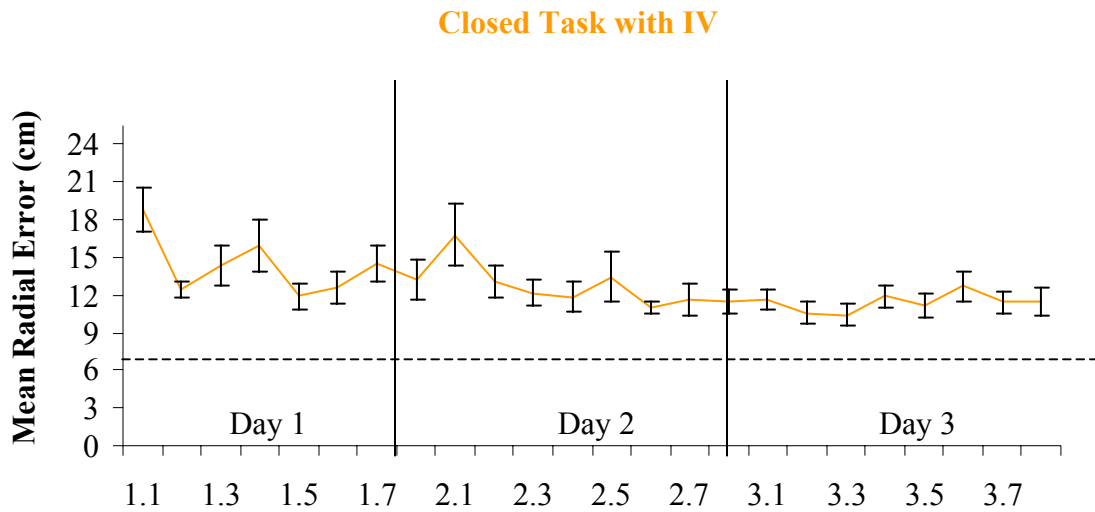


Figure 2.8. Mean radial error (in cm) across the three days of practice (blocks of 20 trials). A mean score inside the target occurs at less than 7.25 cm (dotted line).

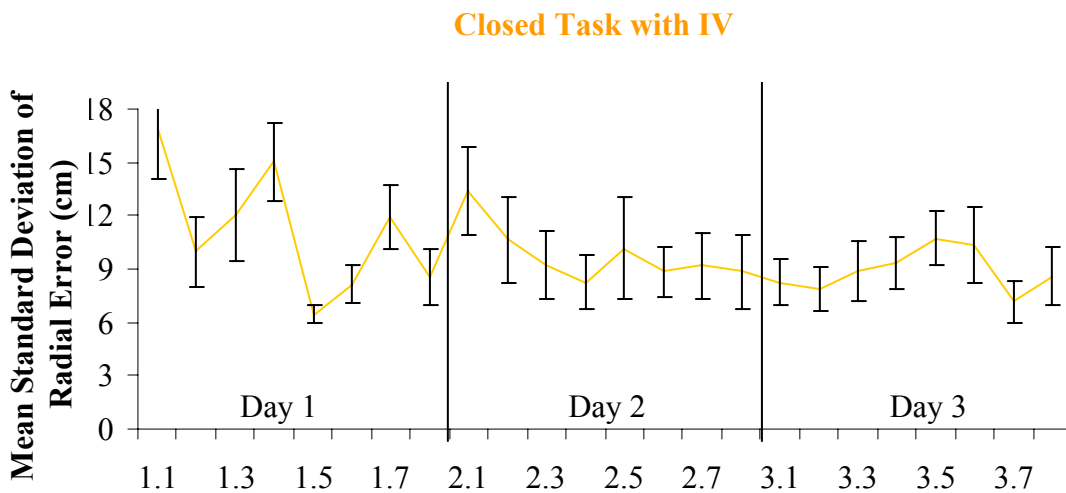


Figure 2.9. Standard deviation of the radial error (from mean blocks of 20 trials) across the three days of practice (within subject -intertrial variability)

Comparison of Accuracy of Early and Late Practice Trials

It is evident that with practice the participants decreased their radial error as they practiced hitting the five targets more consistently. Figure 2.10 shows where the participants were landing the dart on day 1 early in practice (top graph) and how their accuracy changed with practice by day 3 (bottom graph). This figure helps to understand the changes observed in the radial error and to see where the participants' outcomes were focused and how their accuracy improved with practice. Participants are observed landing the dart in a larger area around each intended target early in practice, and by day 3 are observed decreasing the overall spread of the dart locations. With practice, participants are observed to gravitate closer to the center of each target, resulting in an increase in their accuracy and a decrease in the radial error scores, but they are still showing high radial errors.

Experiment 3 (Open) (Open Task with no Intertrial Variability)

The dart throwing task was performed in an open environment with no intertrial variability. The target appeared on the left-hand side of the dartboard and moved horizontally across the middle of the dartboard to the far right side and then reversed direction and returned to its starting position at a constant speed of 0.5 Hz. These conditions were the same for every trial indicating no intertrial variability was present in this experiment. This environmental context provided high task demands since the target was moving and low attentional demands since the pattern of movement was the same every time. It was hypothesized that the participants would start out with large radial errors that would decrease during the three days of practice. Due to the high task demands, the greatest decrease in error

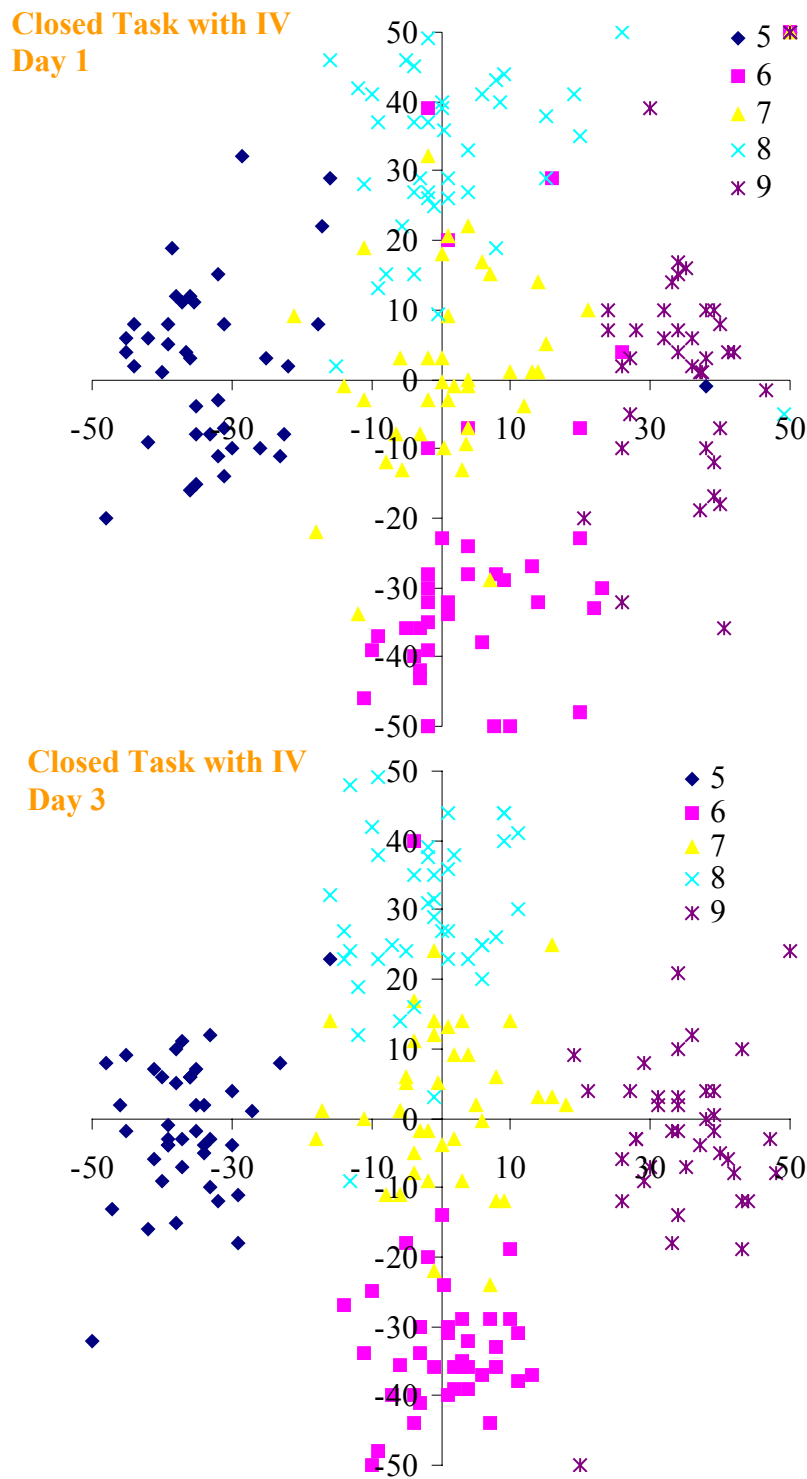


Figure 2.10. The first 5 trials from each participant on day 1 (top) and the last 5 trial from each participant on day 3 (bottom), for each target location in the closed task with intertrial variability.

was hypothesized to occur on day one and two and by day three the errors should plateau. This trend is consistent with the power law of practice and with the negatively accelerated curve typically observed of novices during skill learning (Magill, 2000). The low attentional demands were hypothesized to result in low standard deviation values after day one.

Method

Participants

Eight volunteers, who had not participated in the first two experiments, participated in this experiment. Participants (7 females and 1 male with a mean age of 24.75 years) were recruited from undergraduate and graduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The apparatus was the same as was described for Experiment 1; however, in this experiment the target appeared on the left side of the board and moved along the horizontal axis to the right side of the board and back to its initial starting point at a rate of 0.5hz. (Figure 2.12). The target disappeared before each trial and reappeared similar to Experiment 1, however the participant was instructed to hit a moving target each time. An accelerometer (Kistler) was placed on the back of the dartboard and programmed to stop the target from moving as soon as the dart hit the board. The computer program and accelerometer were programmed to respond as the dart made contact with the board. This high sensitivity level allowed the target to stop moving when the dart made contact with the board and allowed for no visually detectable delays. This allowed the participants to receive the same visual feedback (distance

between the dart and the target) given to the participants in the first two experiments, and allowed for an accurate measurement of the target and dart to be recorded.

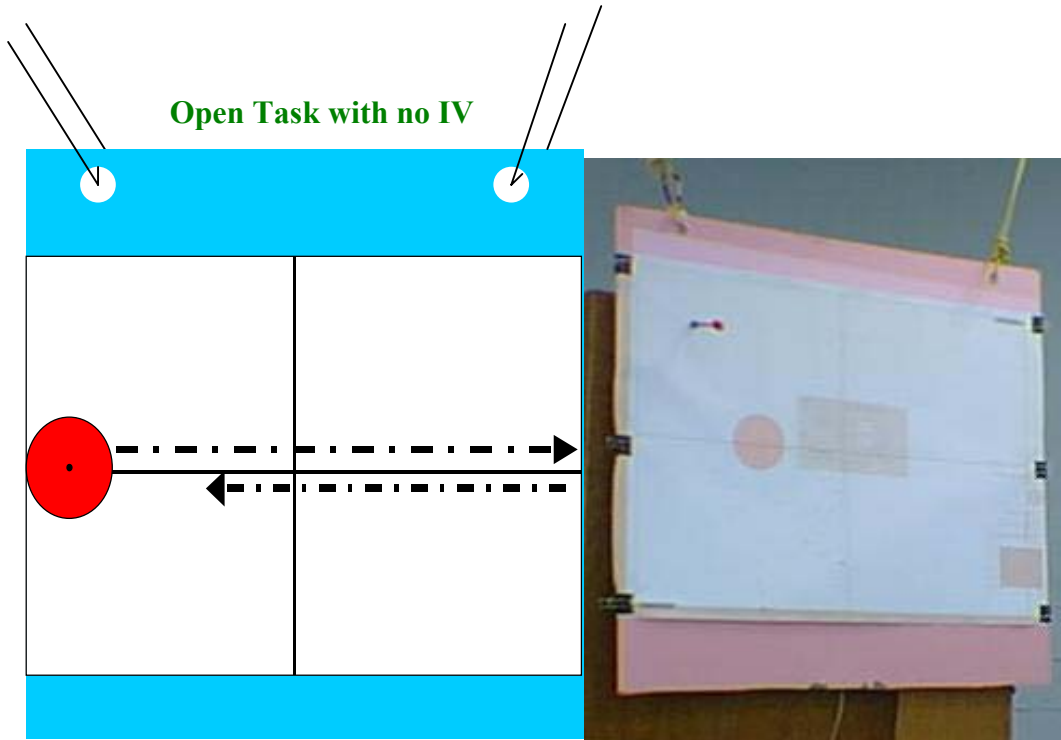


Figure 2.12. Diagram of target and board, suspended from the ceiling (left). Photograph of target moving (right).

Procedure

After reading the instructions the participant was shown the target projected on the dartboard and data collection began if there were no questions. The participant was instructed to hit the target after the target had turned around, but before it had returned to its starting location. The data were collected, calculated, and analyzed using the same procedures as described in Experiment 1; however, only seven participants were used in the analysis because one participant did not complete the experiment as instructed.

Results and Discussion

Mean radial error for the blocks of twenty trials across the three days of practice are displayed in Figure 2.13. This figure shows that the improvement continued throughout the three days of practice. A 3 X 8 (day X trial block) analysis of variance, repeated measures design was performed on the radial error scores in mean blocks of twenty trials. This analysis revealed a significant main effect for day, $F(2,12) = 6.08, p < 0.05$. Post hoc analysis revealed day one and two to be significantly different from day three. The main effect observed in the analysis of the radial error means, indicated that the performance error decreased over time. The greatest change occurred during the first two days, followed by a plateau beginning on day three. The difficulty in hitting a moving target resulted in radial error scores around 20 cm at the beginning of practice and close to 15 cm. by the end of practice. The logarithmic trend line indicated the mean radial error values followed a negatively accelerated curve, which is consistent with what was hypothesized. This trend was also consistent with what is typically observed with novices during skill acquisition.

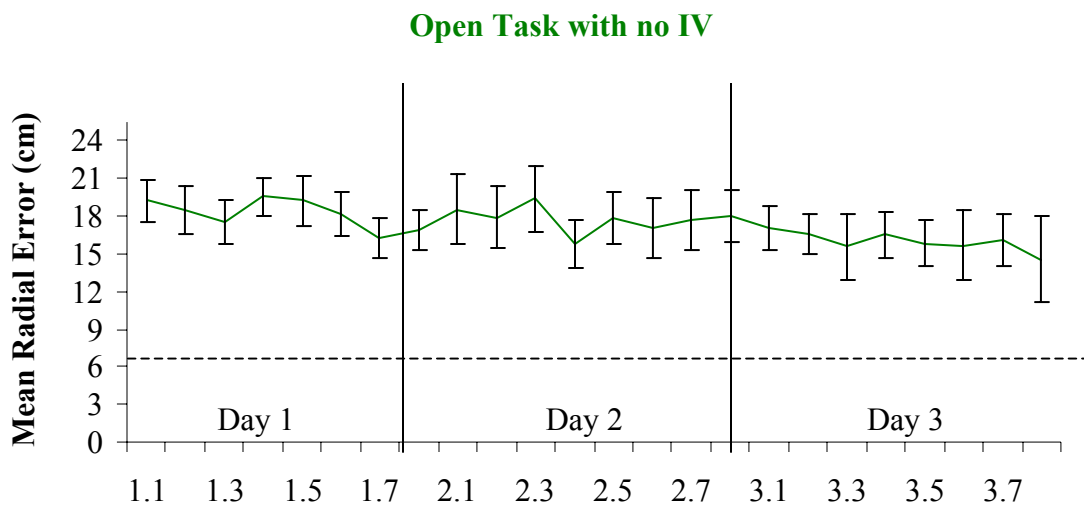


Figure 2.13. Mean radial error (in cm) across the three days of practice (blocks of 20 trials). A mean score inside the target occurs at less than 7.25 cm (dotted line).

Standard deviations of the means, calculated for each block of 20 trials across practice, are displayed in Figure 2.14. A 3 X 8 (Day X trial block) analysis of variance, repeated measures design was performed on the standard deviation values. This analysis did not reveal a significant main effect for day, $F(2,14) = 2.8$; $p > 0.05$. This could be due to the limited change in the standard deviation across the three days of practice. Figure 2.14 shows the standard deviation of the participants remained at a plateau throughout practice, supporting the hypothesis that there would be limited attentional demands when learning consistent tasks. Because the target moved at the same speed each time participants could learn the timing of when to throw. This allowed the learner to reduce some of the difficulty of the task due to its predictability.

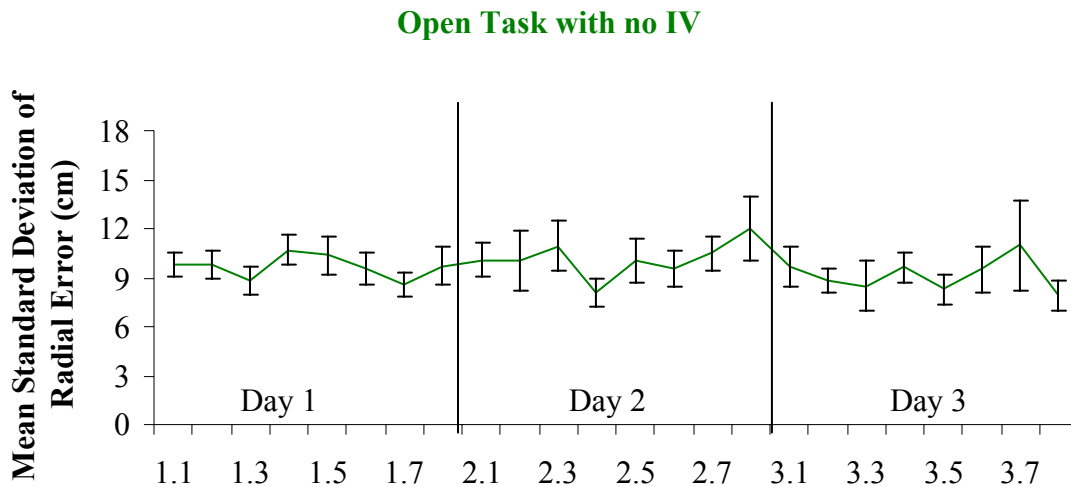


Figure 2.14. Standard deviation of the radial error (from mean blocks of 20 trials) across the three days of practice (within subject -intertrial variability)

Comparison of Accuracy of Early and Late Practice Trials

It is evident that with practice the participants decreased their radial error as they practiced hitting the five targets more consistently. Figure 2.15 shows where the participants

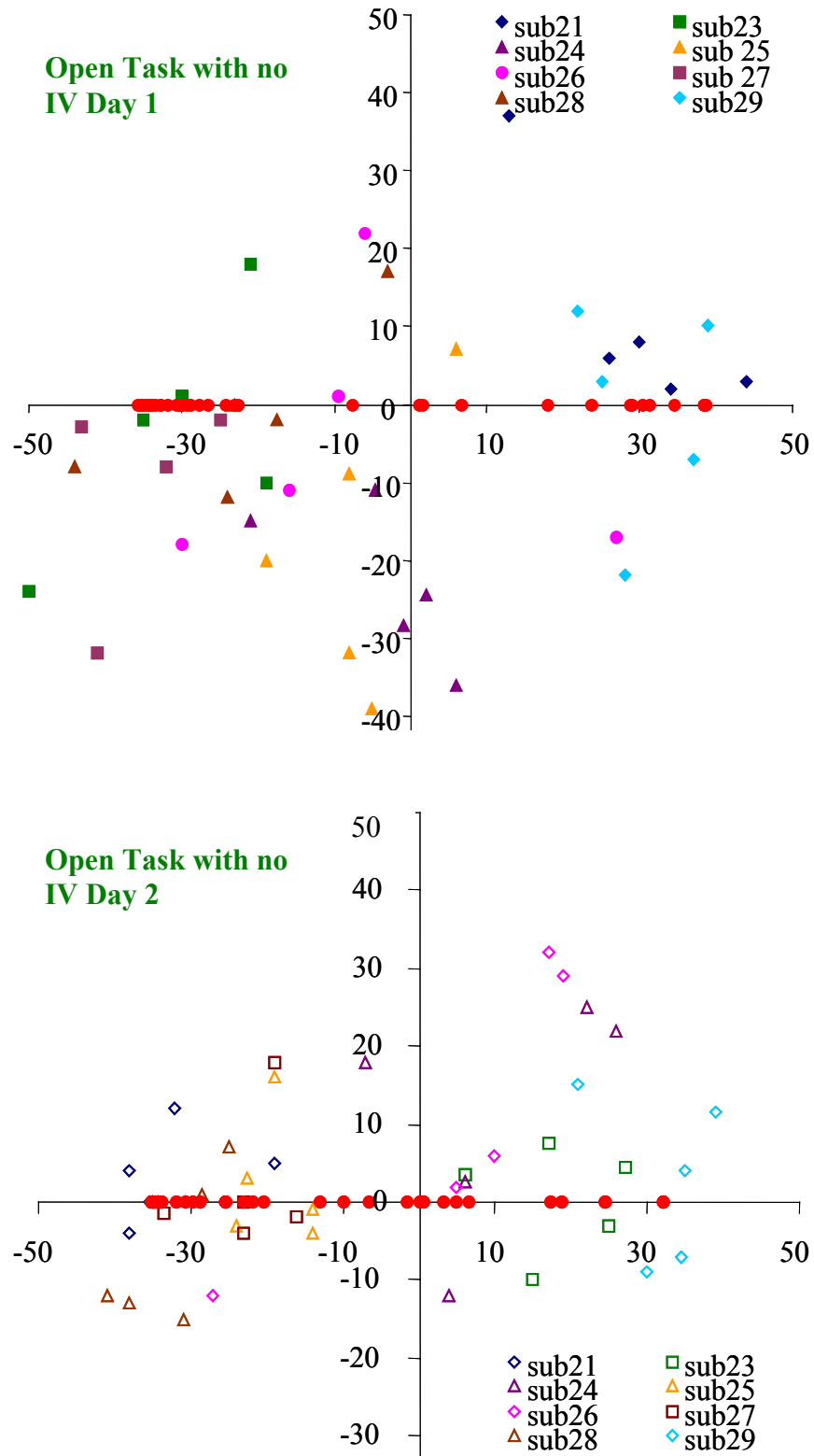


Figure 2.15. The first 5 trials from each participant on day 1 (top) and the last 5 trial from each participant on day 3 (bottom), for each target location in the open task with no intertrial variability. Each subject is color coded.

were landing the dart on day 1, early in practice (top graph) and how their accuracy changed with practice by day 3 (bottom graph). This figure helps to understand the changes observed in the radial error and to see where the participants' throws were focused and how their accuracy improved with practice. Participants are observed favoring the left side of the dartboard early in practice. This indicates the participants were either waiting longer to release the dart or were throwing with a smaller velocity, which would increase the time it took for the dart to reach the board. This observation is consistent with what was expected for the open task. Because of the timing constraints of the moving target, participants were expected to have difficulty initially. With practice, participants are observed to gravitate a little closer to the horizontal axis of the board where the target moved; however, the participants are not performing as well as they could have with additional practice. Figure 2.16 shows the target position for each participant from day 1 and day 3. To determine whether the participants were throwing at different times for each throw or if they each developed their own strategy of when to throw, the target locations for each participant were graphed (Figure 2.16). With this figure, it is clear that a few of the participants changed their timing strategy with practice. Early in practice, the results indicate the majority of the participants waited longer to react to the moving target, but with practice, the participants appear to fall into a comfort area in which they would throw the dart. The bottom graph of Figure 2.16 indicates how the participants learned the timing pattern of the moving target and then tried to throw the dart at a specific time so the target would be at that location for each throw. This strategy allowed one movement pattern to be learned which achieved one consistent outcome, allowing the participants to reduce the difficulty of hitting the moving target.

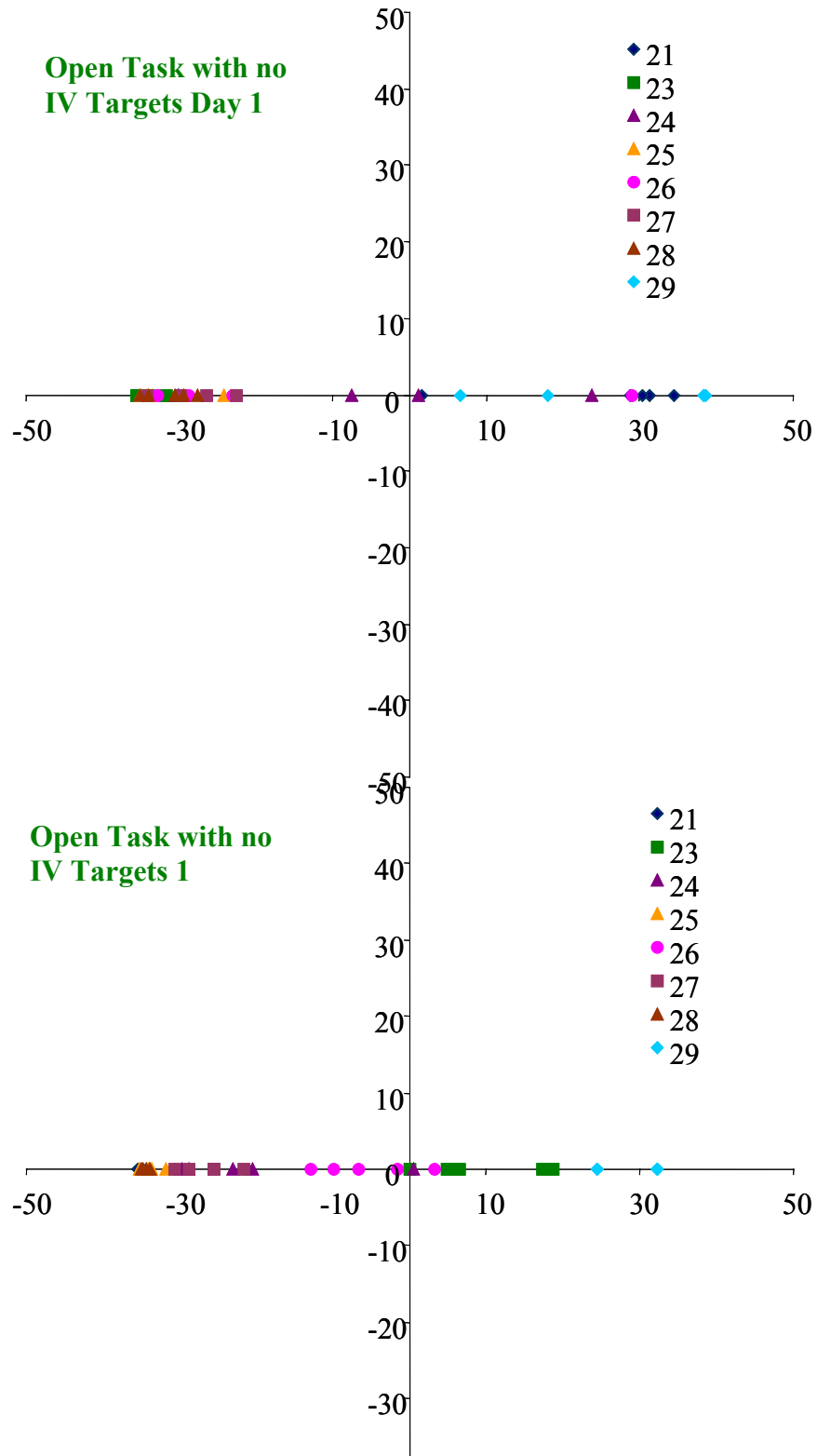


Figure 2.16. The first 5 trials from each participant on day 1 (top) and the last 5 trial from each participant on day 3 (bottom), for each target location in the open task with no intertrial variability. Each subject is color coded.

Experiment 4 (Open) (Open Task with Intertrial Variability)

The dart throwing task was performed in a completely open environment. The target appeared in one of five locations on the dartboard and moved across the dartboard in a linear pattern as the learner threw the dart. The starting location of the target varied for every trial producing intertrial variability for this experiment. This environmental context provided high task and high attention demands. Due to the high task demands, it was hypothesized that the participants would initially have large radial errors that would decrease during the three days of practice. The greatest decrease in error was hypothesized to occur on days one and two and by day three, the errors should plateau. This trend is consistent with the power law of practice and the negatively accelerated curve typically observed of novices during skill learning (Magill, 2000)

Method

Participants

Eight volunteers, who had not participated in the first three experiments, participated in this experiment. Participants (5 females and 3 males with a mean age of 24.14 years) were recruited from undergraduate and graduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The same apparatus was used as was described in Experiment 3; however, in this experiment the target appeared in one of five locations on the board and moved to the opposite side of the board and back in a linear pattern (Figure 2.18). The board was cleared

of all images before the target was presented for each trial. The target appeared and began moving similar to Experiment 3, however the participant did not know the starting location or the direction the target would move.

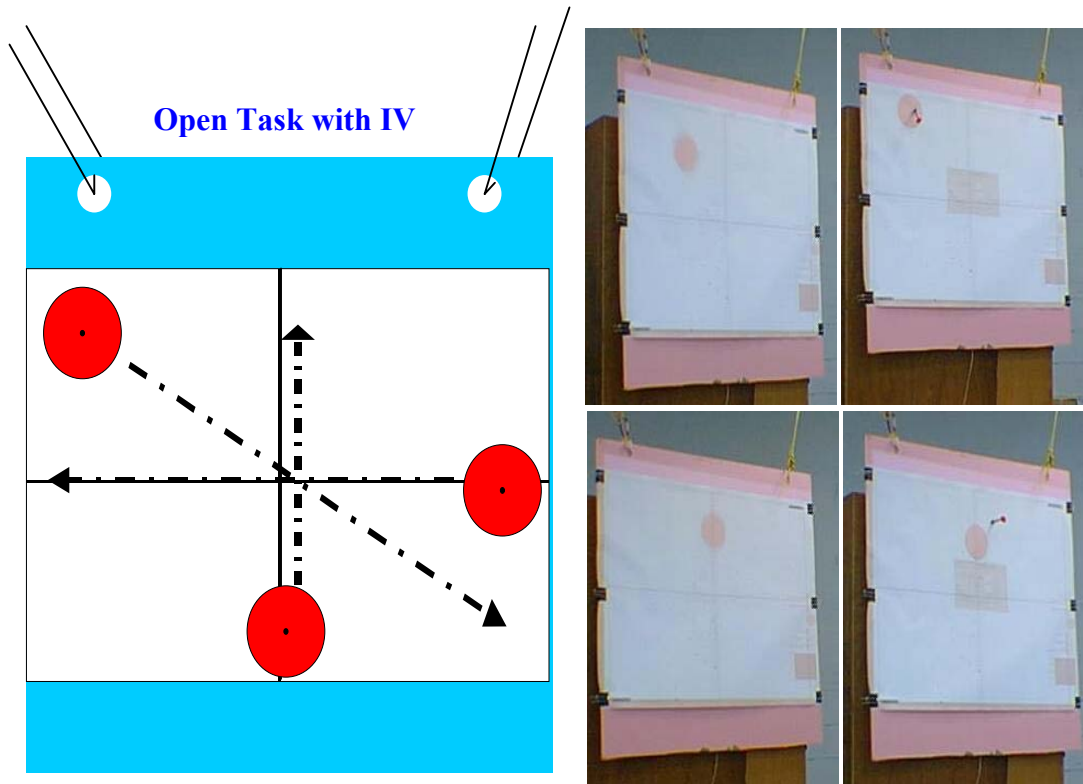


Figure 2.18. Diagram of 3 of the 5 targets, on the suspended board. Photographs of the target moving diagonally (top two) and vertically (bottom two) just before the dart made contact.

Procedure

After reading the written instructions, the participant was shown the target projected on the dartboard and data collection began after all questions were answered. The participant was instructed to hit the target after the target had turned around, but before it had returned to its starting location. The data were collected, calculated, and analyzed using the same procedures as described in Experiment 1.

Results and Discussion

Mean radial error for the blocks of twenty trials across the three days of practice are displayed in Figure 2.19. This Figure shows that the improvement in performance continued during the three days of practice. A 3 X 8 (day X trial block) analysis of variance, repeated measures design was performed on the radial error values in mean blocks of twenty trials. This analysis revealed a significant main effect for day, $F(2,14) = 17.38, p < 0.005$. Post hoc analysis revealed days 1 and 2 to be significantly different from day 3. The largest rate of improvement occurred on days 1 and 2; however, by day 3 participants continued to decrease their error and get closer to the target. The participants had not yet begun to plateau due to the high task and attentional demands impressed upon them. This indicated additional practice was needed for participants to achieve the goal of hitting the target consistently.

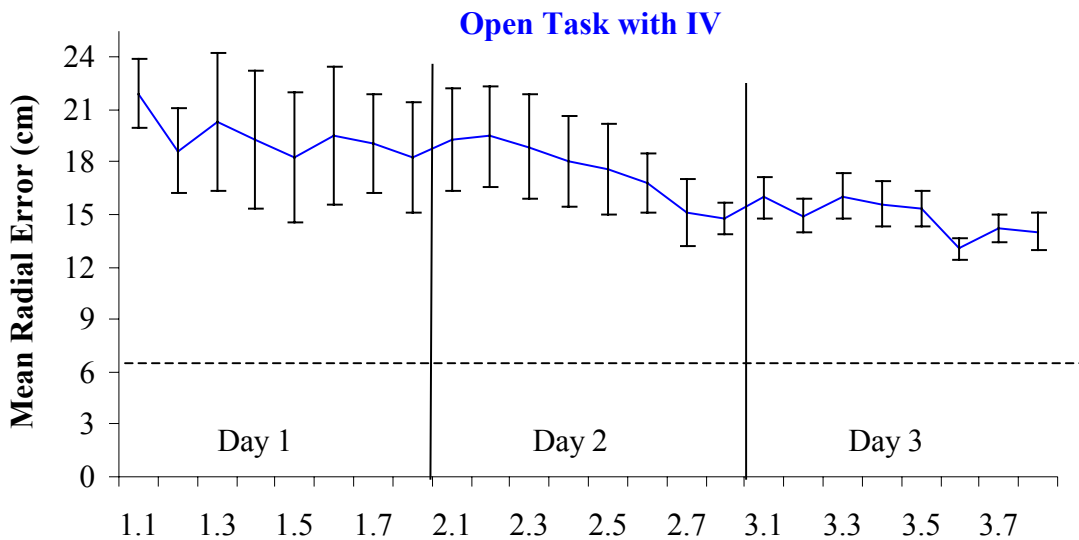


Figure 2.19. Mean radial error (in cm) across the three days of practice (blocks of 20 trials). A mean score inside the target occurs at less than 7.25 cm (dotted line).

Standard deviations of the means were also calculated, for each block of 20 trials across practice, and are displayed in Figure 2.20. A 3 X 8 (day X trial block) analysis of variance, repeated measures design was performed on the standard deviation values. This analysis revealed a significant main effect for day, $F(2,14) = 8.08$; $p < 0.001$. This was due to the steady decrease in the standard deviation scores across the three days of practice. The high attentional demands placed on the participants were evident with the high variability throughout practice.

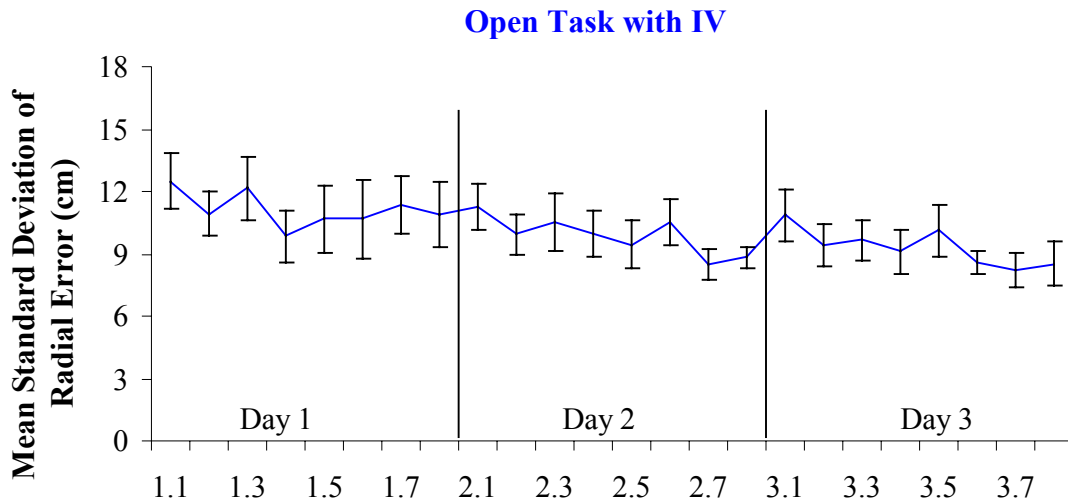


Figure 2.20. Standard deviation of the radial error (from mean blocks of 20 trials) across the three days of practice (within subject -intertrial variability).

The main effects observed in the analysis of the radial error means, indicated that the performance error decreased over time. Figures 2.19 and 2.20 indicate the participants became more consistent throughout practice as they reduced their radial error scores. Although there is difficulty in hitting a moving target, the participants were able to improve their performance with practice. The logarithmic trend lines indicated the mean radial error and the standard deviation values followed a negatively accelerated curve, which is consistent with

what was hypothesized. These trends were also consistent with what is typically observed with novices during skill acquisition.

Comparison of Accuracy of Early and Late Practice Trials

It is evident that with practice the participants decreased their radial error as they practiced hitting the five moving targets more consistently by day 3. The top graph of Figure 2.21 shows that early in practice the participants were treating each movement direction as an individual target to aim for. With practice, the figure shows the participants used a strategy of grouping the target movements to reduce the number of possible aiming locations. The bottom graph shows the participants focusing on three areas of the dartboard in which one or two movement trajectories of the targets would pass. This simplified the task reducing the five target movements to only three areas. Figure 2.21 shows the total area in which the dart landed was much larger on day 1 than on day 3. This indicated both how the participants became more accurate and indicated the participants developed a strategy during the three days of practice. This figure helps to visualize the changes observed in the radial error and to observe where the participants' outcomes were focused and how their accuracy improved with practice. With practice, participants are observed to use a strategy whereby their focus of attention gravitated to three areas on the dartboard where the target would travel, resulting in an increase in their accuracy and a decrease in the radial error scores. This strategy also created a less difficult task to learn. The reduction of the number of possible target movements creates an easier task to learn, while the moving targets create a difficult task to perform.

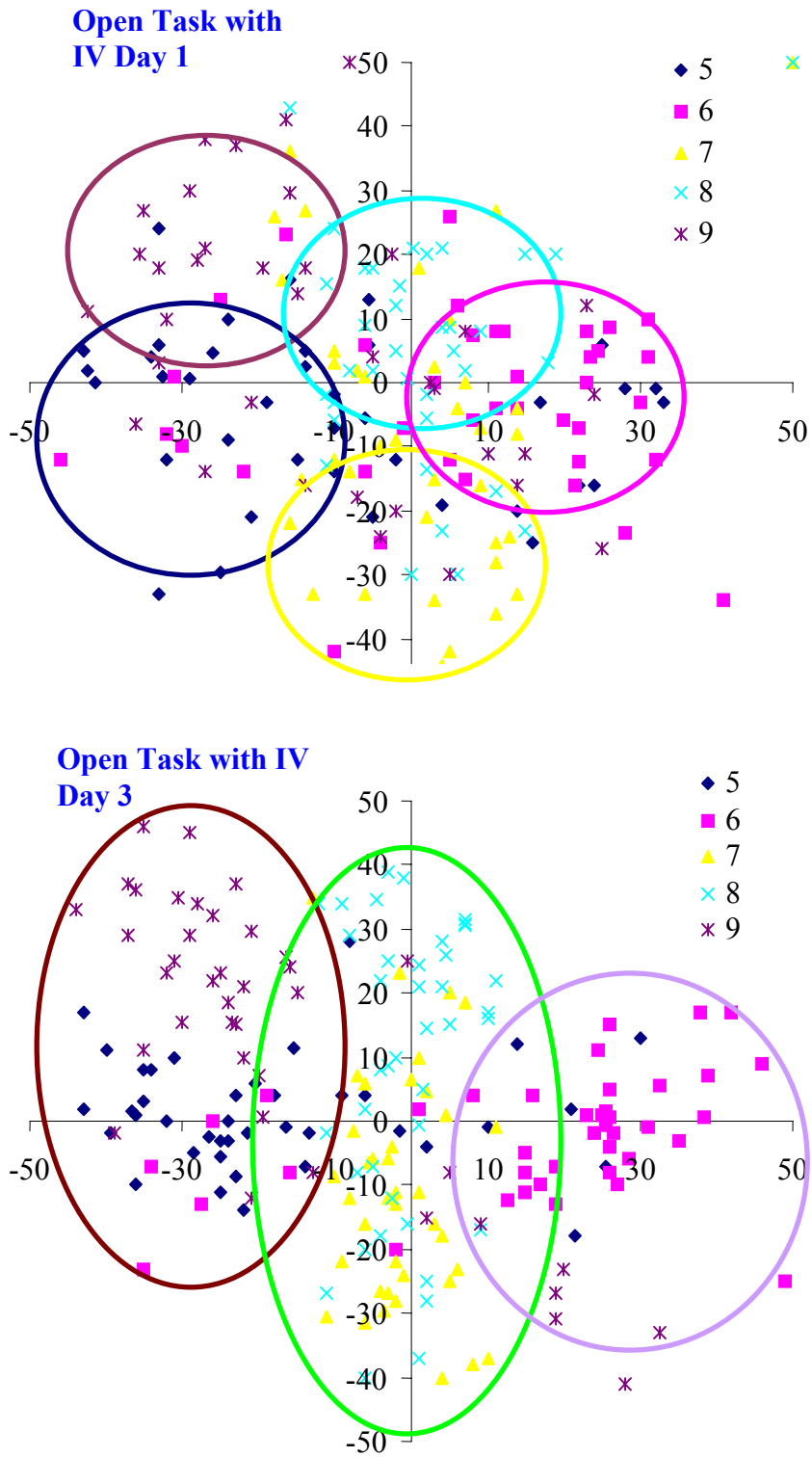


Figure 2.21. The first 5 trials from each participant on day 1 (top) and the last 5 trial from each participant on day 3 (bottom), for each target location in the open task with intertrial variability.

General Discussion

The four experiments were conducted to test the effect of task demands and attentional demands on the outcome performance of the dart throwing task, within each environmental context. The difficulty level increased from Experiment 1 to 4, by placing the target in motion, and/or by introducing intertrial variability. The closed task without intertrial variability practiced in Experiment 1 was designed to be the easiest (low task & low attentional demands), while the open task with intertrial variability practiced in Experiment 4 was designed to be the most difficult (high task & high attentional demands). The results within each task were consistent with what was expected for each task when the outcomes were observed individually (see Table 2.2). The environmental context had an effect on the size of the radial errors, and the rate the errors decreased, in addition to the size and slope of the standard deviations of the radial errors across time. These results provided support that the environmental context affects the demands placed on the learner and the how he or she will perform in a given environmental context.

To understand what effect the environmental context had on the performance and what factors in the environment influenced the performers the most, trend analyses were performed on the mean radial error scores to allow the four tasks to be compared to each other both individually and collapsed into two groups based on their regulatory conditions during practice. The four tasks were compared to one another to observe the trends that occurred in the outcome data during the three days of practice for each of the tasks. The data were analyzed both by grouping the data in their main classification of open and closed, and by comparing all four tasks in a trend analysis allowing comparisons to be made helping to identify how the environmental context affected the performance outcomes. It was

hypothesized that overall, the closed tasks would be easier to perform, resulting in lower radial error scores, while performance on the open tasks would result in higher radial error scores. A graph of the collapsed data provides support for these hypotheses (Figure 2.22). Performance on the closed tasks showed the outcome scores to decrease from 18 cm to 12 cm from the target on average, while the performance on the open tasks started at 21 cm from the target on average and decreased to 14 cm by the end of day 3. These results indicated the moving target was indeed more difficult to accurately hit than the stationary target on average. These findings were exactly as expected and indicated the regulatory conditions affect the outcomes; however, this information alone does not reveal how characteristics in the environment effected the learners. This comparison was important to observe because had the results indicated something different, then this would have been a critical aspect to analyze further.

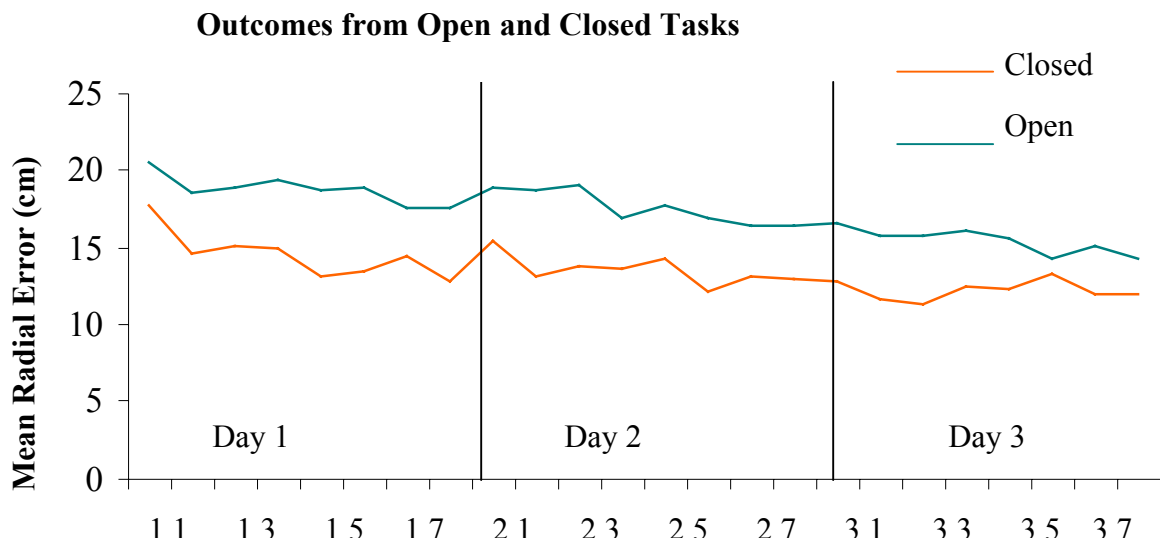


Figure 2.22. Graph of the means of the radial error (blocks of 20 trials) for open vs. closed experiments across the three days of practice.

Although the results provided support to indicate that the increased difficulty of the moving target resulted in an increase in radial error, what was of greater interest was whether the performance outcomes were different for each task. Did the changes in radial error for each of the four tasks provide as clear a distinction as the taxonomy suggests? As attentional demands increased what was the effect on the learners' outcomes and the variability of those outcomes? When task demands increased, but no additional demands were placed on the attentional capacity, what was the trend of the outcome scores? Was the rate of the learning affected more by changes in the regulatory conditions or the absence or presence of intertrial variability? Two trend analyses were performed to answer these questions. One analysis was performed on the mean radial errors from the performance on each of the four tasks and the second analysis was performed on the logarithmic transformation of the radial errors to assess the rates at which the performance outcome changes occurred over the three days.

When comparing the results of the four tasks to one another it was hypothesized that the changes in the performance outcomes would systematically increase as the task difficulty increased. Therefore, the trend of the outcome scores would be similar to the clear distinction of the four cells presented with the taxonomy on Table 2.1. The outcome scores from the closed task with no intertrial variability would be the smallest, while the open task with intertrial variability would have the largest radial errors. The closed task with intertrial variability was expected to have radial errors that were larger than the closed task with no intertrial variability, but larger than the open task with no intertrial variability. Lastly, the results from the open task with no intertrial variability were expected to be smaller than the open task with intertrial variability, and larger than the closed task with intertrial variability.

The overall results supported the hypothesis and indicated that a decrease in error occurred with practice for each of the tasks; however, when the mean outcomes are graphed individually for each task, the magnitude of the errors and the rate of the decrease in the radial errors during practice provided an unclear distinction among the four tasks (Figure 2.23). A 4 X 24 (task X time) analysis of variance, repeated measures design trend analysis was performed on the mean radial errors in Figure 2.23. This trend analysis revealed a significant main effect for both task, $F(3,69) = 1102.83, p < 0.05$; and time, $F(3,69) = 64.84, p < 0.05$. Post-hoc analysis indicated the two closed tasks were significantly ($p < 0.05$) different from the two open tasks. This analysis also revealed the two closed tasks to be similar ($p > 0.05$) to each other and the two open tasks to be similar ($p > 0.05$) to one another, since in each case differences were not observed. These results, indicated the regulatory conditions had a

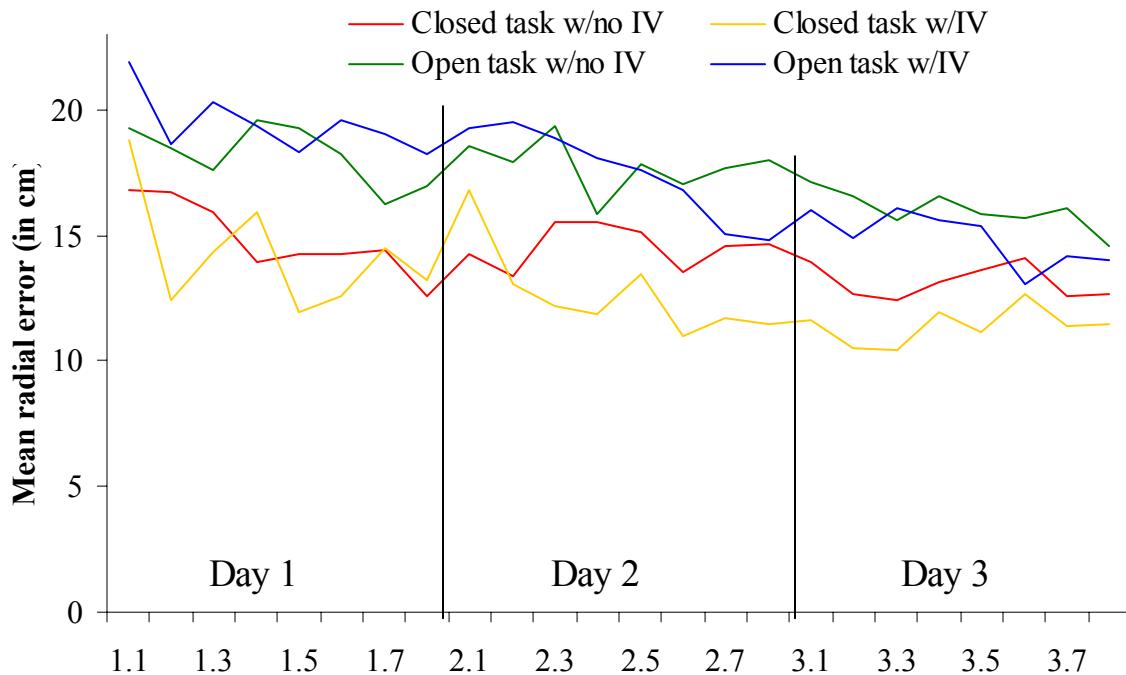


Figure 2.23. Mean radial error (blocks of 20 trials) across the three days of practice, for all four experiments. A mean score inside the target occurs at less than 7.5 cm.

greater impact on the magnitude of the radial errors, support the hypothesis that the increase on task demands will result in an increase in outcome errors. Because the participants training the closed tasks did not have to prepare their movements to coincide effectively with the moving target, it can also be inferred that their preparation time would be reduced for the closed tasks when compared to the open tasks. During performance on the open tasks, the timing constraints of the moving target will initially affect the movement preparation phase because of the spatial and temporal factors in the environmental context that must be conformed to for a successful outcome of the action goal.

Another trend observed in the data was that the slopes of the outcomes for the consistent tasks (tasks with no intertrial variability) were similar to each other, as were the slopes for the variable tasks (tasks with intertrial variability). A 4 X 24 (task X trial block) analysis of variance, repeated measures design was performed on the natural log of the radial error scores. This trend analysis revealed a significant main effect for task $F(3, 69) = 3.61, p < 0.05$; and time $F(23,69) = 6.02, p < 0.05$. Post hoc analysis indicated the slopes of the consistent tasks were not significantly different ($p > 0.05$) from each other, and the slopes of the variable tasks were not significantly different from each other. However, comparing the slopes of the consistent tasks to the slopes of the variable tasks revealed significant differences ($p < 0.05$). These results indicated that the variability of the target's location had a definite effect on the rate of the changes in performance outcomes. The outcome scores for the consistent tasks followed a shallow negatively accelerated curve. The largest changes occurred on the first day followed by a plateau on the second and third day. The slopes in the variable environment indicated the greatest changes occurred during the first two days of practice and began to plateau by day 3. These data supported the hypothesis that the rate in

which the performance changes occurred would be influenced by the environmental context in which the participants trained. This suggests that the participants practicing the variable tasks may have used a similar strategy to one another to reduce their errors, while those practicing the consistent tasks developed their own strategy. These data indicated that the increased demands on the attention with the addition of intertrial variability, has a greater influence than does the increased task demands introduced with regulatory conditions in motion. Because the participants training on the consistent tasks do not have to prepare their movements before each throw, they can just focus on achieving the same outcome each time. The participants learning the variable tasks must develop a strategy that allows them to perform well in multiple situations.

The increase in attentional demands encourages the participant to pay close attention to the changes in the environmental context in order to perform the task correctly. This increase in attention also appears to affect other aspects of attentiveness during the learning of the task. Closer inspection of the changes in the outcome scores revealed a difference in the magnitude of change in the radial errors during the three days of practice. For those who practiced the consistent tasks, the decrease in the radial error on average over three days was less than 4.7 cm; while those who practiced the variable tasks decreased their mean radial error by more than 7.4 cm during the three days of practice. The small decrease in radial errors for the two consistent tasks was not because of a floor effect where the participants could not improve any further. The participants had not mastered the task by the end of day three because they were still hitting outside of the target on average. A possible explanation would be related to the attentiveness of the performers. Because the task characteristics are so predictable, the learners do not have to actively involve themselves in a cognitive problem

solving of how to increase their performance. After a limited number of trials the performer may become comfortable with their performance and not be consciously involved in the learning process. These findings follow what has been observed in studies manipulating the amount of contextual interference during skill acquisition. This consistent environmental context is similar to a low contextual interference practice schedule and appears to result in similar outcomes by the performers in this situation. Low contextual interference (i.e. blocked practice), results in a decrease in performance with practice, but does not always produce the best retention or learning rates, when compared to high contextual interference situations. For the variable environmental context, the participants had a larger decrease in radial error. Their practice environment can be compared to a high contextual interference situation and may explain the increase in their performance improvement. By comparing the mean radial error scores from block eight (last 20 trials) of day 1 to block one (first 20 trials) of day 2, and comparing block eight of day 2 to block one of day 3, it was evident that the participants are retaining what they had learned on the previous day. The participants training on the consistent tasks showed small improvements on days 2 and 3, while those training on the variable tasks showed large improvements on both days 1 and 2.

In conclusion, when comparing the size of the errors and the rate of the performance changes, different trends emerge. These data suggest that although it was hypothesized that increases in the demands placed on the learner would have an effect on their performance, these performance changes do not necessarily change systematically from cell to cell as was expected. The effect of changing only one component of the environmental context had different effects resulting in a gray area between the closed tasks with intertrial variability and open tasks with no intertrial variability. The variability in the outcomes was observed early in

practice in the closed task with intertrial variability, while the radial error scores were consistently larger in the open task with intertrial variability.

What occurred unexpectedly was the difference in the magnitude of the performance improvements although the participants could have improved their radial error more they did not. The cognitive and or psychological aspect of the task appears to be the reason why the participants training on variable tasks improved more than the participants training on the consistent tasks. In this situation, the presence of intertrial variability has a large influence on the magnitude and rate of performance improvements. All of these results taken together provide evidence, which supports the distinction for open and closed skills; however, these results were not as clear when intertrial variability was introduced. It appears that increasing both the task demands and the attentional demands increases the difficulty in different ways. These results indicate the interaction between the environment, task, and the learner is complex and by analyzing only one dimension, too much information is overlooked. Although the outcomes provide important information regarding the changes occurring because of the environmental context, a more complete analysis should include the changes at the movement level also.

CHAPTER 3. CHANGES IN MOVEMENT COORDINATION AS NOVICES LEARN DART THROWING

Introduction

Background

A majority of research studies in motor learning base the measurement of learning on performance outcomes without observing the coordination pattern of the movement produced. To measure the learning of a novel complex motor skill, it is important to compare the learner's performance with the intended goal. However, this information is incomplete because it ignores the changes in coordination that occur during the learning of the novel skill. Focusing on the changes in the coordination pattern of the movement provides information about what evolves during skill learning. Specifically, tracking the movements at the joint or limb-segment level helps determine the relationships among all the joints involved and how these relationships change as the person acquires the skill. Observing how the movements are produced and what changes in coordination occur with practice can then be related to the factors in the environment affecting these changes. The changes in the outcome scores were addressed in Chapter 2, while this chapter identifies the changes in coordination that occurred during practice.

When identifying the coordination patterns of a movement, it is critical to evaluate how coordination changes temporally. How this coordination changes from one point in time to the next provides critical information as to how the learner adapts a movement to produce the skilled activity. The pattern of joint displacement observed during movement production changes over time with practice. These observed changes relate to the adaptation of specific components of the limbs, throughout the learning of a complex motor skill. The changes in

coordination can best be evaluated during the process or organization as described by Bernstein (1967). As the learner determines how to produce a skill, changes in the coordination pattern occur. Bernstein (1967), and others, (Gesell, 1929; Gentile 1972, 2000; Newell, 1985; and Kugler, Kelso, & Turvey, 1980) observed changes in coordination and provided hypotheses of what changes in coordination can be expected during the course of learning a complex motor skill. In addition, they have provided descriptions of coordination changes during skill learning associated with early and later stages of the learning process (Bernstein, 1967; Kugler, et al., 1980; Newell, 1985; & Gentile, 1972, 2000).

Hypothesized Changes in Coordination during Learning

The problem of coordinating all the necessary body parts to successfully achieve the goal of a skill was first noted by Bernstein, in 1967, and was termed the “degrees of freedom problem.” As the beginner performs a new task, he or she must reduce the number of degrees of freedom by keeping the body or multiple body segments in a constrained form. When a beginner initially performs a task, he or she must “utilize all roundabout methods” (Bernstein, 1967, p. 107) before deciding which coordination pattern produces the best outcome. During the progression of skill learning, the degrees of freedom are released gradually, allowing the learner to control more degrees of freedom as the skill level increases. Observation reveals this “freezing” of degrees of freedom at the initial stages of learning to be followed by an “unfreezing” of degrees of freedom toward the later stages of learning.

Coordination patterns were hypothesized to change during skill learning from the constraining of degrees of freedom observed early in practice, to a release later in practice. This has been observed in a number of complex skills including sharp shooting, kicking, handwriting, basketball bouncing, and dart throwing (Arutyunyan, Gurfinkel, & Mirskii,

1968, 1969; Newell & van Emmerik, 1989; McDonald, van Emmerik, & Newell, 1989; Anderson & Sidaway, 1994; Broderick & Newell, 1999; Verijken, van Emmerik, Whiting, & Newell; 1992). To test these hypotheses it was necessary to measure the movements at the kinematic level and measure the angles at each joint and how these angles changed with practice as the tasks were learned. The control of the degrees of freedom was measured throughout the learning of a dart throwing task, in each of the four tasks. It was hypothesized that early in practice participants would use their shoulder to move the arm while stabilizing their hand at the wrist. Following the extensive practice trials the participants were hypothesized to reduce the movement at the shoulder and increase the movement at the wrist. This strategy would provide greater control of the arm during the throwing and aiming of the dart.

Hypothesized Direction of Changes in Coordination

The direction in which these degrees of freedom were released, and greater control was gained, was hypothesized to occur from the more proximal joints initially to the more distal joints later in practice. This proximal to distal strategy observed in developmental skills has also been observed during skill acquisition; however, this strategy has not been observed during the learning of all skills (Arutyunyan, Gurfinkel, & Mirskii, 1968, 1969; Newell and van Emmerik, 1989; Broderick & Newell, 1999). This directional trend was tested in each of the four experiments. The direction in which the degrees of freedom were released was hypothesized to occur in a proximal (shoulder) to distal (wrist) direction for the participants as they learned the dart throwing task within each of their environmental contexts.

Hypothesized Effect of Task on Changes in Coordination

According to Gentile (2000), skills can be categorized into one of four distinct categories based on the environmental context in which the skill is performed, open versus closed, and the absence or presence of intertrial variability (Table 3.1, see Chapter 2 for a complete discussion on environmental context). Higgins and Spaeth (1972) reported one of the only studies that specifically tested the effect of the type of task on the changes in coordination observed with practice. They compared open versus closed skills, to test the fixation versus diversification predictions proposed by Gentile (1972). In this study, the participant who trained on the open skill was predicted to develop movement patterns, which could be adapted to the changing environment (Higgins & Spaeth, 1972). The participant learning the consistent task with no intertrial variability

Table 3.1. A representation of the four skill conditions based on environmental context (closed vs. open) and the absence or presence of intertrial variability (IV).

		<u>Intertrial</u>	
		Absent (Consistent)	Present (Variable)
<u>Environmental Context</u>	Stationary (Closed)	Closed task – w/ no IV	Closed task – w/ IV
	In Motion (Open)	Open task – w/ no IV	Open task – w/ IV

was predicted to produce a consistent movement pattern by the later stages of learning, which would match the environmental condition in which he or she trained. For the closed task, the authors observed a smooth and consistent movement pattern later in practice, which supported the “fixation” movement predictions. The participant who practiced the open skill acquired a

flexible movement pattern that was adapted to the various task conditions, which supported the “diversification” movement predictions. These findings did support Gentile’s (1972) predictions for the effect of environmental context on movement strategies, but only two subjects were used in this study with only two manipulations to the environmental context. The four experiments in the present study extended the research by Higgins and Spaeth (1972), investigating open and closed tasks, with the addition of intertrial variability in two of the four experiments.

Experiments

The tasks learned in the four experiments in the present study were each based on one cell from the 2 X 2 skill matrix in Table 3.1. The experiments individually investigated open and closed skills, both with and without the addition of intertrial variability. In the first experiment, participants learned a closed task with no intertrial variability. Here the participants practiced throwing darts at a stationary target, which was projected in the center of the dartboard for each trial (closed task with no intertrial variability). For the second experiment, participants practiced a closed task, with intertrial variability. The stationary target was randomly projected in one of five locations on the dartboard for each trial (closed task with intertrial variability). For the last two experiments the target was moving at a constant speed (0.05 Hz) as the participant attempted to land the dart within the target circle. For Experiment 3, the target appeared on the left-hand side of the dartboard, moved horizontally across the board to the far right side, and reversed direction until it returned to its starting location. The pattern of movement was the same for each trial providing an environmental context that was in motion with no intertrial variability (open task with no intertrial variability). For the fourth experiment, the learners practiced hitting a moving

target, which randomly appeared in one of five locations and moved across the board and back to its starting location in a linear pattern (open task with intertrial variability).

These four task manipulations allowed the hypotheses to be tested by evaluating performance consistency and movement adaptability by measuring the kinematics of the upper body during training on the dart throwing tasks. Gentile's (2000) work provided a theoretical framework for the experiments investigating the complex interactive processes involved in the acquisition of motor skills. During skill acquisition the learner must adapt and adjust their performance given the environmental and morphology constraints (Gentile, 2000). Measuring the movement patterns used to perform each of the four task variations of the skill allowed for assessments of how the learner adapted the skill to specific task parameter specifications. As the learner practiced the tasks with intertrial variability (i.e. target appearing in different locations each time), the movement pattern should have adapted to the changing environment. Of interest was how the coordination of these movement patterns changed during learning and how the joint-linkages correlated with one another explaining how the degrees of freedom were controlled as the movement was produced. In the four studies, participants learning to throw the dart were expected release their degrees of freedom during the three days of practice. This release in degrees of freedom was also expected to occur from the upper body and shoulder and move towards the elbow and wrist to throw the dart. As the movement at the shoulder decreased and the joint was controlled, the performer would increase the moment at the wrist and produce the movement more from this joint.

Another analysis that is available with a study in an open and closed environment is to observe how the movement variability changes across practice. This can be measured with the cross-correlations of the movements used at the end of practice compared to those used

throughout practice. An increase in the cross-correlation values would indicate a decrease in movement variability, and that the movement was produced more consistently. This is also an indication of how the learner gained control of the movement during learning (Gentile, 2000). Measuring the joints, which display a decrease in movement variability, and comparing these changes to the displacement of each joint during the throw allowed the researcher to extrapolate how the movement was learned. The pattern of movement control from the shoulder initially, followed by the elbow or wrist, indicated the person was learning to control their movements throughout the task and was performing the task more efficiently. These measurements also addressed whether the changes in the coordination patterns followed a proximal to distal direction.

Experiment 1 - Closed (Closed Task with no Intertrial Variability)

The dart throwing task was performed in a completely closed environment. The target appeared in the middle of the dartboard and remained stationary as the learner threw the dart. These conditions were the same for every trial indicating no intertrial variability was present in this experiment. This environmental context provided low task demands because the target was stationary and low attention demands because the target appeared in the same location each trial. It was hypothesized that the participants would have a variable movement pattern early in practice, which would become consistent across the three days of practice. The greatest change was hypothesized to occur on the first day due to the low task demands, and would become consistent with practice due to the absence of intertrial variability. This would be consistent with what was proposed by Gentile (2000), indicating the largest changes in movement occur early in practice. Smaller changes are observed later in practice as the

person refines their movement pattern and becomes more efficient. The degrees of freedom were hypothesized to be released in a proximal to distal direction. This strategy would be observed if the range of motion at the shoulder decreased with practice and the range of motion at the wrist increased with practice. This change would indicate the shoulder would be controlled with practice, while the majority of the movement would be produced from the wrist and elbow joints by the end of practice.

Method

Participants

Eight volunteers participated in this experiment. Participants (7 females and 1 male with a mean age of 22.57 years) were recruited from undergraduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The dartboard was made of a 1.22 X 1.22 m sheet of insulation Styrofoam suspended from the ceiling. A wooden bookcase was placed with its back against the back of the dartboard to stabilize the board after each throw, minimizing the sway of the target for each trial. An X Y grid was printed in centimeters on a 0.91 m X 1.22 m sheet of white bond paper with coordinate (0,0) in the center of a paper. The paper was then centered on the Styrofoam and the grid was used to calibrate the target location prior to data collection and to measure the X, Y coordinates of the dart's location after each throw. The target was a red circle (14 ½

in diameter) projected to the dartboard, with the center of the target placed at coordinate (0,0) for each trial (Figure 3.1). The target was presented using a program (written in Labview, see Appendix D) projected through a projector (Infocus) onto the dartboard. The eight high-definition MCam cameras with Vicon's optical motion capture system were placed in a circular pattern around the throwing area, with the dartboard hanging from the ceiling (Figure 3.2). Kinematic data was recorded using this eight-camera system, including a Sony digital video

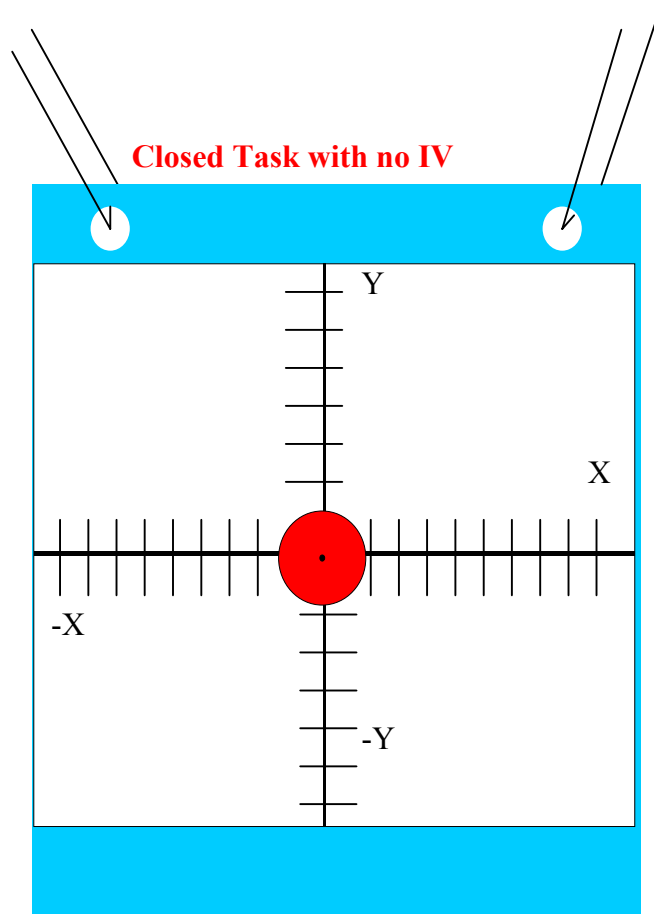


Figure 3.1. Diagram of target and board, suspended from the ceiling.

camera used to collect video data simultaneously with the kinematic data collected. One computer (CompUSA) was used as the platform for the Labview software (used to create and run the experiment which presented the target for each trial). This computer was also used to input the X and Y locations of the dart and target for each trial. A different computer (Dell Computer Corporation) was used to run the Vicon 612 system to collect the kinematic data and video files once every 20 trials (i.e. the 20th trial, 40th, 60th, etc.).

Procedure

After reading the written instructions, 20 reflective markers (14 mm in diameter) were placed on the upper body and throwing arm of the participant. Participants placed a headband with four reflective markers on their head, and a wristband (containing a plastic bar with two markers on either side) on their right wrist. The experimenter then attached reflective markers, using small squares of double sided tape, to the left and right posterior sacro-iliac spines (PSIS), spinous process of the 7th cervical vertebrae (C7), spinous process of the tenth thoracic vertebrae (T10), on the back; and left and right anterior superior iliac spines (ASIS), the sternal notch (clav), and the xiphoid process of the sternum (strn) on the front of the body. On the throwing arm, markers were placed on the shoulder (acromio-clavicular joint), upper arm, elbow (lateral epicondyle), forearm, and hand (third metatarsal) (see figure 3.3). Once all the markers were placed on the participant he or she was then asked to stand still for five seconds while the static kinematic trial was collected. This static trial allowed for the computerized labeling of the markers to create a subject calibration file for each participant each day. The participant was then given a standard metal dart (22 g), which had one reflective marker attached just past the tip towards the tail.

The participant stood 3 m from the dartboard and just to the right of the projector (see the black rectangle and blue markings in figure 3.2). For each throw, participants started with their throwing arm at a 90° angle prior to the presentation of the target. They were told to begin their throw soon after the target appeared on the dartboard. The participant measured the X and Y coordinates of the dart and these values were entered into the computer to calculate the outcome measures (see Chapter 2 for full details). The dart was then removed from the dartboard and the participant returned to the same start location to prepare for the

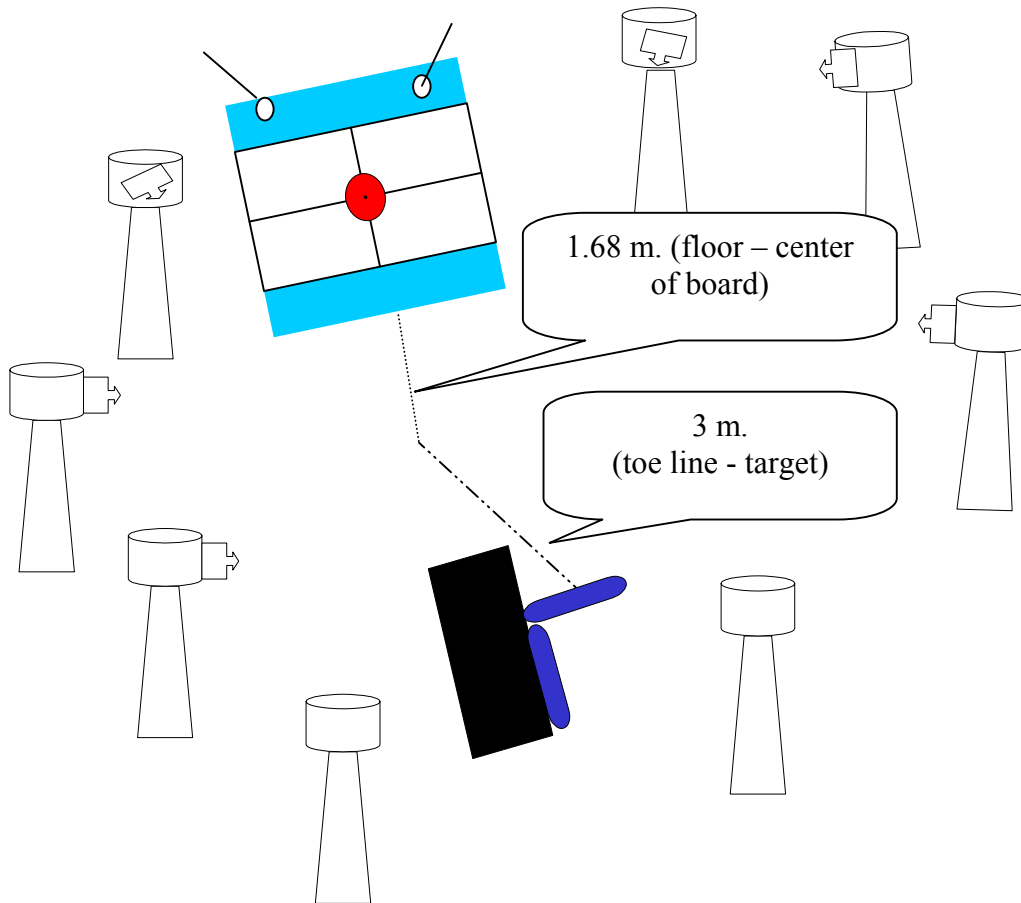


Figure 3.2. Diagram of the camera placement, projector location, toe line, and dartboard.

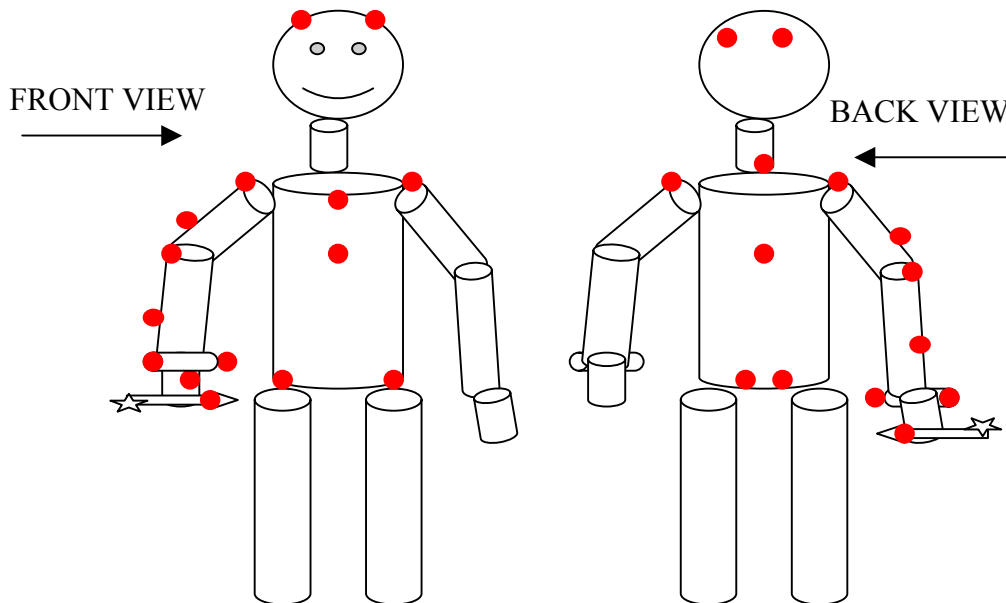


Figure 3.3. Diagram representing the marker placement on the participants and the dart.

next trial. Markings on the floor assured the participants returned to the same start location for each trial. The participant raised his arm to 90° to indicate he or she was ready for the next throw, the board was cleared of any projected images, and the target reappeared for the following trial. The participants trained for approximately one hour, performing 160 trials each day for three days. Before removing the markers, the shoulder offset, elbow width, wrist thickness, hand thickness, and body weight for the participant was measured and recorded.

Data Reduction

After the data were collected, the individual body measurements were entered into the Vicon Workstation software to calculate the joint centers and these data were then processed to calculate joint displacement based on the static calibration trial. The position data for the upper body were calculated for every kinematic trial and the dart throws were normalized from the beginning of the throw (100 frames before dart release) to the end of dart follow through (100 frames following dart release). These data were then imported into the Vicon Polygon software. The Polygon software was used to extract the position data for the shoulder, elbow, and wrist, to be exported to Excel for preparation prior to any statistical analyses. Some trials had missing data and so every trial could not be used in the calculations. To reduce the large amounts of data to a more reasonable amount, the raw data were graphed in Excel and a representative pre-trial (chosen from the first four kinematic trials, first 80 throws) and post-trial (chosen from the last four kinematic trials, last 80 throws) for each day were extracted. In addition to the pre and post trials, data from the last five kinematic trials of day 3 were averaged to determine the movement pattern used at the end of practice for each participant for each joint. The averaged trial from day 3 and the six pre/post trials were used in the cross-correlation calculations and analyses. Because cross-correlation

values only occur between -1 and +1, this results in non-normal data. A Fisher Z log transformation of the cross-correlation values, performed before these data were analyzed, allowed parametric statistics to be performed on these data.

Results and Discussion

The kinematic data were used to identify the changes occurring with practice in the movement coordination. The movement coordination was identified as the displacement of a specific joint during the dart throw. The changes in the movement patterns used during the three days of practice were used to understand how these changes affected the overall performance of the tasks. The cross-correlations of the angular displacement during the dart throw cycle were calculated for each of the joints (elbow, shoulder, wrist) and the joint-linkages (elbow-shoulder, wrist-elbow, shoulder wrist) to indicate the coordination within and between the joints over the three days of practice. The significant differences level for all analyses was set at $p < 0.05$.

Comparisons of the Movement Patterns at Each Joint

The averaged trial, from the last five trials of day 3, was used as the representative movement pattern to be correlated with each of the six pre- and post- trials from the three days of practice. These cross-correlation calculations allowed for comparisons of the movement patterns across time for the shoulder, elbow, and wrist. These comparisons also indicated whether the participants were 1) changing the movement pattern used across time, and 2) if they were becoming more consistent by the end of practice.

It was hypothesized that the movement pattern used would become more consistent as the participant became more practiced in the closed task. To test this hypothesis, the cross-correlations of the movement pattern used on the last trial were correlated with every other

trial. Cross-correlations ranged from 0.88 on day 1 to 0.99 on day 3 for the elbow, 0.64 to 0.96 for the shoulder and 0.57 to 0.98 for the wrist. The low cross-correlations on day 1 indicated the learners used a different movement pattern early in practice from that used on day 3. The high cross-correlations on day 3 indicated the participants were consistent in their movement pattern by the end of the practice. The log transformations of the cross-correlations for the movement pattern at the shoulder, wrist, and elbow joints across the three days are shown in Figure 3.4. These data show that the movement patterns at each joint changed with practice and the three joints changed at a similar rate to each other.

The transformed cross-correlation values were analyzed using a 3 X 6 (joint X trial) analysis of variance, repeated measures design. This analysis revealed a significant main effect for time $F(5, 10) = 13.12; p < 0.05$, and joint, $F(2, 10) = 6.60; p < 0.05$. Post-hoc analysis revealed day 3 to be significantly different from days 1 and 2, and the change in the

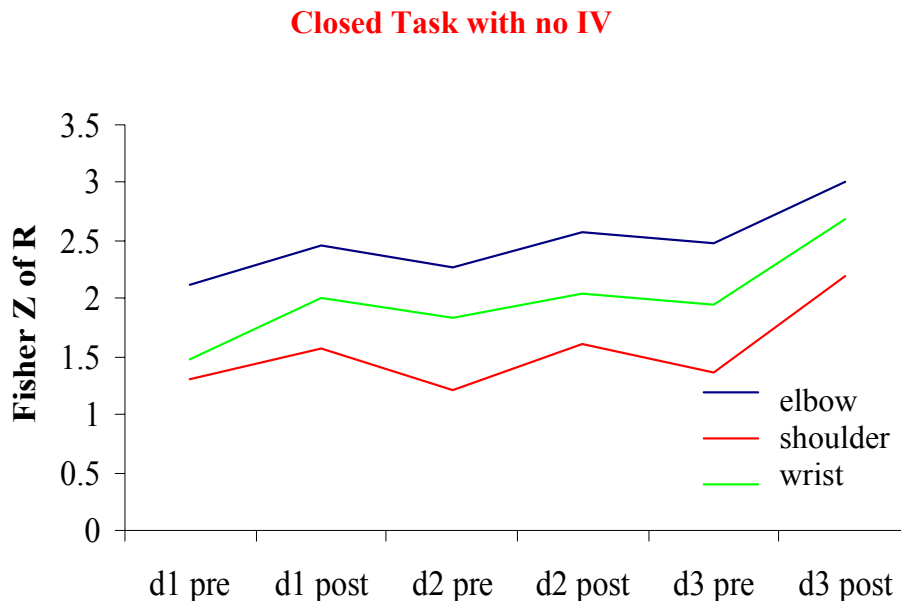


Figure 3.4. Fisher Z transformation of the cross-correlation values across time comparing displacement at each joint.

movement pattern at the elbow to be significantly different from the changes at the shoulder and wrist joints. The participants practicing a closed task with no intertrial variability were hypothesized and observed to use a consistent movement pattern by the end of the three days of practice. These findings support the fixation hypothesis put forth by Gentile (2000) stating the consistent environmental context will result in a consistent movement pattern. This consistent movement pattern was observed by comparing the displacement at each joint from multiple throws on day 3. If this pattern was similar and if the cross-correlation value was high at the end of day 3, the movement pattern was identified as consistent.

Comparisons for Each Joint-Linkage

It was hypothesized that participants would change their coordination patterns from a freezing to a freeing of degrees of freedom, with practice. This change in the relationship of the degrees of freedom was also expected to be in a proximal to distal direction. The movement from the upper body and shoulder observed initially in practice, was expected to decrease as the person became more skilled. The cross-correlations of the angular displacement at each of the joint-linkages were calculated using the pre and post trials. The log transformations of the cross-correlations for the movement pattern at the joint-linkages across the three days are shown in Figure 3.5. Comparing the movement patterns of the elbow to the wrist, wrist to the shoulder, and elbow to the shoulder provided an indication of the relationship and timing between the joints and the degrees of freedom used. To test if a release in the degrees of freedom was observed, and if this occurred in a proximal to distal direction, analysis on the joint-linkages (elbow-wrist, wrist-shoulder, and elbow-shoulder) was performed. A 3 X 6 (joint-linkage X time) analysis of variance, repeated measures design was performed on the transformed data. This analysis revealed a significant main

effect for joint linkage $F(2, 10) = 18.82$; $p < 0.05$. Post-hoc analysis revealed the elbow-wrist linkage to be significantly different from the elbow-shoulder and shoulder-wrist linkages.

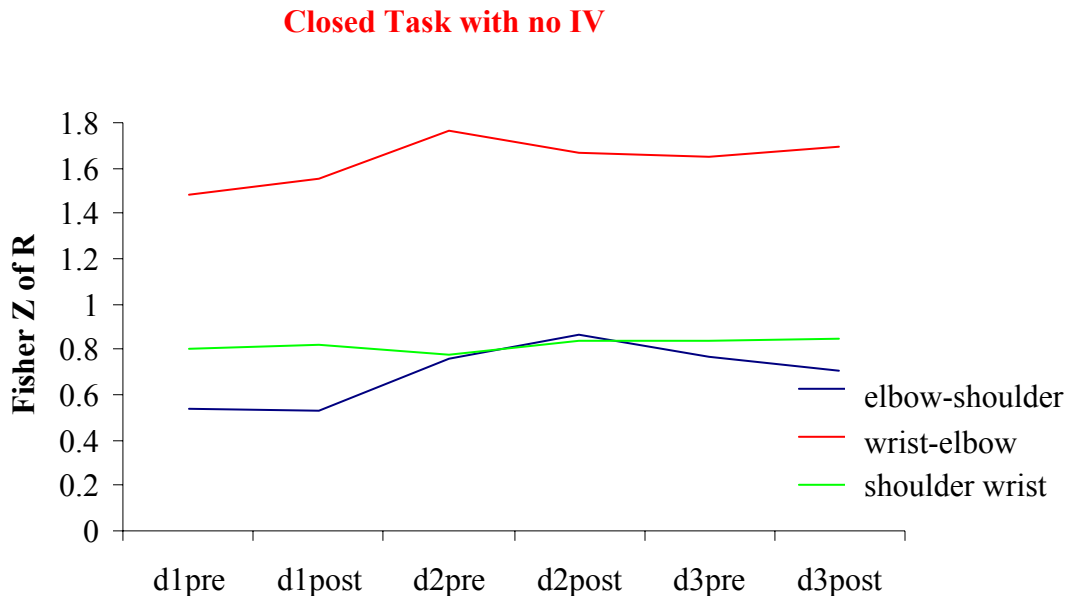


Figure 3.5. Fisher Z transformations of the cross-correlation values for the elbow-shoulder, wrist-elbow, and the shoulder-wrist joint-linkages, comparing displacement patterns between two joints.

These findings provided support for the proximal to distal trend in which the degrees of freedom were controlled. The shoulder had lower cross-correlation values when compared to both the elbow and wrist, while the elbow-wrist linkage, which is the most distal linkage, had the highest cross-correlations. What was not observed, but was expected was a significant change in the degrees of freedom during the three days of practice within each joint-linkage. The small changes within each joint from day 1 to day 3 were not significant ($p > 0.05$) and so these data did not provide a strong indication in the release of the degrees of freedom over time.

Movement Pattern Changes

To explain the changes in the movement that led to the changes in the cross-correlation values, the movement patterns used at each joint on days 1 and 3 were compared to one another. Figure 3.6 provides a graphical representation of what movement patterns an exemplar participant used on day 1 compared to the movements used on day 3, for the shoulder, elbow, and wrist. The exemplar participant was chosen based on the similarity in the displacement patterns to the majority of the participants, and was used to demonstrate the changes in the movements. This graph indicated the participant's elbow moved through a smaller range of motion by day 3, while the range of motion at the wrist increased by the end of practice. These changes are consistent with the proximal to distal direction of the cross-correlations observed for each of the joint-linkages. There appeared to be less movement at the shoulder as the participant threw the dart. What can also be observed is the timing shift in the movement coordination at each of the joints from day 1 to day 3. Comparing the pattern used on day 1 to day 3, with the dart release indicated a change in the range of motion at each joint and the timing of when the dart was released. This movement strategy can be observed in the three-dimensional (3D) representation of the upper body. The link below allows you to view the changes of a representative participant from day 1 and day 3. This program allows the movements to be viewed from any angle. The two synchronized throws taken from day 1 indicate the movement patterns are inconsistent; however, the two synchronized throws taken from day 3 indicate the movement patterns are more consistent and have changed with practice. This 3D representation of the exemplar participant provides a clearer representation of the of the changes in the movements used over time. In the synchronized throws taken from day 1 the participant is observed throwing the dart using the shoulder and wrist, while

the those taken from day 3 show more control at the shoulder with the movement produced at the wrist and elbow (Figure 3.7).

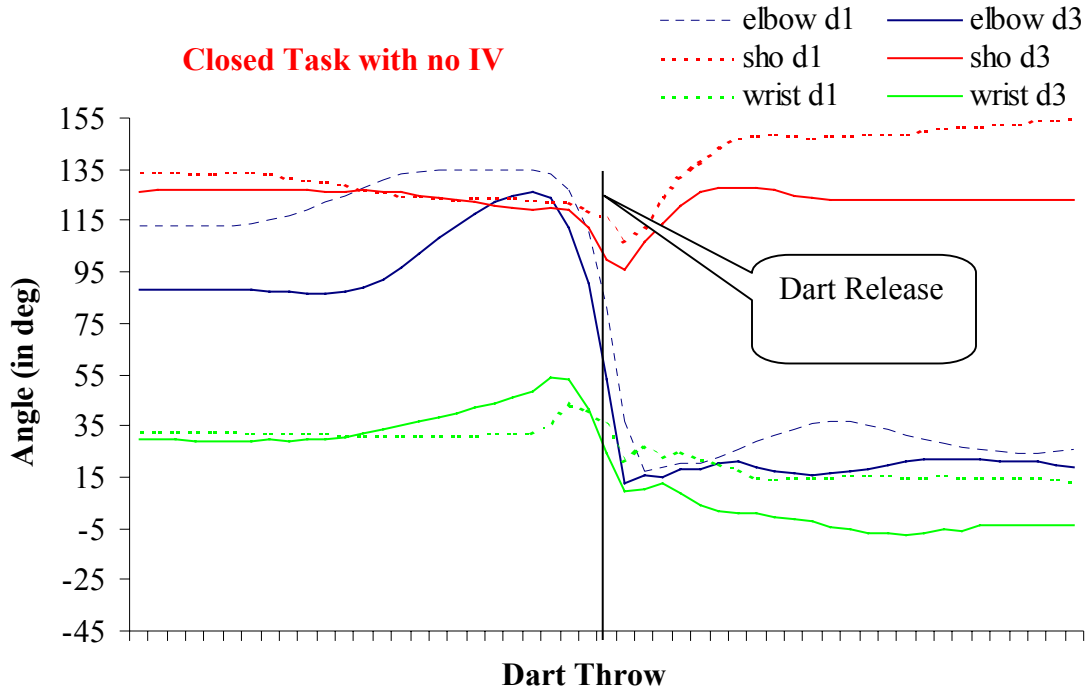


Figure 3.6. A representative participant’s angular displacement during a single dart throw on day 1 (d1) and day 3 (d3), normalized to 100%.

[Click here to see a 3-D imaging of the dart throws.](#) Diamonds represent the upper body and throwing arm used to perform the task.

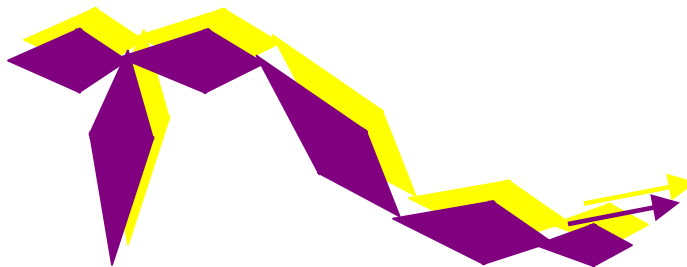


Figure 3.7. Three-dimensional images of an exemplar participant from day 1 and day 3. Compares movement coordination used on two trials synchronized from day 1 and two trials synchronized from day 3.

Experiment 2 (Closed) (Closed Task with Intertrial Variability)

The dart throwing task was performed in a closed environmental context with intertrial variability. The target appeared in one of five locations on the dartboard and remained stationary as the learner threw the dart. Each of the five target locations was presented 32 times each day in a random pattern. This environmental context provided low task demands because the target was stationary, with high attentional demands because the participant did not know where the target would appear for each trial. It was hypothesized that the participants would begin with a variable movement pattern that would adapt to the task demands of the five target locations during the three days of practice. The higher value of the cross-correlations between the movements used on day 3, the more consistent the participant is in their movement coordination. Values that are less than one can be attributed to a participant using a variable movement pattern to adapt to the changing target locations. Because of the high attentional demands of the task, it was hypothesized that the release in the degrees of freedom would not occur until day 3 because of the time it would take for the participants to learn the task and achieve greater control in their movements.

Method

Participants

Eight volunteers, who had not participated in the first experiment, participated in this experiment. Participants (6 females and 2 males with a mean age of 20 years) were recruited from undergraduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The same apparatus described in Experiment 1 was used; however, the stationary target appeared in one of five locations on the dartboard each trial, in a counterbalanced-random order (Figure 3.8). The target disappeared before each trial and reappeared similar to Experiment 1, however the participant did not know where it would appear each time.

Procedure

After reading the written instructions, the 20 markers were attached to the participant. He or she was then shown the target projected on the dartboard and data collection began after all questions were

answered. The data were collected using the same procedures described in Experiment 1.

Data Reduction

The data were also reduced, calculated, and analyzed using the same procedures as were described for Experiment 1.

Results and Discussion

Comparisons of the Movement Patterns at Each Joint

It was hypothesized that the movement pattern used would become more adaptable as the participant became more practiced in the closed task with intertrial variability. To test this hypothesis, the cross-correlations of the movement pattern used on the last trial were correlated with every other trial. Cross-correlations ranged from 0.90 on day 1 to 0.99 on

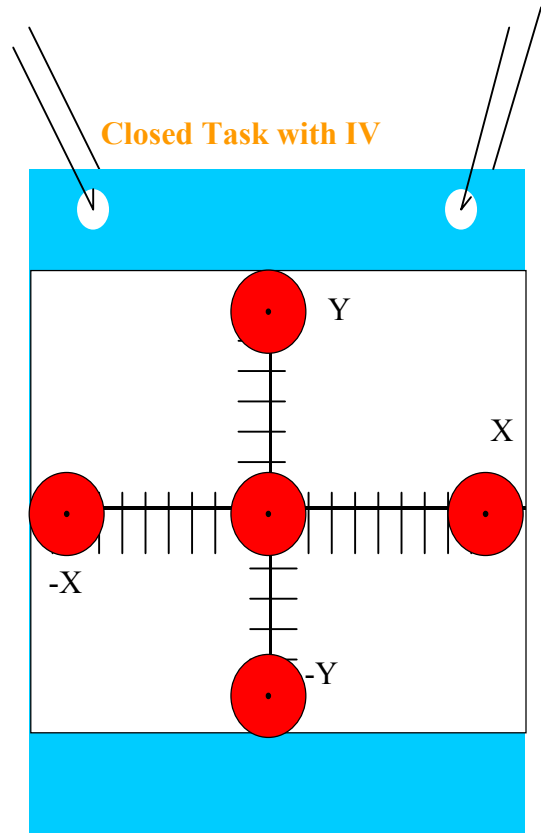


Figure 3.8. Diagram of target and board, suspended from the ceiling.

day 3 for the elbow, 0.72 to 0.99 for the shoulder and .81 to .99 for the wrist. These cross-correlation values indicate the participants used a different pattern and became more consistent, but there was not a large change in the movement pattern used on day 3 from that of day 1. The log transformations of the cross-correlations for the movement pattern at the shoulder, wrist, and elbow joints across the three days are shown in Figure 3.9. These data show that the movement patterns used at each joint changed over time and became consistent by the end of day 3.

The transformed cross-correlation values were analyzed using a 3 X 6 (joint X trial) analysis of variance, repeated measures design. This analysis revealed a significant main effect for time $F(5, 10) = 12.26; p < 0.05$. Post-hoc analysis revealed day 1 to be significantly different from days 2 and 3. The participants practicing a closed task with intertrial variability were observed using a more consistent movement pattern by the end of the three days of practice. The movements at each joint were not significantly different from each

Closed Task with IV

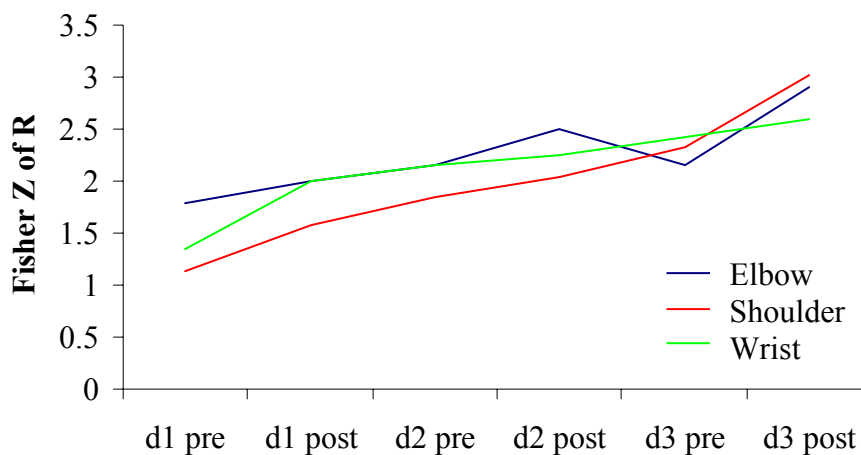


Figure 3.9. Fisher Z transformation of the cross-correlation values across time for each joint displacement comparison.

other indicating there was a similar change for all three joints. It was hypothesized that the participants would have a variable movement pattern that would adapt to the variable target locations; however, it appears that three days of practice was not enough time for the learners to advance far enough in the learning stages to accurately test this hypothesis.

Comparisons for Each Joint-Linkage

It was also hypothesized that participants would be observed changing their coordination from a freezing to a freeing of degrees of freedom with practice. This change in the relationship of the degrees of freedom was expected to change in a proximal to distal direction. The movement initially produced from the upper body and shoulder, was expected to decrease as the participant became more skilled with practice. The log transformations of the joint-linkage cross-correlations across the three days are shown in Figure 3.10. To test if a release in the degrees of freedom was observed, and if this occurred in a proximal to distal

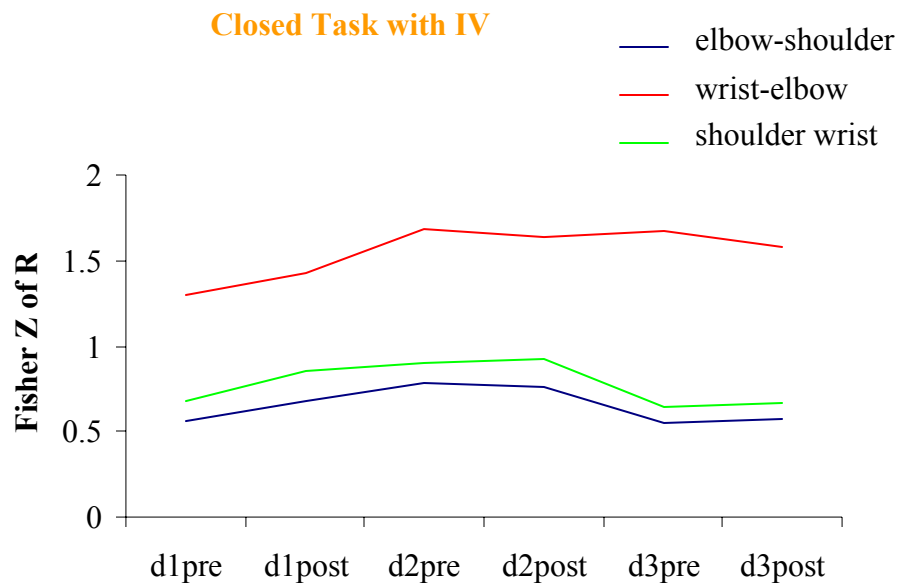


Figure 3.10. Fisher Z transformations of the cross-correlation values for the elbow-shoulder, wrist-elbow, and the shoulder-wrist joint-linkages.

direction, these joint-linkage data (elbow-wrist, wrist-shoulder, and elbow-shoulder) were analyzed. A 3 X 6 (joint-linkage X time) analysis of variance, repeated measures design was performed on the transformed data. This analysis revealed a significant main effect for joint linkage $F(2, 10) = 26.58; p < 0.05$. Post-hoc analysis revealed the elbow-wrist linkage to be significantly different from the elbow-shoulder and shoulder-wrist linkages. These findings provide support for the proximal to distal trend in which the degrees of freedom were controlled. The shoulder had lower cross-correlation values when compared to both the elbow and wrist, while the elbow-wrist linkage, which is the most distal linkage, had the highest cross-correlations. The lack of significance across time indicated the small changes observed during the three days of practice were not significantly different on day 3.

Movement Pattern Changes

To explain what changes occurred in the movement that led to the changes in the cross-correlation values, the movement patterns used at each joint were compared to one another for days 1 and 3. Figure 3.11 provides a graphical representation of what movement patterns an exemplar participant used on day 1 compared to the movements from day 3. This graph indicates the participant's elbow and shoulder moved through a similar range of motion during practice, while the range of motion increased at her wrist by the end of practice. These changes are consistent with the proximal to distal change observed in the joint-linkages.

What is most apparent in this graph is the timing shift of the movement pattern at dart release for all three joints, when the pattern used on day 1 is compared to day 3. This timing shift indicated the participant released the dart sooner in her dart throw movement pattern early in practice, which would result in a high release angle and a longer dart trajectory. The time it would take for the dart to reach the board would be longer than with a later release. On day 3,

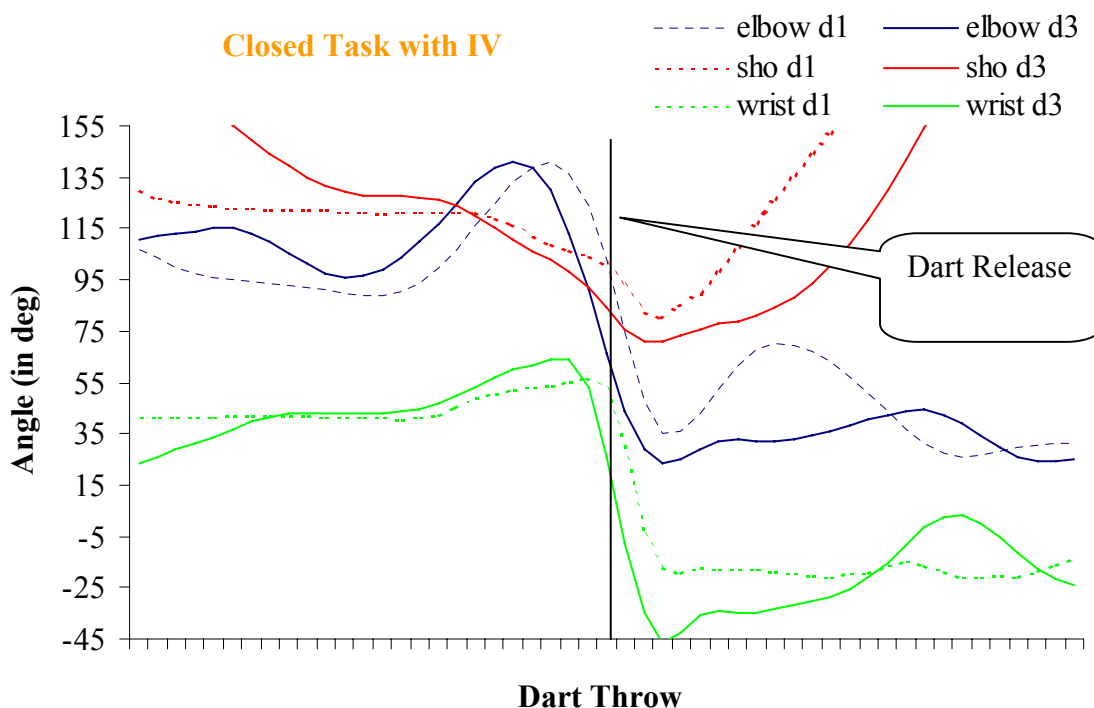


Figure 3.11. A representative participant’s angular displacement during a single dart throw on day 1 (d1) and day 3 (d3), normalized to 100%.

the participant is observed releasing the dart later in the throw indicating the arm had extended further before releasing the dart. This movement strategy would result in a high release angle and a shorter flight path. This movement strategy can be observed in the three-dimensional (3D) representation of the upper body. The link below allows you to view the changes of a representative participant from day 1 and day 3. This program allows the movements to be viewed from any angle. The two synchronized throws taken from day 1 indicate the movement patterns are inconsistent; however, the two synchronized throws taken from day 3 indicate the movement patterns are more consistent and have changed with practice. This 3D representation of the exemplar participant provides a clearer representation of the of the changes in the movements used over time. In the throws taken from day 1 the

participant is observed throwing the dart using a large range of motion and releasing the dart very high. The throws taken from day 3 show more control at the shoulder with the movement produced at the wrist and elbow and a flat release of the dart (Figure 3.12).

[Click here to see a 3-D imaging of the dart throws.](#) Diamonds represent the upper body and throwing arm used to perform the task.

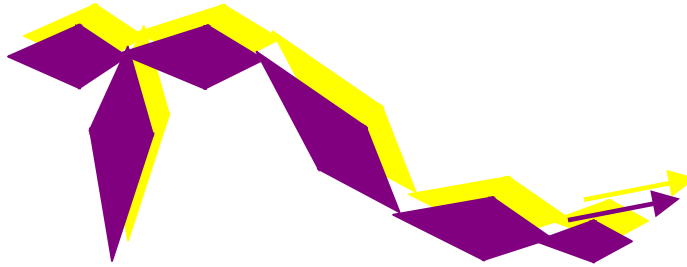


Figure 3.12. Three-dimensional images of an exemplar participant from day 1 and day 3. Compares movement coordination used on two trials synchronized from day 1 and two trials synchronized from day 3.

Experiment 3 (Open) (Open Task with no Intertrial Variability)

The dart throwing task was performed in an open environment with no intertrial variability. The target appeared on the left-hand side of the dartboard and moved horizontally across the middle of the dartboard to the far right side and then reversed direction and returned to its starting position at a constant speed of 0.5 Hz. These conditions were the same for every trial indicating no intertrial variability was present in this experiment. This environmental context provided high task and low attentional demands. It was hypothesized that the participants would have a variable movement pattern early in practice, which would become consistent across the three days of practice. The participants' movement patterns were hypothesized to become consistent with practice due to the absence of intertrial

variability. The changes were hypothesized to occur on the first two days due to the high task demands. This would be consistent with what was proposed by Gentile (2000), indicating the largest changes in movement occur early in practice. Smaller changes are observed later in practice as the person refines their movement pattern and becomes more efficient. The degrees of freedom were hypothesized to be released in a proximal to distal direction. This would be observed if the range of motion at the shoulder decreased indicating this joint was controlled with practice, and the range of motion at the wrist increased indicating the movement was produced from the wrist and elbow by the end of practice.

Method

Participants

Eight volunteers, who had not participated in the first two experiments, participated in this experiment. Participants (7 females and 1 male with a mean age of 24.75 years) were recruited from undergraduate and graduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The apparatus was the same as was described for Experiment 1; however, in this experiment the target appeared on the left side of the board and moved along the horizontal axis to the right side of the board and back to its initial starting point at a rate of 0.5 hz. (Figure 3.13). The target disappeared before each trial and reappeared similar to Experiment 1, however the participant was instructed to hit the moving target after it turned around and before it returned to its starting location. An accelerometer (Kistler) was placed on the back

of the dartboard and programmed to stop the target from moving as soon as the dart hit the board. The computer program and accelerometer were programmed to respond as the dart made contact with the board. This high sensitivity level allowed the target to stop moving when the dart made contact with the board and allowed for no visually detectable delays. This allowed the participants to receive the same visual feedback (the distance between the dart and the target) given to the participants in the first two experiments, and allowed for an accurate measurement of the target and dart to be recorded.

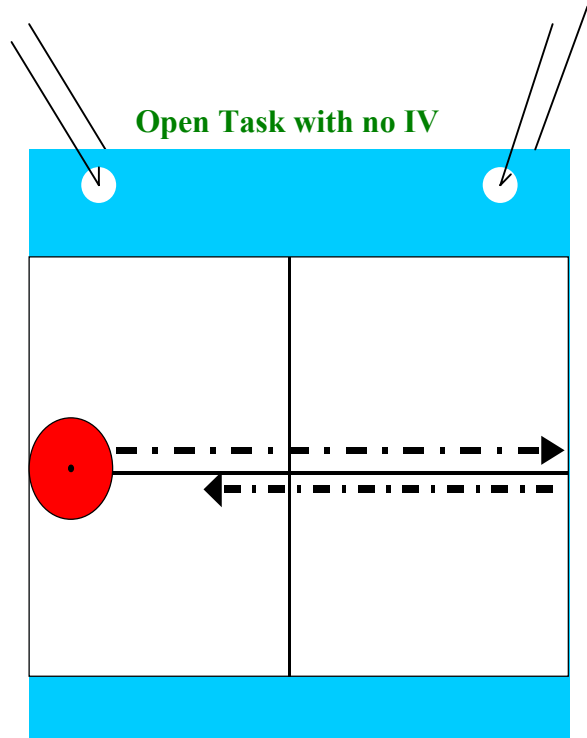


Figure 3.13. Diagram of target and board, suspended from the ceiling.

Procedure

After reading the instructions the participant was shown the target projected on the dartboard and data collection began if there were no questions. The data were collected using the same procedures as described in Experiment 1.

Data Reduction

The data were also reduced, calculated, and analyzed using the same procedures as were described for Experiment 1.

Results and Discussion

The kinematic data were used to identify what changes occurred with time in the movement coordination patterns and how these changes affected the overall performance of

the tasks. The cross-correlations of the angular displacement during the dart throw cycle were calculated for each of the joints and the joint-linkages. The significant differences level for all analyses was set at $p < 0.05$.

Comparisons of the Movement Patterns at Each Joint

The averaged trial from the last five trials of day 3 was used as the movement pattern correlated with each of the six pre and post trials across the three days of practice. These cross-correlation calculations allowed for comparisons of the movement patterns across time for the shoulder, elbow, and wrist. These comparisons also indicated whether the participants were 1) changing the movement pattern used across time, and 2) if they were becoming more consistent by the end of practice.

It was hypothesized that the movement pattern used would become more consistent as the participant became more practiced in the open task with no intertrial variability. To test this hypothesis, the cross-correlations of the movement pattern used on the last trial were correlated with every other trial. Cross-correlations ranged from 0.95 on day 1 to 0.99 on day 3 for the elbow, 0.77 to 0.99 for the shoulder and 0.90 to 0.99 for the wrist. The log transformations of the cross-correlations for the movement pattern at the shoulder, wrist, and elbow joints across the three days are shown in Figure 3.14. These data show that the movement patterns used changed over time and become similar to each other by day 3; however, the movement patterns did not appear to change by a large amount. The relatively high cross-correlations on day 1 indicate the movement pattern used on day 1 was related to the pattern used on day 3.

Open Task with no IV

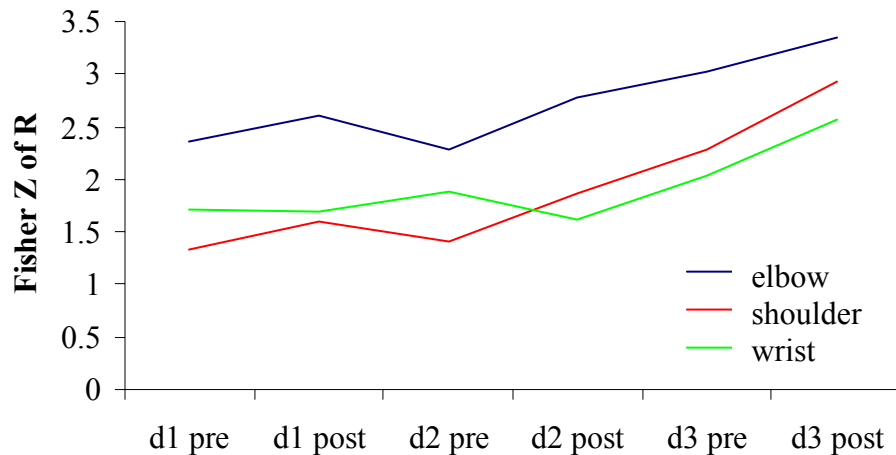


Figure 3.14. Fisher Z transformation of the cross-correlation values across time for each joint displacement comparison.

The transformed cross-correlation values were analyzed using a 3 X 6 (joint X trial) analysis of variance, repeated measures design. This analysis revealed a significant main effect for time $F(5, 10) = 10.06$; $p < 0.05$ and joint, $F(2, 10) = 10.90$; $p < 0.05$. Post-hoc analysis revealed day 3 to be significantly different from days 1 and 2, and the change in the movement pattern at the elbow to be significantly different from the change at the shoulder joint. The participants practicing the open task with no intertrial variability were observed using a consistent movement pattern by the end of the three days of practice. These findings support the fixation hypothesis put forth by Gentile (1972).

Comparisons for Each Joint-Linkage

It was hypothesized that participants would be observed changing their coordination from a freezing to a freeing of degrees of freedom with practice. This change in the relationship of the degrees of freedom was also expected to change in a proximal to distal

direction. The movement from the upper body and shoulder observed initially in practice, was expected to decrease as the person became more skilled. The six pre- and post- trials were also used to calculate the cross-correlations of the angular displacement of the joint-linkages comparing the movement patterns of the elbow to the wrist, wrist to the shoulder, and elbow to the shoulder. The log transformations of the cross-correlations for the movement pattern at the joint-linkages across the three days are shown in Figure 3.15. These calculations provided an indication of the relationship and timing between the joints in regards to the degrees of freedom used. To test if a release in the degrees of freedom was observed, and if this occurred in a proximal to distal direction, the joint-linkages (elbow-wrist, wrist-shoulder, and elbow-shoulder) were analyzed. A 3 X 6 (joint-linkage X time) analysis of variance, repeated measures design was performed on the transformed data. This analysis revealed a significant main effect for joint linkage $F(2, 10) = 18.58; p < 0.05$. Post-hoc analysis revealed the elbow-wrist linkage to be significantly different from the elbow-shoulder and shoulder-wrist linkages. These findings provide support for the proximal to distal trend in which the degrees of freedom were controlled. The shoulder had lower cross-correlation values when compared to both the elbow and wrist, while the elbow-wrist linkage has the highest cross-correlations and is also the most distal linkage. Although there were changes in the magnitude of the cross-correlations across the three days, these changes were not significant. The participants were observed decreasing their elbow-wrist linkage indicating the participants were beginning to release their degrees of freedom as was hypothesized.

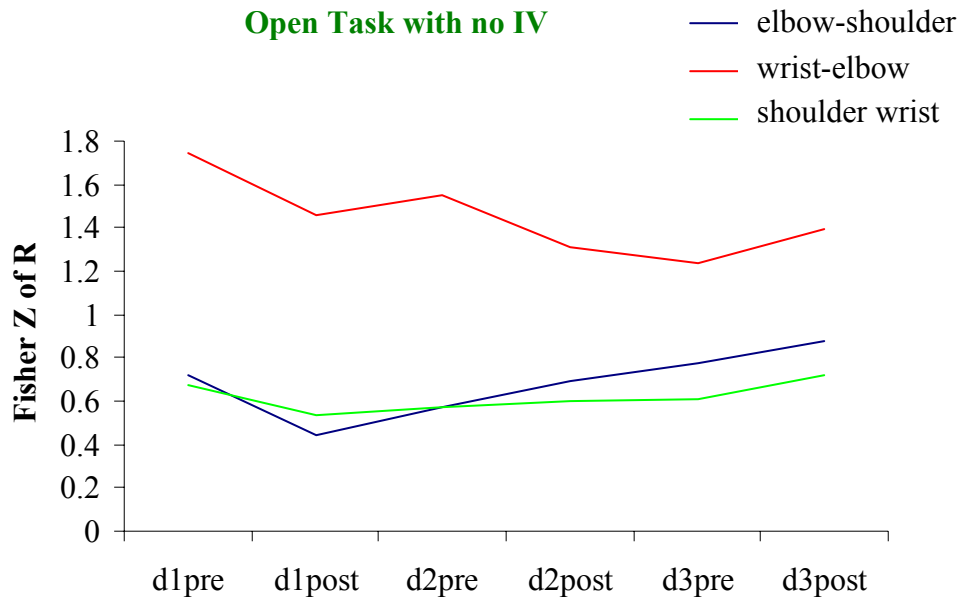


Figure 3.15. Fisher Z transformations of the cross-correlation values for the elbow-shoulder, wrist-elbow, and the shoulder-wrist joint-linkages.

Movement Pattern Changes

To explain what changes occurred in the movement that led to the changes in the cross-correlation values, the movement patterns used at each joint were compared to one another for days 1 and 3. Figure 3.16 provides a graphical representation of what movement patterns an exemplar participant used on day 1 compared to the movements from day 3. This graph indicates the participant had little change in the movement patterns used during practice. These changes are consistent with the proximal to distal change observed in the joint-linkages. What is most apparent in this graph is the small timing shift of the movement pattern at dart release for all three joints, when the pattern used on day 1 is compared to day 3. This movement strategy can be observed in the three-dimensional (3D) representation of the

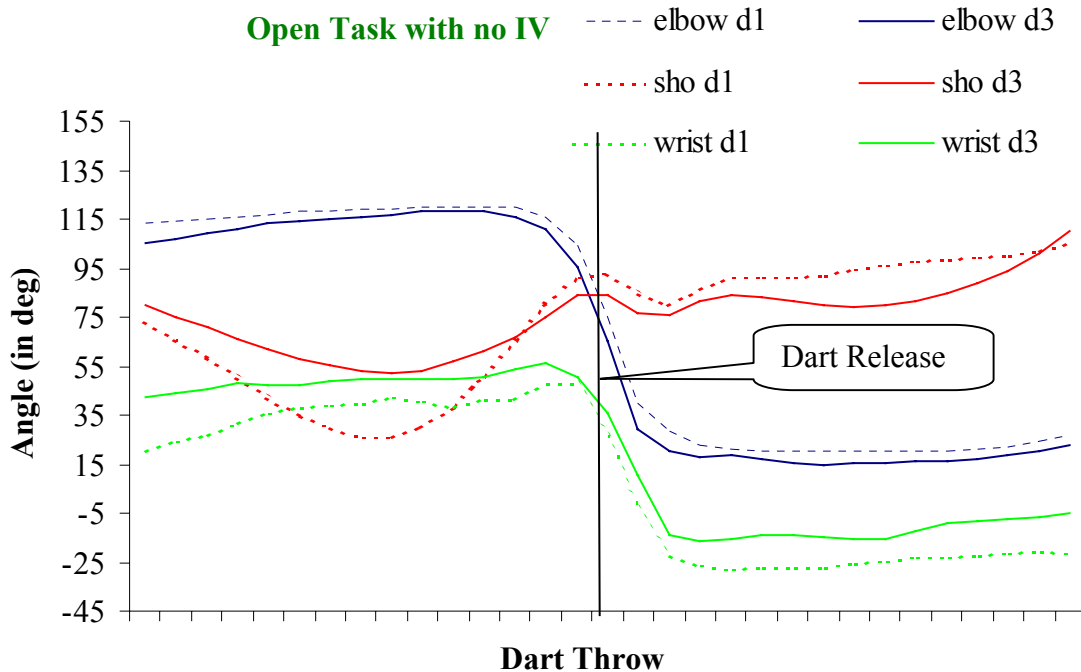


Figure 3.16. A representative participant's angular displacement during a single dart throw on day 1 (d1) and day 3 (d3), normalized to 100%.

upper body. The link below allows you to view the changes of a representative participant from day 1 and day 3. This program allows the movements to be viewed from any angle. The two synchronized throws taken from day 1 indicate the movement patterns are inconsistent; however, the two synchronized throws taken from day 3 indicate the movement patterns are more consistent and have changed with practice. This 3D representation of the exemplar participant provides a clearer representation of the changes in the movements used over time. In the throws taken from day 1 the participant is observed throwing the dart using a large range of motion and releasing the dart very high. The throws taken from day 3 shows more control with the body and the movement is produced from the shoulder, wrist, and elbow (Figure 3.17). These movement representations suggest the increase in difficulty

of the task results in a slower change in the movements. The participant is still using more degrees of freedom than are necessary indicating she is still in the earlier learning stages. For a more efficient throw she would only need to use her forearm and hand independently; however, she is still producing the arm movement by using her shoulder instead of controlling the movements at the shoulder joint.

[Click here to see a 3-D imaging of the dart throws.](#) Diamonds represent the upper body and throwing arm used to perform the task.

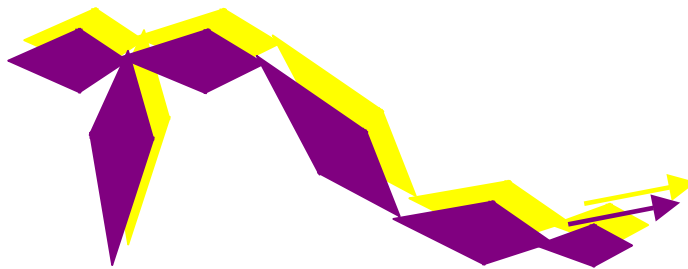


Figure 3.17. Three-dimensional images of an exemplar participant from day 1 and day 3. Compares movement coordination used on two trials synchronized from day 1 and two trials synchronized from day 3.

Experiment 4 (Open) (Open Task with Intertrial Variability)

The dart throwing task was performed in a completely open environment. The target appeared in one of five locations on the dartboard and moved across the dartboard in a linear pattern as the learner threw the dart. The starting location of the target varied for every trial producing intertrial variability for this open task. This environmental context provided high task and high attention demands. Due to the high task demands, it was hypothesized that the participants would develop a movement pattern that could be adapted to the changing environmental context during the three days of practice. This trend would follow the

predictions of the diversification hypothesis (Gentile, 1972). The greatest change in the movements used was hypothesized to occur on the last two days due to the difficulty in hitting a moving target.

Method

Participants

Eight volunteers, who had not participated in the first three experiments, participated in this experiment. Participants (5 females and 3 males with a mean age of 24.14 years) were recruited from undergraduate and graduate classes at Louisiana State University. Participants completed a survey, which included questions specific to dart throwing and related throwing experiences, and only those with limited dart experience (less than three times per year) participated in the study. All preferred their right hand for throwing.

Apparatus

The same apparatus was used as was described in Experiment 3; however, in this experiment the target appeared in one of five locations on the board and moved to the opposite side of the board and back in a linear pattern (Figure 3.18). The board was cleared of all images before the target was presented for each trial. The target appeared and began moving similar to Experiment 3,

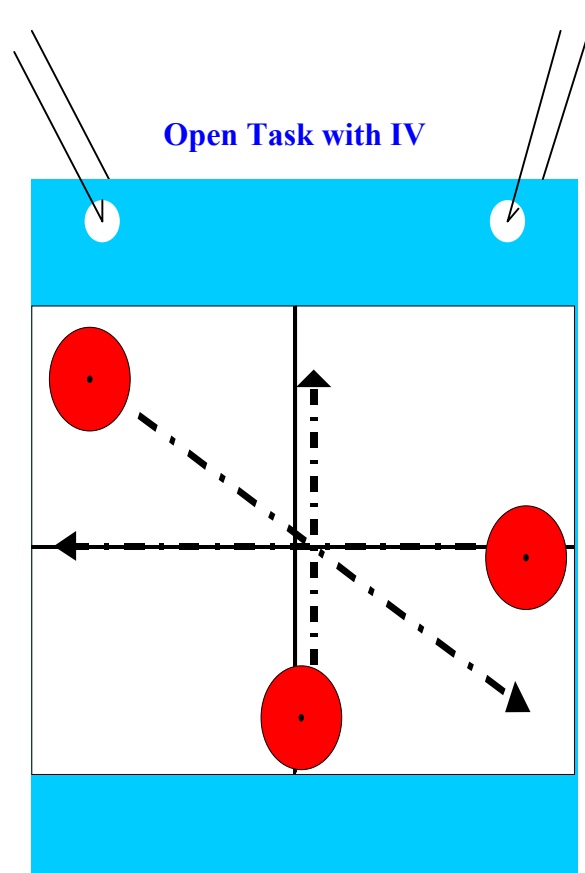


Figure 3.18. Diagram of 3 of the 5 targets, on the suspended board.

however the participant did not know the starting location or the direction the target would move. The participant was instructed to hit the moving target after it had turned around and before it returned to its starting location.

Procedure

After reading the written instructions, the participant was shown the target projected on the dartboard and data collection began after all questions were answered. The data were collected using the same procedures as described in Experiment 1.

Data Reduction

The data were also reduced, calculated, and analyzed using the same procedures as were described for Experiment 1; however, only six participants were used in the analyses because of technical problems in exporting the data for two of the participants.

Results and Discussion

The kinematic data were used to identify what changes occurred with time in the movement coordination patterns and how these changes affected the overall performance of the tasks. The cross-correlations of the angular displacement during the dart throw cycle were calculated for each of the joints and the joint-linkages. The significant differences level for all analyses was set at $p \leq 0.05$.

Comparisons of the Movement Patterns at Each Joint

The averaged trial from the last five trials of day 3 was used as the movement pattern correlated with each of the six pre and post trials across the three days of practice. These cross-correlation calculations allowed for comparisons of the movement patterns across time for the shoulder, elbow and wrist. These comparisons also indicated whether the participants

were 1) changing the movement pattern used across time, and 2) if they were becoming more consistent by the end of practice.

It was hypothesized that the movement pattern used would become more consistent as the participant became more practiced in the closed task. To test this hypothesis, the cross-correlations of the movement pattern used on the last trial were correlated with every other trial. Cross-correlations ranged from 0.94 on day 1 to 0.99 on day 3 for the elbow, 0.72 to 0.96 for the shoulder and 0.89 to 0.97 for the wrist. These values indicate the movement pattern changed over time; however, the small difference between the cross-correlation values indicates the movement used on day 3 is related to the pattern used on day 1. The log transformations of the cross-correlations for the movement pattern at the shoulder, wrist, and elbow joints across the three days are shown in Figure 3.19. These data show that the movement patterns used changed over time and become similar to each other by the end of day 3. These results were analyzed using a 3 X 6 (joint X trial) analysis of variance, repeated

Open Task with IV

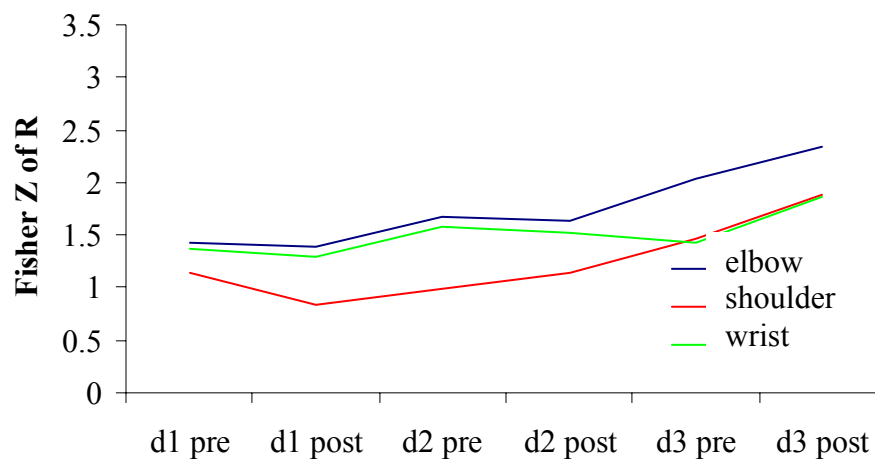


Figure 3.19. Graph of the Fisher Z transformation of the cross-correlation values across time for each joint.

measures design on the transformed cross-correlation values. This analysis revealed a significant main effect for time $F(5, 10) = 5.5; p < 0.05$. Post-hoc analysis revealed day 3 to be significantly different from days 1 and 2. The participants practicing the open task with intertrial variability were observed to have the greatest change at the end of the three days of practice due to the high task demands.

Comparisons for Each Joint-Linkage

It was hypothesized that participants would be observed changing their coordination from a freezing to freeing of degrees of freedom with practice. This change in the relationship of the degrees of freedom was also expected to change in a proximal to distal direction. The movement from the upper body and shoulder observed initially in practice, was expected to decrease as the person became more skilled. The six pre- and post- trials were also used to calculate the cross-correlations of the angular displacement of the joint-linkages comparing the movement patterns of the elbow to the wrist, wrist to the shoulder, and elbow to the shoulder. The log transformations of the cross-correlations for the movement pattern at the shoulder, wrist, and elbow joints across the three days are shown in Figure 3.20. These values provided an indication of the relationship and timing between the joints with regards to the degrees of freedom used. To test if a release in the degrees of freedom was observed, and if this occurred in a proximal to distal direction, analysis on the joint-linkages (elbow-wrist, wrist-shoulder, and elbow-shoulder) were performed.

A 3 X 6 (joint-linkage X time) analysis of variance, repeated measures design was performed on the transformed data. This analysis revealed a significant main effect for joint linkage $F(2, 10) = 7.56; p < 0.05$. Post-hoc analysis revealed the elbow-wrist linkage to be significantly different from the elbow-shoulder and shoulder-wrist linkages. These findings

provide support for the proximal to distal trend in which the degrees of freedom were controlled. The shoulder had lower cross-correlation values when compared to both the elbow and wrist, while the elbow-wrist linkage has the highest cross-correlations and is also the most distal linkage. This shows the participant threw the dart while the elbow and wrist moved as a fixed unit. Although there was a decrease in the cross-correlation values during the three days of practice, the magnitude of the changes was not significant. This indicates

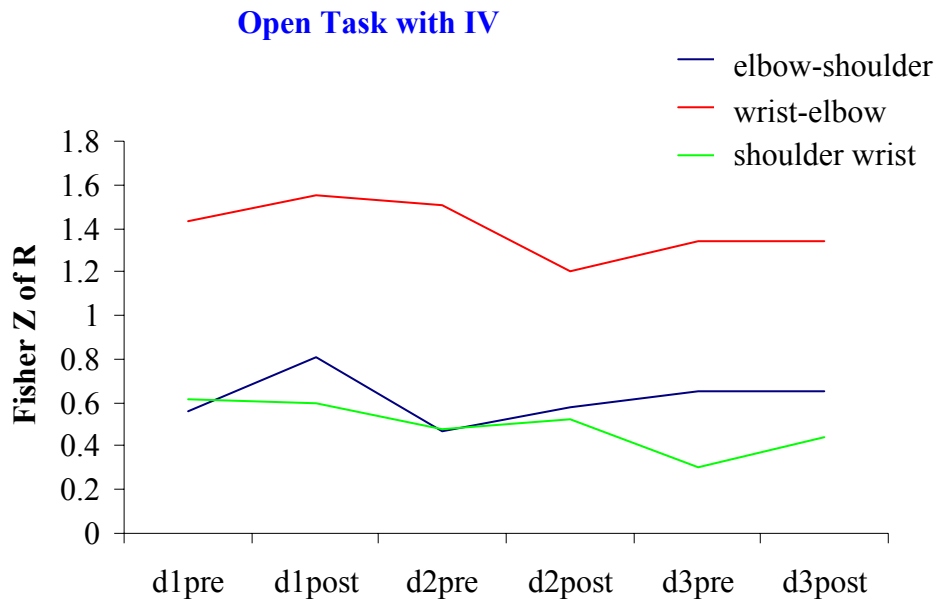


Figure 3.20. Fisher Z transformations of the cross-correlation values for the elbow-shoulder, wrist-elbow, and the shoulder-wrist joint-linkages.

the participants were beginning to release their degrees of freedom but have not completely uncoupled the joints.

Movement Pattern Changes

To explain what changes occurred in the movement that led to the changes in the cross-correlation values, the movement patterns used at each joint were compared to one another for days 1 and 3. Figure 3.21 provides a graphical representation of what movement

patterns were used by an exemplar participant on day 1 compared to the movements on day 3. This graph indicates the participant had little change in the movement patterns used during practice. These minimal changes in the movement coordination support the hypothesis that the task difficulty would affect the rate and magnitude of the coordination changes. What is most apparent in this graph is the timing shift of the movement pattern at dart release for all three joints. The participant is observed releasing the dart sooner during the throw on day 3, than she did on day 1.

The three-dimensional (3D) representation of the upper body taken from this exemplar participant provided a clearer representation of the changes in the movements used over time. The link below allows you to view the changes of a representative participant from day 1 and day 3. This program allows the movements to be viewed from any angle. The two

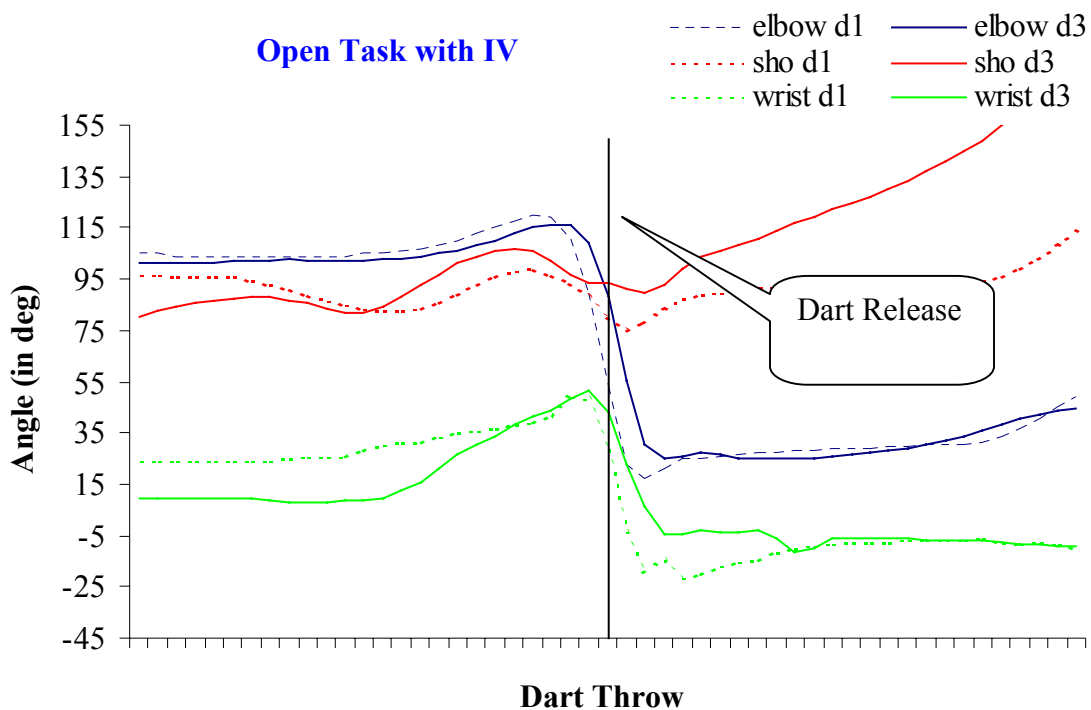


Figure 3.21. A representative participant’s angular displacement during a dart throw on day 1 (d1) and day 3 (d3), normalized to 100%.

synchronized throws taken from day 1 indicate the movement patterns are inconsistent; however, the two synchronized throws taken from day 3 indicate the movement patterns are more consistent and have changed with practice. In the throws taken from day 1 the participant is observed throwing the dart using a large range of motion and releasing the dart very high. In the video taken from day 1, the participant is observed throwing the dart using the body to move the arm during the dart throw. The throws taken from day 3 show the upper body involved in the dart throw producing the arm movement from the shoulder and elbow (Figure 3.22). This suggested the increase in difficulty of the task results in a small changes in the movements during the three days of practice. The participant is still using more degrees of freedom than are necessary indicating she is still in the earlier learning stages. This is seen in the increased movement at the shoulder joint and the elbow and wrist moving as a fixed unit. If the degrees of freedom had been released with practice, the participant would be using a more effective and possible a more efficient movement pattern. The additional movements at the shoulder as opposed to the wrist indicate the participant is using her upper

[Click here to see a 3-D imaging of the dart throws.](#) Diamonds represent the upper body and throwing arm used to perform the task.

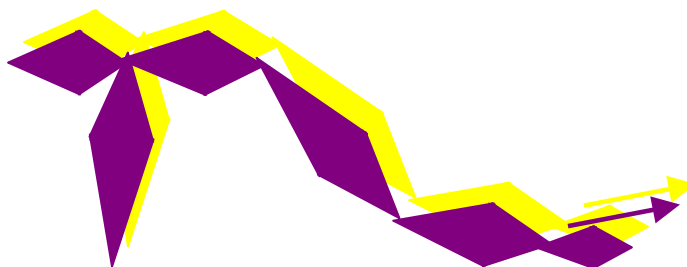


Figure 3.22. Three-dimensional images of an exemplar participant from day 1 and day 3. Compares movement coordination used on two trials synchronized from day 1 and two trials synchronized from day 3.

body to generate velocity instead of her arm. Because the participants were still in the early learning stages, it is difficult to test the diversification hypothesis. However, the 3D representations do provide indication that this hypothesis would have been supported. By comparing throws to the same target versus throws to a different target, the movements indicate the coordination patterns were similar for the same target; however there are slight differences when the participant had to throw to two different targets.

General Discussion

The four experiments tested the effect of task demands and attentional demands on the movement patterns used during performance within a specific environmental context. The specific interest was on identifying the changes in the movement coordination, over the three days of practice. Both the changes at each joint and the relationship between joints were observed during the three days of practice. These changes observed were also compared to the different environmental contexts in which the participants trained to identify how the different environmental contexts affected these changes. The difficulty level increased from Experiment 1 to 4, by placing the target in motion, and/or by introducing intertrial variability. The closed task without intertrial variability performed in Experiment 1 was the easiest (low task and low attentional demands), while the open task with intertrial variability performed in Experiment 4 was the most difficult (high task and high attentional demands). The results observed during the training on each task were consistent with what was expected when measuring the changes that occurred in the movements. Changes in the environmental context affected both the change in the coordination patterns used over time, and the rate of that change.

Comparisons of the Movement Patterns at Each Joint

The movement pattern used to throw the dart was observed at each joint and the displacement pattern was compared to the pre- and post-trials for each of the three days. The displacement at the elbow was significantly different than the shoulder and wrist for the two consistent tasks (no intertrial variability), while the variable tasks (with intertrial variability) revealed the shoulder and wrist to be similar. These results indicate the amount of intertrial variability in the environmental context had an more of an effect on the learning strategy used, than did changes to the regulatory conditions (stationary versus in-motion environment), when comparing changes in the movements at the joints.

Analysis of the cross-correlations of the movement patterns used at each joint was significantly different for each joint across time, for all four tasks. The displacement patterns of the wrist, elbow, and shoulder indicated changes occurred in the movement patterns used over time as novices trained on their respective tasks and in their respective environmental contexts. Across the three days of practice, learners became more consistent in the pattern used in all four contexts; however, the amount of change across the three days varied for the four contexts. The largest change in the cross-correlations comparing the movement patterns at each joint was observed for the closed task with no intertrial variability, while the two variable tasks had the smallest change in cross correlations of the movement pattern at each joint. These results indicate the increased attention demands detract from the attention that can be given to the movement coordination.

When intertrial variability was present, the overall change in the movement patterns was smaller than what was observed for the closed task with no intertrial variability. Although it was observed that in all four tasks the movement patterns changed with practice,

the magnitude of this change varied between the four tasks. For the tasks with intertrial variability, the magnitude of the change measured by the cross-correlation value did not change by as much as was observed for the closed task with no intertrial variability. These results provided support that the environmental context affects the demands placed on the learner and how he or she performs in the given environmental context. Because of the additional demands to the participant's attention and/or the increase in the task demands, the rate in which the tasks were learned was slower for the variable tasks than for the consistent tasks. The learners were able to attend to critical features in their environment that helped them to perform the task with some success, but they were unable to direct full attention to their movements and the changes that needed to be made to perform a more successful and effective movement pattern.

When the regulatory conditions were in motion, the results of the changes in the movement coordination were observed to be due to a timing shift in the movement patterns. On day 1, the participants training on the open tasks were observed to release the dart later in the movement pattern. This means that the elbow had extended further through the throwing motion before the dart was released when compared to day 3. By day three, the participants were observed releasing the dart sooner in the throwing motion. Because the targets were moving in this condition, the participants had to factor in the flight time of the dart and adjust their aim and the timing of their dart release. These changes, which would allow for a more accurate throw, explain why the changes observed were due to a timing shift rather than a different pattern of movement. The task difficulty slows the rate of movement coordination changes since their attention is on the outcome of their performance. This detracts their focus of attention from their movements and places it on their outcomes.

Comparisons for Each Joint-Linkage

Analysis of the cross-correlations of joint-linkages showed the elbow-wrist linkage to be significantly different from the elbow-shoulder and the shoulder-wrist linkages, for all four tasks. A trend analysis of the joint-linkages was performed to compare the changes that occurred during the training of the four tasks. This analysis was performed on the log transformation of the cross-correlations of the joint-linkages. The analysis revealed a significant interaction between the elbow-wrist joint-linkage and the task $F(3, 15) = 2.09$; $p < 0.05$. This interaction occurred because the two closed tasks showed a slight increase in their cross-correlations early in practice followed by a plateau, while the two open tasks showed a decrease in the cross-correlations at the elbow-wrist linkage. These observations suggest that the influence of environmental context had a different effect on the strategies used in relation to the release in the degrees of freedom with practice.

The type of task being learned has been observed to effect the direction in which the degrees of freedom are released (Arutyunyan, Gurfinkel, & Mirskii, 1968, 1969; Newell & van Emmerik, 1989; McDonald, van Emmerik, & Newell, 1989; Anderson & Sidaway, 1994; Broderick & Newell, 1999; Verijken, van Emmerik, Whiting, & Newell; 1992); however, with the skill of dart throwing, the release should follow a proximal to distal trend. To properly throw a dart one needs to control the shoulder and produce the movement from the elbow and wrist. The results of the present experiments indicate this trend was observed in the control of the movements, but the changes in the movement coordination with practice were related to the environmental context in which the task was practiced. The regulatory conditions appeared to have had a greater effect on how the degrees of freedom were released than did intertrial variability. The release of the degrees of freedom is not generally

associated with the environmental context in terms of when this release will be observed. According to the present findings, how and when the degrees of freedom are released appears to be related to the regulatory conditions in which the task is learned, instead of the task itself. Generally, if the release of the degrees of freedom does not occur in a proximal to distal direction, the blame is placed on the task characteristics. The findings from these studies would indicate that it is possibly due to how the performer interacts with the environmental context, or a combination of both the task and the environment. Further testing would need to be conducted to attempt separating the effects of the task and the environmental context on the release in the degrees of freedom during skill learning.

Conclusion

When comparing the results of the four tasks to one another, the trend of the changes at the movement level appeared to be affected by the environmental context differently for different measurements. The overall results of the four tasks indicated that a change in the displacement at each joint occurred with practice for each of the tasks and there was a release in the degrees of freedom for the open tasks. High cross-correlations of the joint linkages indicated the relationship of the elbow and wrist joints acted as a rigid unit, instead of independent units during the movement coordination. The high cross-correlation values at the elbow-wrist joint linkage meant the performers were linking the hand to the forearm, instead of moving the forearm independent of the hand.

When comparing the size of the changes and the rate of the performance changes, different trends emerged. These data suggest that although it was hypothesized that increases in the demands placed on the learner have an effect on their performance, these performance changes do not necessarily change systematically as the task difficulty does. The effect of

changing only one component of the environmental context has a non-linear effect resulting in a gray area between the closed tasks with intertrial variability and open tasks with no intertrial variability. This gray area is apparent when observing the movement pattern changes at each joint to the changes in the joint-linkage relationships. Observing the changes for each task with practice indicates the motor control system does not react exactly as a machine would. The interaction of the environment, task, and performer creates a multi-dimensional relationship of movement changes with practice.

The changes in the movement patterns were observed early in practice for the closed tasks, while there were smaller changes in the movements across time for the open tasks. It appears that increasing both the task demands and the attentional demands increase the difficulty in different ways. Kinematic analyses indicated that with increasing amounts of practice participants began to release the linkage between shoulder and elbow while continuing to link the wrist and elbow to a higher degree during the throw, regardless of the environmental context in which they trained. However, as novices acquired more experience, they began to release these degrees of freedom to increase their skill performance capabilities. The correlations of the elbow-wrist joint-linkage presented a different pattern for the moving tasks when compared to the stationary. The results of the performance on each of the four tasks provides evidence that the environment in which one practices does affect how one performs the movements and what changes take place over time.

CHAPTER 4. GENERAL DISCUSSION

The four experiments investigated the effect of the environmental context on changes at both the outcome and movement performance level during skill acquisition. Both the outcomes and kinematics were measured to assess the environmental context effects and were addressed separately in Chapters 2 and 3, respectively. This concluding chapter provides a general discussion synthesizing the changes observed in the outcomes and kinematics across time. This synthesis provides an interpretation of the relationship of the changes observed with practice for both the outcome and kinematic measures, and what these results indicated in regards to the effect of the environmental context on the task learned.

In an attempt to assimilate the outcome and movement data, I looked back at what the participants were attempting to learn in each experiment and what influence the environmental context had on their skill acquisition. Within each experiment, the participants attempted to perform the skill of dart throwing in a specific environmental context. The general skill characteristics of dart throwing remained the same for all four tasks; however, the spatial and/or temporal characteristics varied for each task. The skill of dart throwing, is a complex skill by nature, due to the difficulty in generating the correct velocity and dart release angle to achieve the action goal of landing the dart inside the target in a specific location. The dart throwing skill in the present studies was modified to create a more complex and difficult task, by changing the spatial and temporal characteristics of the action goal. What were the effects of these modifications on the performance outcomes and movement coordination changes? What changes were observed to indicate how the motor control system adapted within each environmental

context? The present series of studies demonstrated changes in the outcomes and movement coordination were related to the task and environmental context demands.

The Effect of Task on Skill Learning Performance

The environmental context during the motor skill learning was hypothesized to have an effect on both the performance outcomes and the movements during skill acquisition (Gentile, 1972; 2000). It was hypothesized that the environmental context would affect the movement coordination and the outcome performance scores, during skill acquisition. During the learning of both closed and open skills in the present studies, the absence or presence of intertrial variability did affect the attentional demands, the movement organization, and memory representation as suggested by Gentile (2000). These effects were observed in the increased radial errors, the variability of those errors, and the magnitude of the changes in the movement coordination. As was expected, the tasks involving specific timing characteristics to achieve the action goal affected the changes in performance for both the outcomes and movements (Gentile, 2000). The timing constraints of the open tasks placed additional demands on the information processing and the timing of movement initiation, which resulted in difficult tasks to perform successfully.

The performance error measured at the outcome level decreased with practice and the results indicated that the intertrial variability had a greater effect on the rate at which the learners improved. This is illustrated by figure 2.23 indicating how changing the spatial characteristics (closed task w/IV), or changing the spatial and temporal characteristics (open task w/IV) of the action goal, the performers developed an effective strategy to achieve the action goal and reduce their errors. In the performance of the

open task with no intertrial variability, the performers were observed changing their movement timing with practice, but were not observed decreasing their radial errors by a large amount during the three days of practice. These participants developed an effective movement pattern and then adjusted the timing of their movements to meet the demands of the environment. In contrast, for the tasks with spatially changing features, the learners adapted their movements both spatially and temporally to conform to the changing features in the environmental context. These changes were illustrated in Chapter 3 with figures 3.6, 3.10, 3.15, and 3.20. These figures presented the changes in the movement coordination and/or the timing shift observed during practice. Observing the actual movement coordination used to perform the tasks provides a clearer indication of how the participants move their limbs to produce the movement. As they begin to use different movements the strategies used to perform the tasks are evident.

In the four dart throwing tasks, the performers were under time constraints as to when to throw the dart; however, these timing constraints should not have influenced the consistent tasks due to their predictability. In the two consistent tasks this should not have influenced the learner very much because there was little movement preparation needed to perform the task each time; however, for the two variable tasks this timing constraint was observed affecting the cognitive demands of the participants. Although reaction time was not measured, and participants did not have to throw the dart immediately following the appearance of this target, studies on reaction time may provide the answer to explain the differences observed related to the task demands. By increasing the complexity of the task, increases in the reaction time are observed due to increases in the time needed for movement preparation (Henry & Rogers, 1960). This explains why

the rate of the performance outcome changes was the same for the two variable tasks. The influence of the additional cognitive processing needed to learn the task resulted in larger changes in the outcomes, but smaller changes in the movements. The attention was focused on the outcome of the movements and not the movements themselves.

Essential Changes in the Pattern of Movements during Learning

Measuring what changes occurred in the performance outcomes and movement coordination, the timing of these changes, the rate of the changes, the magnitude of these changes, provided the bigger picture of how motor skills were learned and the effect of the environmental context on this learning and performance improvements. Identifying coordination changes from one point in time to the next provided critical information concerning how the learners adapted their movements to produce skilled activity. The changes in coordination, observed by Bernstein (1967), and others, (Gesell, 1929; Gentile 1972, 2000; Newell, 1985; and Kugler, Kelso, & Turvey, 1980) during the course of learning a complex motor skill, were also observed in the present studies. For the two variable tasks the increase in attentional demands held the attentiveness of the learners during the training, but this is also what occupied most of their limited attentional resources. By focusing on the variability of the target location, the learners could not focus as much attention on learning and adapting of the movement pattern to achieve the action goal. These results were observed in Figures 3.4 and 3.14 for the consistent tasks with larger changes in the movements and in Figures 3.9 and 3.18 for the variable tasks with smaller changes observed in the movements for those tasks. The results suggested the learners should be instructed as to where to direct their attentional focus to enhance the performance improvements occurring with skill acquisition.

The relationship between the joints were also measured and it was hypothesized that changes would be observed in the degrees of freedom. During the progression of skill learning, the degrees of freedom were expected to be released gradually, allowing the learner to use and/or control the necessary degrees of freedom as his or her skill level increased (Arutyunyan, Gurfinkel, & Mirskii, 1968, 1969; Newell & van Emmerik, 1989; McDonald, van Emmerik, & Newell, 1989; Anderson & Sidaway, 1994; Broderick & Newell, 1999; Verijken, van Emmerik, Whiting, & Newell; 1992). The direction in which degrees of freedom were released, and greater control was gained, was hypothesized to occur from the more proximal joints initially, to the more distal joints later in practice, as this has been observed for many skills. In the present studies the participants who were observed learning the open tasks, began to reduce their degrees of freedom at the elbow-wrist joint linkage, but over time these changes within each joint-linkage were not significant. Both the behavior of the joint-linkages and the magnitude of the radial error scores indicated the participants were still in the early learning stages. This explains why the degrees of freedom presented a proximal to distal direction of movement control, but not a release during the three days of practice. These changes in the relationship of the degrees of freedom provided insight toward how the performer changes his or her movement coordination during skill acquisition. The timing constraints of the open tasks influenced how the participants changed their movement coordination over time.

The release of the degrees of freedom has been attributed to maturational processes by some (Gesell, 1929) and mechanical factors of the task (Bernstein, 1967; McDonald, van Emmerik, & Newell, 1989). The differences in the changes observed for

each task, comparing the relationship of the joint-linkages at the wrist-elbow, shoulder-wrist and shoulder-elbow indicated that the proximal to distal trend was influenced more so by the environmental context than the task itself. These data indicate there were changes in the relationship of the joints over time, but what appeared to have a stronger influence was the individual joints influence on the coordination changes with practice. Based on the results of these four tasks, how the learners 'solve' the degrees of freedom problem and how they change the movement coordination are more a function of the learner interacts with the environmental, task, and his or her motor ability.

Relationship between the Movement and Performance Outcomes Assessing performance outcomes and movement coordination patterns provided critical information related to the changes that occurred with practice; however, the changes that occurred during skill acquisition need to be compared to one another for a complete assessment and understanding of the strategies used by the participants to increase their performance during training. Because of the format of the different outcome and movement measurements, there were no statistical analyses that could be used to compare the movement coordination to the radial error scores at one time. However, the results were compared by observing when the significant changes occurred for the performance and movement outcomes during the three days of practice for the four tasks. This comparison revealed an interesting trend among the four tasks.

Reviewing the timing of the changes for the two variable tasks revealed day 1 to be significantly different from days 2 and 3, for both the decreases in radial error and the movement changes at the joints. What these results suggested is that the movement changes that occurred at each of the three joints resulted in a decrease in the participants'

radial error scores. These results suggested that the amount of intertrial variability in the environmental context affected both the outcomes and the kinematics similarly. This also suggested that the absence or presence of intertrial variability had a stronger influence than the regulatory conditions. The increase in the attentional demands influenced the timing during the three days of practice for when the performance outcomes and the movement coordination occurred.

Reviewing the timing of the changes for the two consistent tasks, revealed day 3 to be significantly different from days 1 and 2 for both the decreases in radial error and the changes in movement coordination at the joints. Similarities were also observed for the consistent tasks, when comparing both measures indicating the decreases in attentional demands, reduced the attention given to the movement coordination used to perform these tasks. These observations indicated the timing of the changes was similar for the consistent tasks for both measures of performance.

Initially, it appeared as though the changes in the movement patterns and outcomes changed similarly for all four environmental contexts. When the changes observed in the timing across the three days were compared, the consistent tasks were observed to change at the same time during the three days of practice for both the outcome and kinematic measures. The variable tasks were also observed to change at the same rate for both measures. When the performance on the consistent tasks was compared to the performance on the variable tasks, two different trends emerged. This initial observation when comparing the movements and the outcomes indicated that the movement patterns changed with practice for all four tasks and the radial error decreased for all four tasks. This would indicate that either outcome scores or movement

coordination changes would provide the same information. This would suggest that no additional information is given by measuring both the performance outcome and performance production measures.

Upon closer analysis; however, different trends emerged from the outcome and movement data. The greatest amount of change in the movement pattern occurred for the closed task with no intertrial variability, but this task is also where the smallest change in mean radial error was observed over the three days of practice. The opposite trend was observed for the variable tasks where smaller changes in the movement were observed while these two tasks also resulted in the two largest changes in mean radial error over the three days of practice. These results support the initial purpose of looking at both outcomes and movements together to explain the effect of the environmental context during skill acquisition since each type of measure provides critical information.

If the learners changed their movements but did not increase their outcome performance level, why did they change their movements, or why did the outcome errors continue to decrease while the participants were observed using similar movements over time? If the participants were exhibiting a 'floor effect', it would have explained why the movements continue to change even when the outcomes did not; however, for all four tasks learners continued to land the dart outside of the target on average, even by the end of day 3. This indicated that the participants could have continued to improve on their outcome performance, but did not continue to do so. The answer could be related to the attentiveness of the learners in the given task. The amount of cognitive interaction with the task was different for the consistent tasks when compared to the variable tasks. Because of the repetitiveness and predictability of the consistent tasks the participants

may have had a difficult time keeping their interest on the task. With little effort after the initial day of practice, they could have performed the task and achieved the action goal while not investing large amounts of attentional resources to the outcome performance.

The large changes in the movements can be attributed to the large number of trials. In order to perform all 160 trials each day the participants would learn a more efficient movement pattern, explaining why the movement pattern changes were greater than performance outcome changes for the participants training on the consistent tasks. On the other hand, for the variable tasks, performers had to focus their attentional resources on the target location to achieve the action goal. This focus of attention resulted in the participants ignoring how they were moving by not attending to their movements. This explains why the participants learning the variable tasks had large changes in the radial error improvements and smaller changes in the movement coordination.

Conclusion of strategies during learning

A possible strategy appeared as movement and outcome data were compared, which explained why the closed task with intertrial variability was more difficult to learn than the open task with intertrial variability. The participants practicing the closed task with intertrial variability had to aim at five different target locations, and learn the movement patterns that paralleled these variations of the target locations. The figure in Chapter 2 (Figure 2.10) shows the scattering of the first five and last five trials for each participant at each target location. These graphs show how the participants had five distinct aiming locations. During the three days of practice, they had to learn the correct movement pattern to be successful at each location. These five distinct target locations

resulted in a more difficult task to learn, when compared to the other three tasks. Distinct movement patterns were needed to throw the dart accurately to each of the five target locations, as opposed to only one movement pattern needed for the two consistent tasks.

The participants performing the open task with intertrial variability were able to develop a strategy where they would throw the dart in similar locations for the different target movement patterns (see Figure 2.21). Figure 2.21 presents the first five and last five trials for all the participants, who trained on the open task with intertrial variability, for each of the five target movements. These results indicated early in practice (day 1) the participants had a larger scattering of throws, because the participants were treating each of the five movements as individual target movements to aim towards. However, with practice the participants began to focus on three main areas of the board where the targets would pass as they moved across the dartboard. This strategy for the open task allowed the participants to reduce the number of movement patterns to be learned, by focusing on two to three general areas on the board where two to three of the target movements would pass. Although the open task with intertrial variability was more difficult to perform since the target was moving, it was not as difficult to learn, as was the closed task with intertrial variability. Because the participants could develop this strategy to reduce the number of target aiming locations, the difficulty of the task by the end of the three days was less than that of the closed task with intertrial variability. This strategy helped the participants reduce the difficulty of learning the task.

Conclusions

All of the data taken together suggested that the two tasks with intertrial variability present were more difficult than the consistent tasks. What was also observed

was that the closed task with intertrial variability was the most difficult to learn because of the unpredictability of where the target would appear, and the variability of the five different target locations, was coupled with the five different movements that needed to be learned for this task. The open task with intertrial variability was observed to be the most difficult to perform, because they still had to hit a moving target that varied each trial. However, this task was easier to learn, than the closed task with intertrial variability, because the participants could develop a strategy in which they reduced the number of movements to be learned by grouping the five directional target movements into two to three general areas on the board. This strategy decreased the attentional demands of the task.

As the regulatory conditions change from stationary to in motion, or as intertrial variability is added to the environmental context of the task, non-linear changes in behavior are observed. Knowing how and when changes occur in the coordination patterns, and what information influences these changes, allows the researcher to provide better instructions and feedback for the learner. This knowledge can be applied in both rehabilitation and sports settings. As occupational and physical therapists search for more effective and efficient ways to rehabilitate their patients, and coaches search for better coaching methods, information on the movements will become critical to achieving this goal. This knowledge will help in guiding the instructions given to the patients and athletes to guide their attentional focus and improve their rate of improvement and learning. To understand the movement patterns and coordination changes occurring during learning, and how they relate to the outcomes being measured, more research needs to be done, taking into consideration these factors when developing new studies.

Future Research

The next step to further assess the effect of the environmental context on both the outcomes and movements would be to study the effect of attentional demands on learning, and the effect of movement goal versus outcome goal instructions. By assessing attentional demands, we will better understand why the absence and presence of intertrial variability had such a strong effect on performance. It was clear in the research presented here that varying intertrial variability resulted in different movement and outcome performance trends, than did the manipulation of the regulatory conditions. It is of interest to determine how and why intertrial variability affected the participants' performance at multiple levels. Another way to identify the effect of intertrial variability would be to examine the influence of instructions during training. The studies presented here did not provide instructions related to movement goals since the participants were only told to get as close to the target as possible. If some participants had been given specific movement commands, while others were only given outcome goal related instructions, different trends in the results may have appeared. Since, different strategies were assumed to be used in the performance of the tasks with intertrial variability, instructions may have aided the development of these strategies and allowed the participants to progress further along the stages of learning. Future research will help to connect the pieces of the puzzle of understanding skill acquisition and the variables that affect motor skill learning.

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**APPENDIX. LITERATURE REVIEW, CONSENT FOR HUMAN SUBJECT
RESEARCH, INSTRUCTIONS, COMPUTER PROGRAM AND RELIABILITY
PILOT STUDIES**

MOVEMENT COORDINATION CHANGES RELATED TO LEARNING COMPLEX MOTOR SKILLS: A LITERATURE REVIEW

Abstract

During motor skill learning, changes in movement coordination patterns have been predicted. Theories and models providing support for changes taking place in movement coordination patterns have been tested. The work of Bernstein, (1967), Gentile, (1972, 2000), Newell, (1985), and Fitts & Posner, (1967) have provided what can be observed and evaluated in the analysis of complex skill learning. This literature review provides a synthesis of the empirical findings that test the hypotheses of these researchers within the realm of complex tasks. Main findings report that the type of task and the experience of the performer influence the strategies utilized during learning. These strategies include directional trends such as freezing to freeing of degrees of freedom, a proximal to distal pattern of the performance limb, a determination between essential and non-essential variables, and the search for mechanical efficiency. The task, environment, and organism all work synergistically as a whole and cannot be separated out when analyzing coordination changes in complex skill learning. With an understanding of what changes occur in coordination, we can look to answer why these changes occur, and what influences the changes.

Introduction

Background

A majority of research studies in motor learning bases the measurement of learning on performance outcomes without observing the coordination pattern of the movement produced. To measure the learning of a novel complex motor skill, it is important to compare the learner's performance with the intended goal. However, this information is incomplete because it ignores the coordination changes that occur during the learning of the novel skill. Thus, for a more complete picture of motor skill learning both the outcome of the movement and the coordination pattern of the movement should be assessed. Focusing on coordination changes in the movement pattern provides information about what evolves during skill learning. Coordination changes provide additional information about how movements are produced and the factors in the environment affecting these changes.

Although skill learning can be assessed on the basis of outcome measures of performance, such as points awarded or movement time, it is important to note that the same outcome score can result from very different movement patterns. For example, a volleyball serve with the goal of hitting the ball over the net and bouncing in the far left-hand corner can result from an underhand or an overhand serve. However, each serve will have very different coordination patterns. Specifically, tracking the movements at the joint or limb-segment level helps determine the relationships among all the joints involved and how these relationships change as the person acquires the skill. Analyzing the movement pattern can also provide information regarding the changes in movements and coordination for some actions, which can then be compared to the outcome measures achieved to provide a complete analysis of the behavior.

The use of kinematics to assess the learning of complex motor skills is relatively recent due to technological advancements. Because measures of coordination change provide critical information indicating how movements change during learning, it is important to investigate motor skill learning from that perspective. A goal of this research would be to provide empirical evidence to evaluate models and theories of skill learning. It could also lead to the development of new theories to answer how the task, the learner and its environment affect coordination and the outcome. But what research has been done up to this point? And what is pertinent for future studies?

After defining coordination as reported in the literature, and some predictions that have been made for coordination changes during skill learning, this paper is organized as follows. Several hypotheses related to coordination change characteristics or strategies during the stages of learning will be reviewed, followed by their quantitative investigations. A summary of findings will be reported for these studies that look at coordination changes during the learning of new motor skills within each strategy. The final sections synthesize the implications of this research and suggest hypotheses for future investigations.

Coordination and Coordination Changes Defined

Coordination is an important term used throughout this paper; however, multiple definitions exist. One definition considers coordination as the behavior of two or more degrees of freedom (e.g. upper arm, lower arm, and hand) in relation to each other in the production of a skilled activity (e.g. throwing a ball or reaching for a glass) (Schmidt & Lee, 1999). The key term in this definition is “skilled activity” where skilled performance of an activity is viewed as “coordinated,” and unskilled performance is “uncoordinated.” This definition reflects the view of coordination as a state of being. Although, this use of the term

“coordination” is common, a more precise definition, one based on Bernstein’s definition, will be used for this review.

Bernstein (1967) defined coordination as “the kinematic composition of a motor act, [which] is not a universal invariant [guaranteeing] achievement of the motor goal” (p. 106). This definition is more commonly associated with biomechanical measures of movement, and has motor control and motor learning roots. Therefore, coordination involves a “process of mastering redundant degrees of freedom of the moving organ,” or more briefly, the “organization of the control of the motor apparatus” (Bernstein, 1967, p.127). This definition describes coordination as the relation of two joints, segments, limbs, etc. at any specific point in time. According to this view, how the limbs are “coordinated” does not distinguish the skill level of the performer.

When identifying the coordination patterns of a movement, it is critical to evaluate how coordination changes temporally. Coordination changes can best be evaluated during the process or organization as described by Bernstein (1967). As the learner determines the most efficient or best way to produce a skill, changes in the coordination pattern occur. How this coordination changes from one point in time to the next provides critical information as to how the learner adapts a movement to produce skilled activity. More specifically, coordination describes how the joints are positioned at an exact moment, and how this position changes at this moment across time. This adaptation of specific components of the limbs, throughout the learning of a complex motor skill, is referred to as coordination changes.

Hypothesized Coordination Changes During Skill Learning

Bernstein (1967), and others, (Gesell, 1929; Gentile 1972, 2000; Newell, 1985; and Kugler, Kelso, & Turvey, 1980) observed coordination changes as learners learned a new skill. Several researchers provide hypotheses of what coordination changes can be expected during the course of learning a complex motor skill. Bernstein (1967), Kugler, et al. (1980), Newell (1985), and Gentile (1972, 2000) provided descriptions of coordination changes during skill learning associated with early and later stages of the learning process. These hypotheses of coordination changes include solving the degrees of freedom problem, proximal to distal trends of change, determining essential and non-essential variables, developing movement efficiency, and fixating or diversifying coordination patterns dependent upon task.

Solving the Degrees of Freedom Problem

The problem of coordinating all the necessary body parts to successfully perform the goal at hand during a skill was first noted by Bernstein, in 1967, and was termed the “degrees of freedom problem.” Inherent in this problem, which occurs during initial learning, is the difficulty in the simultaneous control of multiple, independently moving body parts (Schmidt & Lee, 1999). Learners are observed “rigidly, spastically” (Bernstein, 1967, p. 108) fixing the number of joints or limbs involved when initially performing a skill. As the beginner performs a new task, he/she must reduce the number of degrees of freedom by keeping the body or multiple body segments in a constrained form. This “freezing” of degrees of freedom at the initial stages of learning is followed by an “unfreezing” of degrees of freedom toward the later stages of learning. When a beginner initially performs a task, he or she must “utilize all roundabout methods” (Bernstein, 1967, p. 107) before deciding which coordination pattern

produces the best outcome. During the progression of skill learning, the degrees of freedom are released gradually, allowing the learner to use more degrees of freedom as the skill level increases. For example, as a child learns to catch a ball the arms are extended straight out with the shoulder joint only being used to catch; however, as the child improves the elbow and wrist joints are then added to catch with a smooth, consistent coordination pattern. This progression of learning is observed with a release of the joints and muscles used during skill performance (Kugler, et al., 1980).

Another way to explain how the learner solves the degrees of freedom problem is to break down the solution into multiple components. Reduction in the amount of instructions and when these instructions are provided will also result in an easier solution (Kugler, et al., 1980). By reducing the number of possible solutions the problem is easier to solve, which is what the learner does by freezing degrees of freedom. As the learner slowly adds information or degrees of freedom the skill can be learned gradually.

Empirical Findings: Freezing to Freeing of Degrees of Freedom

Coordination patterns are observed to change during skill learning from a freezing of degrees of freedom early in practice, to a release later in practice. Arutyunyan, Gurfinkel, & Mirskii (1968, 1969) found support for the strategy of freezing to freeing degrees of freedom by observing the kinematics of novice and expert marksmen during shooting. Experienced marksmen were observed to have low cross-correlations of their wrist and shoulder, which aided in the reduced variability in the outcome score. To achieve this the expert marksmen moved their wrist and shoulder joints independently. The experts' strategy to freeze the distal portion of the limb and absorb the wrist movements provided a steady hand for shooting. The inexperienced marksmen were reported to have high cross-correlations in their wrist and

shoulder joint-linkages. This freezing of the arm segments by the novices resulted in both joints moving simultaneously. The aiming was difficult to control, resulting in low outcome scores for the unskilled marksmen.

Similar coordination changes in the coordination and control of limb segments was observed with a handwriting task. A study using a complex task of writing with both non-preferred and preferred hands, measured coordination changes at the shoulder, elbow, wrist, and pen tip (Newell & van Emmerik, 1989). Higher cross-correlations of the limb segments were observed for the non-preferred limb when compared to the preferred limb in the naturally right-handed participants, supporting a freezing to freeing strategy. The trend of cross-correlation values remained the same from preferred to non-preferred limbs. These findings suggest one strategy learner's use is to reduce the variability and changes in the coordination mode as a function of practice (Newell & van Emmerik, 1989).

Another study finding support for a strategy to freeze degrees of freedom early in practice used dart throwing to address coordination and practice aspects. McDonald, van Emmerik, & Newell, (1989) hypothesized that changes in limb kinematics with an unrestrained dart-throwing task would be observed across practice. Kinematic data from the hip, shoulder, elbow, wrist, and hand along with outcome scores from five concentric circles were recorded. The kinematic variables were then compared between the two limbs, and between pre- and post practice, in order to observe the variability and coordination changes of the variables manipulated. Analysis of the non-preferred arm showed high cross-correlations among the three joints, which was interpreted as a freezing of degrees of freedom since the limbs acted more as a fixed unit. McDonald et al. (1989) also found significant reduction in cross-correlations between angular displacement of the wrist-elbow and wrist-shoulder joint

linkages across practice trials in the preferred arm. This is interpreted as a freeing of degrees of freedom during learning. When analyzing the angular displacement of the preferred arm it was found that the motion at the elbow joint was less variable than that at the wrist and shoulder joints. Here the learners presented a strategy to focus their attention on stabilizing the elbow. Measurements of the hand trajectory and the release point of the dart were found to be highly consistent across practice. All of these results were interpreted further to show that the unpracticed dominant hand had higher cross correlations of angular velocity (freezing), than the practiced limb (freeing).

Anderson and Sidaway (1994) compared expert soccer players with novices on their performance of an instep drive soccer kick. Kinematic data of the shoulder, hip, knee, and ankle joints, and distal head of the toe revealed considerable improvement in the movement pattern for the novice group; however, novices did not reach the level of the expert performers due to the limited practice. More effective timing between the hip and knee occurred as a result of practice, as did an increase in the range of motion (ROM). During the pre-practice trials the hip and knee were constrained, while in the post practice trial the novices flexed and extended their hips and knees in a similar pattern as that of the experts. These results did provide support for the freezing to freeing strategy as was hypothesized. The authors concluded that attention should be placed on the range of motion of the joints in the latter stages of learning, since the largest changes in coordination were observed here.

In another study measuring coordination, Broderick & Newell (1999) compared skill level, based on outcome measures, with that of kinematic characteristics. Participants at different skill levels, size and age practiced a ball-bouncing skill, while kinematics at the wrist, elbow, knuckle, finger, and ball, were recorded. Consistent with a freezing-to-freeing

degrees of freedom strategy for learning this skill, correlations were higher for the elbow-shoulder and the shoulder-wrist linkages for the novices than for the experts. In addition, the coupling between the shoulder and elbow decreased across trials for novices, while the expert subjects performed a very consistent movement pattern across trials. Movement variability was also observed to decrease as the skill level increased.

Verijken, van Emmerik, Whiting, & Newell (1992) also observed a similar strategy of freezing to freeing of degrees of freedom as participants practiced performing on a ski simulator apparatus. Results, based on the standard deviations of the joint angles, showed that participants fixed the knee and ankle joints in a rigid manner early in practice, but began to actively use these joints during the seven days of practice. The performers were able to produce a smoother movement that was more controlled as additional degrees of freedom were introduced. The authors note that additional practice may have resulted in greater improvements in their movement coordination, as the behavior had not reached a plateau after the seven days of practice.

As has been shown here by each of these studies, the freezing to freeing degrees of freedom strategy is used during the learning of complex skills. As individuals practice a new skill the increase in their consistency of movements and their control of the movements is correlated with the degrees of freedom used to perform the movement. The strategy has been supported with a variety of complex skills observed either during learning or by comparing experts and novices.

A Proximal-to-Distal Trend

The direction in which the degrees of freedom are released has been observed to occur in a similar direction for many tasks. Gesell (1929) reported that as infants learn grasping and

other phylogenetic skills the coordination changes of the movement pattern occur in a proximal-to-distal trend. For instance, when reaching toward an object, the infant will produce the movement from the shoulder joint and push the arm forward. As the infant practices this movement, he or she will begin to utilize elbow and wrist joints to accomplish the action. Eventually, the fingers themselves will be “freed” to reach and grasp. As new tasks are learned, the direction of the development of the learned movements progresses from gross to fine motor movements. Studies that looked at the coordination of ontogenetic tasks revealed many parallels with phylogenetic activities (Newell, 1989). The directional trends (e.g. cephalo to caudal, proximal to distal, ulnar to radial) and unfreezing of degrees of freedom that are controlled independent parallel these developmental trends.

Empirical Findings: Proximal-to-Distal Pattern of Limbs Used in Skill

Performance

The proximal-to-distal strategy observed in the development of phylogenetic tasks has also been observed during skill acquisition of ontogenetic tasks, such as pistol aiming, handwriting, soccer kicking, and simulated skiing. Arutyunyan, Gurfinkel, & Mirskii (1968, 1969) compared the coordination patterns of skilled versus unskilled marksmen on a pistol-aiming task. The study compared coordination patterns of two skill level groups and how the joints are independently introduced into the movement for each group. The strategy of the experienced marksmen was to control movement variability at the distal part of the limb, including the pistol, while the novices linked both the shoulder and wrist, which did not allow control of the movement variability. In turn, the outcome score for the experts remained consistent, as subjects were able to control and stabilize the movements in the wrist, while the novices produced inconsistent and inaccurate shots. This presents a strategy where the

experienced marksmen had learned, after years of practice, to absorb any movement in the proximal portions of the arm, so that the pistol and hand remained still. The novices, however, had not reached this level of control.

Newell and van Emmerik (1989) also found evidence for the proximal to distal movement of the coordination changes using a handwriting task. The coordination of limb links in writing task appeared to be controlled distally at the wrist joint in the preferred-limb, and proximally at the shoulder joint in non-preferred limb. These results support a proximal to distal strategy (Newell & van Emmerik, 1989). Although the subjects performed 10,000 trials, writing both their signature and the small cursive letter “e,” with the non-preferred hand, the preferred hand had years of practice. Since the amount of practice the preferred limb had received was substantially greater than that of the non-preferred limb, this type of study is similar to comparing novices to experts. Additional practice performing this skill is needed to move the coordination strategy from proximal (shoulder) to distal (wrist) in the unpracticed limb.

This proximal to distal strategy was also observed during the learning a soccer kick by novices, as the direction of freeing started from the hip and continued toward the foot. This coordination pattern of the novices began to resemble that of the experts (Broderick & Newell, 1999). Again, due to lack of practice the novices were unable to perform at the level of the experts; however, the trend that was observed followed the proximal to distal pattern.

One study using a complex task of bouncing a ball reported contradictory evidence for the proximal to distal pattern of learning. When Broderick and Newell (1999) compared their results to the prediction of Gesell (1929), they were not able to separate the effect of skill level and developmental stages of their participants. Some analyses showed a proximal to

distal organization across learning stages; however, this was not found for all factors observed. An interesting finding was that correlations of the proximal joints were found to be higher for the experts and the correlations of the distal joints were higher for the novices. The authors did not attribute these results to the proximal to distal strategy. This variability was attributed to the task since small changes, in the position of the hand in relation to the body or the ball, have large impacts on where and how the ball bounces. This would in turn affect how the participant performed the skill of bouncing the basketball. These unexpected findings could be due to the task used as the performer had to both provide a movement related to the goal of bouncing the ball, and then had to adjust subsequent movements to the reaction of the ball. Most tasks previously had used open-ended tasks where once the trial is completed, the next trial starts with the same environmental context. Another explanation, stemming from the work of Arutyunyan, and his co-authors (1967), is that the experts may have been linking their wrist to the basketball in order to gain additional control in the movement to allow the shoulder to absorb the movement variability. This behavior was also observed in marksmen (Arutyunyan, et al, 1967) and may explain the unexpected results the authors presented.

Determining Essential and Non-Essential Variables

One way to describe coordination changes is to describe the behavior mathematically. Certain behavioral variables exhibit a non-linear pattern while others exhibit a linear pattern as they change during learning (Kugler et al., 1980; Gentile, 2000). Kugler et al. (1980) termed these variables essential and non-essential, respectively. Essential variables are associated with coordination and specify the “points of maximum conservation” of stability, while the non-essential variables are associated with variability and control (Kugler et al.,

1980, p.28). Learners first develop coordination by acquiring the best “topological characteristics” for the skill, such as timing, spatial distance and force (Newell, 1985; Kugler et al, 1980). These characteristics are the essential variables acquired along with the organization of the movement. During this first stage, as the learner adapts the movement pattern he/she must also take aspects of the environment into account. This is where the focus is mainly on the changes in coordination, and is referred to as the coordination stage (Kugler, et al., 1980; Newell, 1985).

As the skill is learned, the essential topological characteristics will be identified and learned. However, without the refinement of the non-essential variables, the movement will be too rigid and inflexible. As learners refine their movements, they begin to acquire the non-essential variables that add variability, which in turn provides greater control of the movement. It is in this “control” stage where learners adapt their movement patterns to small perturbations while consistently achieving the goal (Newell, 1985). The learner’s goal is to generate a stable and optimal pattern of movements. The non-essential variables provide the necessary variability to perform a skill with a high-level of control.

Empirical Findings: Determining Essential and Non-Essential Variables

The search strategies used by the participants can also be explained using a linear/non-linear viewpoint of how the learner progresses from one stage to the next. Den Brinker and Van Hekken (1982) set up a movement analysis system to observe slalom-ski type movements using a ski-simulator. Most studies concerned with larger whole body movements only observed specific movements, to reduce the difficulty during the analysis and discussion. However, Den Brinker and Van Hekken (1982) used measures of amplitude, frequency and smoothness to provide information about the entire movement instead of only

measuring time spent in selected parts of the cycle or the time when reversals in the movement occurred. The participants practiced making large, smooth movements at a slow (.30 Hz.) and fast (.42 Hz.) frequency determined by a metronome. Improvement was observed across days as the amplitude increased steadily; however, the greatest improvements were measured in the first day of practice and by day four, participants were approaching a ceiling effect. It was observed that subjects tried to adjust their timing on day 1 to meet the tempo demands; however, this was not observed on days two through four. Attention could not be placed on both timing and amplitude at all times during practice due to demands on the learner. This behavior was attributed to the acquisition of essential variables needed to perform the task. The learners' strategy was to focus on their movements while ignoring the constraints of the metronome.

The participants' improvement in smoothness and amplitude, while disregarding timing, support learning stage theories which state that initially the learner is trying to "get the idea of the movement" (Gentile, 1972) or trying to learn the "appropriate topological characteristics of the body and limbs" or essential variables (Newell, 1985). The cross-correlations between the absolute values of the position and velocity signals provided the best measure of how smooth the movement was performed. The greatest improvement in smoothness occurred in the earlier days of practice. Had the participants been given additional practice the authors may have observed characteristics seen in the later stages of learning and all three variables could have been adapted into the movement by the learners. The non-essential variables would have been acquired, providing greater control during the task.

An interesting finding in this study was the asymmetry in the cross-correlation values for all of the joint linkages, except the knee and ankle linkage, when comparing the right and left side of the body (Den Brinker and Van Hekken, 1982). Participants were observed to perform the task asymmetrically later in practice. This finding was attributed to the strategy of searching for essential and non-essential variables by constraining limbs to reduce task difficulty. These differences were thought to occur as the learner tried new strategies with one limb while keeping the other constrained (Verijken, et al., 1992). The learner was then able to search for non-essential variables necessary for control during performance by reducing the difficulty of the task.

Developing Movement Efficiency

Another way to describe coordination changes during learning is to look at changes in the progression of efficiency of movement. By calculating the energy used during task performance, efficiency of movement over practice can be assessed. Efficiency is measured through various measures such as caloric output, kinetics, and kinematics.

Mechanical efficiency based on caloric cost or work output predicts that a decrease in metabolic energy expenditure indicates the learner is becoming more skilled. Comparing the metabolic energy levels (e.g. VO_2 output) at different stages of learning shows coordination change is occurring during skill learning as a learner becomes more efficient. This supports the prediction that as a person becomes more skilled at an activity, there is a reduction in the amount of energy used (Kugler, et al., 1980).

Another efficiency measure is the amount of force used throughout the movement as a learner moves from one learning stage to the next. As the learner becomes more skilled, the ability to utilize passive frictional, inertial, and reactive forces in the learners' environment

improves (Newell & McDonald, 1992; Bernstein, 1967; Gentile, 2000). Bernstein (1967) posits that initially a programmed movement cannot occur because the organism must learn to react to the environment, since he/she cannot predict the exact outcome of the forces from movements. More recently, this idea of motor adaptation has been supported showing learners use the limited information acquired on previous trials to react to perturbations in the environment (Scheidt, Dingwell, & Mussa-Ivaldi, 2001; Conditt, Gandolfo, & Mussa-Ivaldi, 1997). It is during the later stages of learning when the learner begins to adapt his/her coordination to utilize the forces present in the environment. This is observed as the learner increases efficiency and performs the skill with minimum energy expenditure (Newell, 1985). Gentile (2000) observes that participants learn to “regulate intersegmental force dynamics” using a feedforward control and integrating both the passive and active forces (p.153). This feedforward control occurs when a person plans the coordination of their movements and muscle forces based on the activity they are about to perform (i.e. jumping from a higher surface to a lower surface). The surface conditions and height of the jump will lead to different muscle and joint angle preparations.

Understanding how changes in kinematics relate to changes in energy efficiency also provides useful information on the efficiency of the learner. The accelerative and decelerative patterns of limb movements indicate where the learners focus their energy during the movement production. Another change observed in efficiency of movement using kinematics is a “blending of successive movements” (Gentile, 2000, p.156). Here the learner prepares for a secondary movement as the primary movement is being carried out. For example, pianists or typists begin to move to the next key while still depressing the key before that one. A smoothing of movements is observed as one movement leads into another - as though they are

one movement. The last change Gentile (2000) observes is a “coupling of simultaneous components” such as timing and spacing (p157). For instance, the learner will reach and grasp simultaneously. Each of these three efficiency changes observed relate to the changes in the coordination patterns occurring.

Empirical Findings: The Search for Mechanical Efficiency

Kugler et al. (1980) hypothesized that one strategy used during learning is driven by the search for efficiency of movement. They suggested that an organizing factor could be related to metabolic energy cost during skill performance. In 1987, Sparrow & Irizarry-Lopez reported that there had not been any studies in the literature reporting findings on the efficiency of movement across learning. The authors observed mechanical efficiency and movement efficiency of adult participants learning to crawl, comparing changes in coordination and control with output in metabolic energy. Five males crawled (on hands and feet) on a treadmill at .76 m/s, for 35-minute sessions across ten days of practice. The amount of expired air per minute and internal and external work was calculated for each body segment from the velocity data. Mechanical efficiency (E%) was calculated by dividing mechanical work rate by metabolic rate. The authors observed a decrease in metabolic output for the first 5 to 6 days and then only minor changes were observed thereafter; however, no significant change was observed in the mechanical efficiency or power output.

Kinematic data for the joint centers on the right side of the body and the left wrist and left toe, were also analyzed. The length and duration of support and swing were calculated, along with the segments on the right side of the body from the foot to the upper arm. Cross-correlations of the angles from the thigh and lower leg were analyzed. The results showed considerable changes in the stride duration and step length of hand and foot movements over

practice. When the swing and support phases were calculated as a percentage, large similarities were found between walking and crawling. This was attributed to efficiency in human locomotion. The results did not clearly show that the most efficient mode was achieved through practice; however, it was observed that as the hand and footstep length equaled each other, there was a decrease in the metabolic output and improvements in mechanical efficiency. Sparrow & Irizarry-Lopez (1987) concluded that the changes in the coordination patterns changed similarly with the decrease in metabolic cost and there was great variability in the adaptations across practice for each individual studied. This study did establish solid findings that mechanical efficiency can be used to assess motor skill learning.

Beggs and Howarth (1972) and Darling and Cooke (1987) used simple tasks, which did not allow the complex changes to occur in the movement pattern itself; however, they were able to observe changes imposed by the goal of the task. These researchers observed changes in the acceleration curves in a reaching and aiming task, and a simple arm movement, respectively. This increase in efficiency of movement was observed in both accelerative and decelerative phases of the arms movement during these tasks as a function of practice. As the learners became more skilled, they used a strategy to move quickly to the target with little variability; however, during the decelerative phase an increase in the variability was observed (Beggs & Howarth, 1972; Darling & Cooke, 1987). This compensatory strategy allowed the learner to reach peak velocity sooner, while the movement time for the decelerative phase increased allowing for a more efficient movement pattern. When additional practice was provided, the variability was reduced for the decelerative phase; however, it remained higher than for the accelerative phase (Darling & Cooke, 1987). This discrepancy could be due to either the lack of practice or a floor effect in improvement.

Effect of Task on Coordination Change Strategy

Gentile's learning model (1972) describes how learners adapt a movement pattern to the type of task being learned. During the initial learning stage, producing perfectly skilled movements throughout the entire complex skill proves difficult. Gentile (2000) recently described this stage as involving active problem solving. As the learner explores various ways to achieve the action goal successfully, he or she acquires a movement pattern that attains the goal. Here the learner tries to "get the idea of the movement" (Gentile, 1972). The learner understands what needs to be done, but may not be able to actually perform the task consistently or accurately. The learner tries multiple strategies and chooses the most effective one to use in later stages. Initially this results in high variability in the movement pattern; however, this variability decreases with practice and a stable movement pattern emerges. The learner then organizes the movement to produce more effective movements to match the environmental conditions. These adaptations to the environment are not predicted to occur until the later stages of learning.

In later stages, coordination characteristics are specific to an open and closed task continuum. A stable movement pattern would be the goal of a closed task, while some variability in the pattern would be expected for open tasks. When coordination is measured during the later stages of learning, the task performance should result in consistent movement patterns ("fixation") or variable movement patterns ("diversification").

Empirical Findings: Relationship of Task and Coordination

The type of task used has been attributed to outcomes in many studies; however, few have studied this phenomenon specifically. A particularly interesting finding reported in a study of handwriting was the lack of a significant difference between limbs in the naturally

left-handed participants (Newell & van Emmerik, 1989). The nature of the task (e.g. writing orientation, limb dominance, size of writing) strongly influenced the emergence of a given coordination pattern; however this was different than the comparison in limbs for the naturally right-handed subjects. This finding was attributed to the direction of motion and perhaps posture constraints. The significance of this study is that it shows how the task constraints, past experience or training can affect coordination strategies used to achieve the new goal.

Higgins and Spaeth, (1972) reported one of the only studies that specifically tested the effect of the type of task on coordination changes. They compared open versus closed skills, to test the hypotheses proposed by Gentile (1972). The questions they investigated included: what are the essential changes in the pattern of movement that occur during the acquisition of a skill, and what is the relationship between movement and performance outcomes? To investigate these issues they used cinematographical analysis and a motion analyzer. They predicted participants in the open skill condition would have movement diversity during the initial stages that would lead to a repertoire of movements based on the environmental conditions, while the closed task group would produce a more consistent movement pattern in the later stages of learning, which would match the single environmental condition they performed under.

In this study, only one male subject was used in each of the two groups. In the closed condition, the learner performed 200 dart throws to a stationary square. For the open condition the participants had six different combinations of target preview and three different target speeds. The participant performed the dart throws until he achieved two successive hits within a five-inch target square. The experiment series ended when the participant reached the criterion for each of the 6 conditions. Kinematics of the head, shoulder, elbow and wrist

were used in the analysis of the movement pattern. Early in practice the participants displayed inconsistent behavior and there was no distinction between the conditions as was expected. However, for the later stages of learning two hypotheses were tested. For the closed task, the analysis focused on identification of the movement pattern and determination of the degree of consistency of the pattern across days. For the open condition, the analysis looked at identification of the movement pattern used under each of the conditions to determine how consistent the participant was within each of the six conditions. For the closed task the authors observed a smooth and consistent movement pattern later in practice, along with high outcome scores, which supported the “fixation” hypothesis. Consistent hand trajectory, for both limbs throughout practice, could be due to the strategy used to minimize the variability of the approach to the release point, or this could also be due to task constraints. Subjects practicing in the open condition acquired a flexible movement pattern that was adapted to the various practice conditions (diversification). These findings supported Gentile’s (1972) predictions for the effect of task on movement strategies.

Conclusions of Empirical Evidence

The empirical findings show coordination changes observed during skill learning are greatly influenced by the task used and the skill level of the performer. Research evidence clearly shows the movement pattern of beginners as distinctly different from that of skilled performers. What is also known is that characteristics in qualitative properties change during the learning process (Newell, 1989); however, there have been relatively few studies examining these changes in coordination as a function of practice (Newell, 1985). The strategy observed in some studies investigating coordination changes, has been greatly influenced by the task studied, its constraints, the measurements taken, and the level of the

performer. These variables affect the different strategies used during skill learning; however, the relationship between the strategies and task constraints has yet to be established in motor learning and development research (Newell & McDonald, 1994).

The strategies used and the influences of the task learned are shown to be critical factors in assessing coordination changes during skill learning. The findings reported from these studies show that it is important to take into account all factors influencing learning including the task, environment and the learner. It is then that inferences can be made from the measurements taken. McDonald, et al. (1989) concluded that the level of variance observed in the limb trajectories, end-point, and relative joint angles are part of a larger level of parameters such as the interaction of the organism and environment, or limitations due to the limbs or muscles. Coordination pattern changes cannot be a result of the task constraints alone; the organism and environment also have an affect on the outcome (Gibson, 1966, 1979; Kugler, Kelso, & Turvey, 1980; Newell, 1985; Kugler & Turvey, 1987; Kelso, Holt, Rubin, & Kugler, 1981; Broderick & Newell; 1999). These conclusions lead to research in how individuals understand and use their environment during skill acquisition and the role variability plays during the learning process (Newell, Kugler, van Emmerik, & McDonald, 1989). This also leads to research investigating the type of task used and the role it plays in the movement outcome.

Implications for Theoretical and Applied Issues

There have not been any new formal theories in motor learning since the 1980's. Theories have emerged across other disciplines that consider the interaction between the organism and its environment. New theories need to also take into account the environment, skill level, task and how those factors affect complex skill learning. Hypotheses regarding

changes that occur during the learning of complex motor skills have been presented; however, no empirical evidence for how or why these changes occur exists (Newell & McDonald, 1994). Research into how and why these changes occur may drive new interactive theories. Since these changes can be empirically measured with kinematics, kinetics and outcome scores, it is this evidence of coordination changes during learning that will drive new learning theories.

Understanding the changes that occur and when they occur during coordination of movements also leads to better organization of the practice of skills. This knowledge also helps to identify critical components necessary for efficient skill acquisition (e.g. where to place attention, when to move the limbs, how to move the limbs). Left undiscovered is what mechanisms drive these observed learning strategies. The critical mechanisms for skilled performance should drive the instructions and training methods, used by teachers and therapists. For example, if postural support were needed before a patient can learn to reach to a glass without falling or re-injuring him or herself, the focus of the instructions and training would be on acquiring this mechanism before focusing on the skill itself. As each mechanism, critical to the skill, is achieved and established, the final skill will be both more consistent and efficient in regards to goal attainment (Newell, 1985).

Knowing how and when changes occur in the coordination patterns, and what information influences these changes, allows the researcher to provide better instructions and feedback for the learner. This in turn will lead to more efficient and effective learning. This knowledge can be applied in both rehabilitation and sports settings. As occupational and physical therapists search for more effective and efficient ways to rehabilitate their patients, and coaches search for better coaching methods, information on the movements will become

critical to achieving this goal. This knowledge will help in guiding the instructions given to the patients and athletes to guide their attentional focus and improve their re-learning speed. To understand the movement patterns and coordination changes occurring during learning, and how they relate to the outcomes being measured, more research needs to be done. Each of these factors should be taken into consideration when developing new studies

Future Research

The research literature shows the changes that occur during skill learning, but not why or how these changes occur or the relationship between the task and the strategy used. Therefore, the next proposed step is to conduct an experiment that looks at a variety of tasks that fall along the skill continuum. Gentile's (2000) work provides a theoretical framework for future studies to investigate the complex interactive processes involved in the acquisition of motor skills. Hypotheses can be extracted from her work regarding the coordination changes when comparing skills along the open/closed continuum and those with or without intertrial variability. During skill acquisition the learner must adapt and adjust their performance given the environmental and morphology constraints (Gentile, 2000). If Gentile's hypotheses are correct, then a stable movement pattern for an open skill will lead to unsuccessful performance; however, this same movement pattern is the goal of a closed skill. With the addition of intertrial variability, learners are hypothesized to develop a movement pattern that adapts to multiple action goals within a skill. The best way to test these hypotheses is with a task that can be performed under both open and closed environmental conditions, and which the task characteristics can vary from trial to trial. This type of task allows for the fixation and diversification predictions of Gentile (1972) to be tested by evaluating performance consistency at the level of the movement and the outcome.

Measuring the movement patterns for each variation of a task allows the researcher to assess how the learner adapts the skill to specific task parameter specifications. As the learner practices an open skill under various conditions (i.e. changing the direction, speed, or trajectory), the movement pattern must be adaptable. How the coordination of these movement patterns changes during learning and how the joint-linkages are correlated with one another relates to freezing or freeing of degrees of freedom prediction. Another analysis that is available with a study in an open and closed environment is to observe how the movement variability changes across practice. This can be measured with the standard deviation of the values across trials. This is also a measure of how the movement organization simplified during learning (Gentile, 2000). These measurements will also address whether the changes in coordination patterns follow Gesell's proximal to distal hypothesis and/or Bernstein's freezing to freeing of degrees of freedom prediction.

Another problem hypothesized for learners to overcome is how they control their movements given environmental forces. The learners must learn to use the active and passive forces to produce a smooth, coordinated movement (Bernstein, 1967; Gentile, 2000; Scheidt, et al., 2001; Conditt, et al., 1997). This can be observed through kinematic measures. Prior to understanding the behavior of the environmental forces, learners will show high variability in their movements. This is because they have little control of their movements and limited knowledge of how to react to the environmental forces.

Another future research possibility is to examine the influence of instructions and attentional focus on coordination changes during learning. Many studies have looked at the influence of instructions, attentional focus, and task on implicit versus explicit learning; however, it is important to test how these variables affect the coordination patterns used. The

performers may use very different movement patterns during learning due to the instructions given or due to the learning context. The outcomes could be attributed to implicit/explicit learning. These issues can be teased out by looking at the instructions and task constraints individually and as they interact. Adapting where the attentional focus is placed and whether it is implicit or explicit will help lead to the best instructions for the most efficient learning.

As the information about coordination changes during skill learning shows, there are many unknown answers about how this takes place. How the task, environment and learner interact and how the coordination patterns change during learning have yet to be established. The different strategies observed and the influence of the task and its constraints needs to be researched in greater detail. Further investigation into the integrative approach should yield improved motor theories for motor learning and control.

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**IRB APPROVAL FOR THE FOUR EXPERIMENTS TESTING COORDINATION
CHANGES DURING COMPLEX SKILL LEARNING.**

IRB #: _____ **LSU Proposal #:** _____

LSU INSTITUTIONAL REVIEW BOARD (IRB) for 578-8692
HUMAN RESEARCH SUBJECT PROTECTION FAX 6792
Office: 203 B-1 David Boyd Hall

APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

Instructions: Complete this form. If exemption seems likely, submit it. If not, submit regular IRB application. Help is available from Dr. Robert Mathews, 578-8692, irb@lsu.edu or any screening committee member.

Principal Investigator Jennifer J. Jeansonne **Student?** Y/N

Ph: 578-2036 **E-mail** jjeans@lsu.edu **Dept/Unit** Kinesiology

If Student, name supervising professor Dr. Richard Magill **Ph:** 578-2036

Mailing Address 112 H.P. Long Fieldhouse **Ph** 578-2036

Project Title Coordination changes during complex skill learning

Agency expected to fund project NA

Subject pool (e.g. Psychology Students) Kinesiology students

Circle any "**vulnerable populations**" to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature _____ **Date** _____ (no per signatures)
=====

Screening Committee Action: Exempted ____ Not Exempted ____

Reviewer _____ Signature _____ Date _____

Part A: DETERMINATION OF "RESEARCH" and POTENTIAL FOR RISK

This section determines whether the project meets the Department of Health and Human Services definition of "research" and if not, whether it nevertheless presents more than "minimal risk" to humans that makes IRB review prudent and necessary.

1. Is the project a systematic investigation designed to develop or contribute to generalizable knowledge?

(Note "systematic investigation" includes "research development, testing and evaluation"; therefore some instructional development and service programs will include a "research" component).

YES
 NO

2. Does the project present physical, psychological, social or legal risks to the participants reasonably expected to exceed those risks normally experienced in daily life or in routine diagnostic physical or psychological examination or testing? You must consider the consequences if individual data inadvertently become public.

YES Stop. This research cannot be exempted--**submit application for IRB review.**
 NO Continue to see if research can be exempted from IRB oversight

3. Are any of your participants incarcerated?

YES Stop. This research cannot be exempted--**submit application for IRB review.**
 NO Continue to see if research can be exempted from IRB oversight.

Part B: EXEMPTION CRITERIA FOR RESEARCH PROJECTS

Research is exemptible when all research methods are one or more of the following five methods. Check statements that apply to your study:

1. Uses only existing data, documents, records, or specimens properly obtained. The research must also comply with one of the following:

- either that:**
 a) **subjects cannot be identified** in the research data directly or statistically, and no-one can trace back from research data to identify a participant;
or that
b) **the sources are publicly available**

 2. Research or demonstration service/care programs, e.g. health care delivery.

The research must also comply with all of the following:

- a) It is directly **conducted or approved by the head of a US Govt. department or agency.**

and that

- b) **it concerns only issues under usual administrative control** (48 Fed Reg 9268-9), e.g., regulations, eligibility, services, or delivery systems;

and that

- c) **its research/evaluation methods are also exempt from IRB review.**

- **NA** 3. **For research not involving vulnerable people [prisoner, fetus, pregnancy, children, or mentally impaired]: observe public behavior (including participatory observation), or do interviews or surveys or educational tests:**

The research must also comply with **one** of the following:

either that

- a) **the participants cannot be identified**, directly or statistically;
or that
b) **the responses/observations could not harm participants if made public;**
or that
c) **federal statute(s) completely protect all participants' confidentiality;**
or that
d) **all respondents are elected, appointed, or candidates for public officials.**

- 4. **In education setting, research to evaluate normal educational practices.**

- 5. **For research not involving vulnerable volunteers [see "3" above], do food research to evaluate quality, taste, or consumer acceptance.**

The research must also comply with **one** of the following:

either that

- NA** a) **the food has no additives;**
or that
 NA b) **the food is certified safe by the USDA, FDA, or EPA.**

Exemption Applicant: If it appears that your study qualifies for exemption send:

- (A) **Two copies of this completed form,**
(B) **a brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts A & B),**
(C) **copies of all instruments to be used**
(D) **the consent form that you will use in the study**

to: ONE screening committee member (listed below) in the most closely related department/discipline or to IRB office.

NOTE: Even when exempted, the researcher is required to exercise prudence in protecting the interests of research subjects, obtain informed consent if appropriate, and **must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont**

Report), 45 CFR 46, and LSU Guide to Informed Consent; (Available from OSP or <http://www.fas.lsu.edu/osp/irb>)

HUMAN SUBJECTS SCREENING COMMITTEE MEMBERS can assist & review:

Dr. Landin* (Kinesiol) 578-2916

Protocol

1. Participants will enter testing room and be informed of the procedures of the task.
2. Participants will read the informed consent form and all questions will be answered prior to receiving any signatures.
3. Participants will throw the darts with their right hand at the target projected in front of them. One dart will be thrown at a time and all those involved will remain behind the thrower until the dart has landed to avoid any injury.
4. Participants will perform 160 trials per day for 3 days of training.
5. Reflective markers will be placed on their upper arm, lower arm, hand, trunk and the dart.
6. Kinematic data will be recorded using the Vicon ® Motion Analysis system, and the dart release.
7. Participants will perform the throws in 8 blocks of 20 trials each day, with rest intervals between blocks.
8. On the 5th day, participants will perform throws for three new moving targets and what was practiced during the first four days.
9. Different practice situations will be provided for each of the four experiments:
 - A. Variable Open (Open-Open)
 - B. Consistent Open (Open-Closed)
 - C. Variable Closed (Closed-Open)
 - D. Closed (Closed-Closed)
10. The participant, in each of the four experiments, with the lowest radial error score after the three days of practice will be given a \$20.00 reward.
11. To assure confidentiality of the data and participants, the hard copy of the information sheet listing both the participant names and their corresponding participant number will be kept in cabinet in a locked office. Only the participant number will be coded on the computer.

Project Abstract

Title: **Changes in coordination during skill acquisition**

Principle Investigator: Jennifer J. Jeansonne

Background: The use of kinematic measures and outcome measures have each been used separately to determine coordination changes as an indication of learning. The research in the field of motor behavior has focused on measuring the effect of practice manipulations on outcome measures to assess the rate and amount of learning taking place. Recently; however, researchers have been able to measure learning through kinetic and kinematic measures and further our understanding of changes, which take place throughout learning. Bernstein (1967) first discussed the process a beginner takes, when initially performing a task, to solve the “degrees of freedom” problem. This is explained as a “freezing” of degrees of freedom at the initial stages of learning, leading to an “unfreezing” of degrees of freedom toward the later stages of learning where there is a release of the joints and muscles used. As a beginner learns a task there seems to be an excessive number of degrees of freedom and the learner must reduce the choices to be able to perform the movement. For example, as the coordination patterns change and the learner is able to use additional degrees of freedom, the movement pattern becomes smoother (Vereijken, van Emmerik, Whiting, & Newell, 1992). Predictions have been made based on the environmental conditions during acquisition such as a stable practice condition (sitting in a chair) or a moving or variable condition (walking through a crowded hallway). Some important issues when measuring coordination changes are what changes occur during the acquisition of a skill, specifically in the movement pattern. Understanding what the relationship is between the movement and performance outcomes is also important in understanding what may be used as good indicators of skill acquisition. The influence of the condition in which the skill is practiced may also have an effect on how the skill is learned.

Purpose: The purpose of this proposed study is to determine what changes occur during the acquisition of the skill, specifically in the movement pattern. Also, to identify the relationship among the movement patterns of the training groups along the open/closed skill continuum.

METHODS

Participants: The proposed experiment will require 40 right handed participants, aged 19-40, taken from the general population of Louisiana State University, Baton Rouge. Participants with experience with throwing darts will be excluded from the study. There will be a \$20.00 reward for the participant scoring the lowest radial error across the four days of practice for each experiment. No left-handed participants will be used due to the method and equipment design.

Apparatus: The kinematic data collection will be recorded by the Vicon Motion analysis cameras and saved on an IBM compatible computer. Reflective markers will be placed on the joint centers of the specified limbs. A target will be projected on a 4' X 4' dartboard surface. The target will be a 5" circle. In the moving conditions, the target will stop when the dart hits

the board. Feedback will be observed and measured in two directions. These values will be used in the analysis of the outcome measures. If the dart misses the board completely a miss will be recorded.

Procedures: Participants will enter the testing room and be given information and instructions for the study. They will each then be assigned to one of 4 experiments, which will determine the practice situation. Once they have read and signed the informed consent, and all questions have been answered, preparation for data collection will begin. Markers will be placed on the segment centers of the upper arm, lower arm, hand, and trunk.

Participants will be instructed to throw the dart at the board using their preferred hand.

Participants will be given different target practice situations (10 participants in each group).

One group will be aiming at a moving target, while others will aim at a random moving target, one group to stationary targets, randomly placed and one at a stationary target. The tasks include open-open task, open-closed task, closed-open task, & closed-closed task, respectively. Each participant will perform four days of practice involving 160 trials each day (8 blocks of 20) for three days. Data will be collected on the last trial of every block of 20 trials.

Motion Kinematics: The parameters to be used will include hand and dart trajectory displacement and velocity. Angular displacement and velocity of the wrist, elbow, shoulder, upper arm, lower arm, hand, and trunk will also be calculated for the analysis. Each trial will be calculated on the time series from elbow flexion to dart release. The motion kinematics will examine the degree of consistency of the pattern throughout learning and calculate the change in the use of degrees of freedom using values from the cross-correlations. Changes in the acceleration profiles will also be evaluated to assess the consistency of the movement throughout learning.

Consent Form

Motor Behavior Laboratory, Department of Kinesiology
Louisiana State University, Baton Rouge

- Title:** **Changes in coordination during skill acquisition**
- Performance Site:** Data collection will be performed in the Motor Behavior Laboratory located in the room 3 Gym-Armory, LSU, Baton Rouge.
- Contact:** Jennifer J. Jeansonne can be reached at the Department of Kinesiology (Phone: 578-2036) between 7:30 and 4:30, Monday through Friday.
- Purpose of the Study:** Identify changes in coordination patterns during skill acquisition of right-handed participants.
- Participants:** 40 right-handed participants between the ages of 19 and 40 will be recruited from Louisiana State University, Baton Rouge. Left-handed participants will be excluded from the research.
- Study Procedure:** Upon enter the laboratory, the participant will be requested to read consent form and then discuss the experiment with the investigator. Any questions concerning the research will be answered.
- Training:** The participants will stand and throw the darts at the dart board directly in front of them for 160 trials per day. The participants will train for 3 days within a week time period. The experimenter will provide instructions for the experiment given the experiment assignment.
- Benefits:** This study provides \$20.00 to the participant scoring the lowest radial error across the 3 days of practice. The study does not provide direct health or mental benefits to the participants involved. The results of the study will benefit the society as it lead to a better understanding on the changes in the process of skill learning.
- Risks/Discomfort:** Participating in this project may produce minor physical discomfort for the participant if the arm becomes tired during the throwing trials. Risk of accidentally being struck by a dart is minimized by only allowing one dart to be thrown at a time, and all those involved will remain behind the thrower until the dart has landed.
- Right to Refusal:** Participation in this study is voluntary and that participants may change their mind and withdraw from the study at any time without penalty or loss of any benefit to which he/she may otherwise be entitled.

Privacy: The study will be confidential and the data collected will not be able to link to the participants direct or indirectly. To assure confidentiality of the data and participants, the hard copy of the information sheet listing both the participant names and their corresponding participant number will be kept in cabinet in a locked office. Only the participant number will be coded on the computer.

Financial Information: There will be neither monetary compensation nor cost to the participant associated with participating in this research.

“The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concerns, I can contact Dr. Robert Mathews, LSU Institutional Review Board, (225)-578-8692. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.”

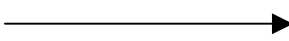
Participant Signature


Date


DART THROWING INSTRUCTIONS AND PROTOCOL FOR EXPERIMENTS 1-4

Task: Dart Throwing– Experiment 1 – Closed w/no IV

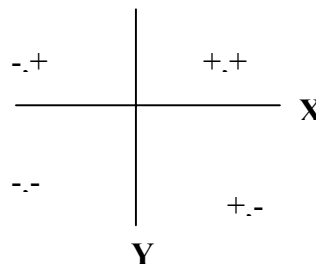
Goal: Throw the dart into the red circle.

You will stand within the box and throw the dart at the red target. 

Before each trial you will need to be ready with your arm at 90° and when the experimenter hits O.K., the circle will disappear and reappear on the board. 

WHEN the target reappears, throw the dart at the target. 

After the throw you will walk up to the board and read your x, y coordinates of where the dart landed to the experimenter.



The even coordinates are labeled, the odd coordinates are the lines in between and if the dart lands in between two lines it is recorded as .5

Be sure to give the X (horizontal) coordinate before the Y (vertical) value, and if the value is negative please record that also.

After taking your dart out of the board, return to the box and prepare for your next throw.

Try to get as close to the red circle every trial.

Remember: The person with the lowest radial error score at the end of the 3 days of training will receive \$20.00

If you have any questions, please feel free to ask now, or at anytime during the experiment.

Task: Dart Throwing– Experiment 2 – Closed w/IV

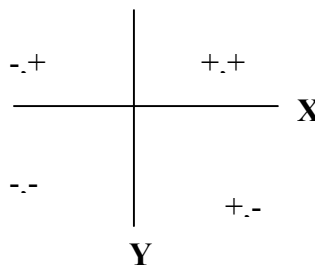
Goal: Throw the dart into the red circle.

You will stand within the box and throw the dart at the red target.

Before each trial you will need to be ready with your arm at 90° and when the experimenter hits O.K., the circle will disappear and reappear on the board.

WHEN the target reappears, throw the dart at the target.

After the throw you will walk up to the board and read your x, y coordinates of where the dart landed to the experimenter.



The even coordinates are labeled, the odd coordinates are the lines in between and if the dart lands in between two lines it is recorded as .5

Be sure to give the X (horizontal) coordinate before the Y (vertical) value, and if the value is negative please record that also.

After taking your dart out of the board, return to the box and prepare for your next throw.

Each time the circle will reappear in a **new** location

Try to get as close to the red circle every trial.

Remember: The person with the lowest radial error score at the end of the 3 days of training will receive \$20.00

If you have any questions, please feel free to ask now, or at anytime during the experiment.

Task: Dart Throwing – Experiment 3 – Open w/no IV

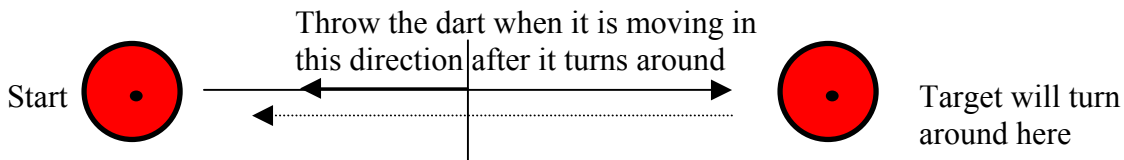
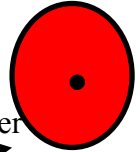
Goal: Throw the dart into the moving red circle.

You will stand within the box and throw the dart at the red target.

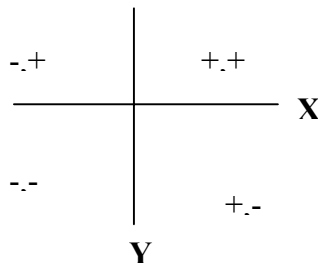
Before each trial you will need to be ready with your arm at 90° and when the experimenter hits O.K., the circle will disappear and reappear on the board.

WHEN the target reappears, throw the dart at the target.

The red target will be moving when it re-appears. The goal is to throw the target after it reverses its direction, but before it returns to its starting location. You will need to release during the first sine wave cycle.



After the throw you will walk up to the board and read your x, y coordinates of where the dart landed to the experimenter.



The even coordinates are labeled, the odd coordinates are the lines in between and if the dart lands in between two lines it is recorded as .5

Be sure to give the X (horizontal) coordinate before the Y (vertical) value, and if the value is negative please record that also.

After taking your dart out of the board, return to the box and prepare for your next throw.

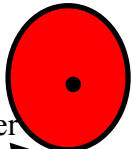
Try to get as close to the red circle every trial.

Remember: The person with the lowest radial error score at the end of the 3 days of training will receive \$20.00

If you have any questions, please feel free to ask now, or at anytime during the experiment.

Task: Dart Throwing– Experiment 4 - Open w/IV

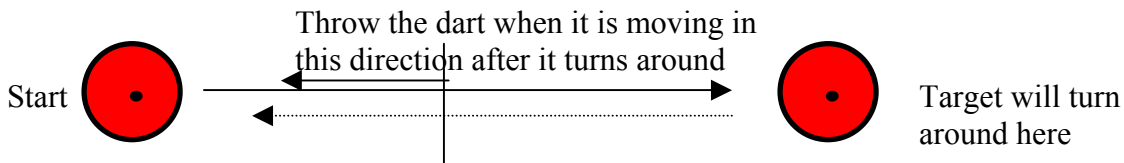
Goal: Throw the dart into the moving red circle.

You will stand within the box and throw the dart at the red target. 

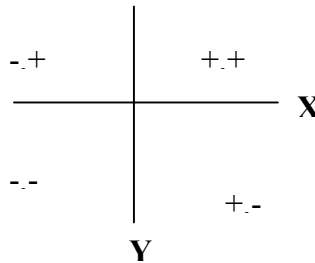
Before each trial you will need to be ready with your arm at 90° and when the experimenter hits O.K., the circle will disappear and reappear on the board.

WHEN the target reappears, throw the dart at the target.

The red target will be moving when it re-appears. The goal is to throw the target after it reverses its direction, but before it returns to its starting location. You will need to release during the first sine wave cycle.



After the throw you will walk up to the board and read your x, y coordinates of where the dart landed to the experimenter.



The even coordinates are labeled, the odd coordinates are the lines in between and if the dart lands in between two lines it is recorded as .5

Be sure to give the X (horizontal) coordinate before the Y (vertical) value, and if the value is negative please record that also.

After taking your dart out of the board, return to the box and prepare for your next throw.

Try to get as close to the red circle every trial.

Each time the target will move in a **new** direction, but you still need to throw within the first cycle.

Remember: The person with the lowest radial error score at the end of the 3 days of training will receive \$20.00

If you have any questions, please feel free to ask now, or at anytime during the experiment.

HYPERLINK TO THE COMPUTER PROGRAM USED TO RUN THE FOUR EXPERIMENTS

The hyperlink below will open the computer program used to run the four experiments. This program was used written and executed using Labview software and hardware from National Instruments. The computer program was used to calibrate the target position each day, present the target for every trial, monitor the accelerometer and stop the target motion in the two open experiments, and save the target and dart coordinates for each trial in each subjects' file. The Labview software must be installed on your computer, including a current license, for the program to open and run correctly.

[Click here to open the program](#)

RELIABILITY TESTS OF THE PERFORMANCE OUTCOME DEPENDENT MEASURE

Reliability Test for the Radial Error Measure

Reliability Scores for the Closed Task with no Intertrial Variability

To test the reliability of the outcome performance measure used in the dissertation experiments, a pilot reliability study was conducted to test the radial error measures that would be used to assess performance improvements for the learning of the dart throwing tasks. The experimental setup used the same procedures as was described in Chapter 2 for Experiment 1. Seven inexperienced participants performed 100 practice throws followed by 20 additional trials to be used in the analysis. The radial error scores were analyzed in a 7 X 20 (Subject x Trials) analysis of variance. The results of these data indicated the intraclass correlation coefficient to have a reliability score of $R=0.77$ for the radial error scores.

Reliability Scores for the Closed Task with Intertrial Variability

The experimental setup used the same procedures as was described in Chapter 2 for Experiment 2. To test the reliability of the radial error scores seven inexperienced participants, who had not participated in the first reliability study, performed 120 practice throws followed by 20 additional trials that were used in the analysis. The radial error scores were analyzed in a 7 X 20 (Subject x Trials) analysis of variance. The results of these data indicated an intraclass correlation coefficient with a reliability score of $R=0.76$ for the radial error scores.

VITA

Jennifer Johnson Jeansonne, was born in Albuquerque, New Mexico, on April 17, 1974 and given the name Jennifer Linnea Johnson. She spent a year in the mountains in New Mexico before moving with the family to Denver, Colorado. After spending four years in the snow and mountains the family moved again this time to Round Rock, Texas. It is here that she began attending school in an attempt to quench her thirst for knowledge. After graduating from Round Rock High School, Jennifer headed to College Station, Texas, to begin her studies in college at Texas A&M University. She managed to balance her studies with her involvement on the club soccer team and working as an official for a variety of individual and team sports. After a final semester of student teaching at an elementary school and a high school in physical education and psychology courses, Jennifer graduated with her Bachelor of Science in kinesiology, and a lifetime certificate to teach physical education and psychology in Texas. She returned to Texas A&M the following semester to complete her Master of Science degree in kinesiology with a psychology minor before leaving for Louisiana State University to begin her doctorate in kinesiology and psychology. During her years in Louisiana, Jennifer met and fell in love with a cajun in Baton Rouge and was married to Carl Jeansonne in May of 2001. Upon graduation from Louisiana State University in May of 2003, Jennifer will continue working at Southeastern Louisiana University as an Assistant Professor teaching undergraduate and graduate courses in motor behavior and biomechanics, while continuing her research in the two fields.