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Manipulation of vision while learning a sensory driven motor task: establishing a boundary to the specificity of practice hypothesis

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Manipulation of vision while learning a sensory driven motor task: establishing a boundary to the specificity of practice hypothesis

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For my mom.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

It has been suggested that learning is specific to the source of information available during practice (Proteau, Marteniuk, & Levesque, 1992). This hypothesis is quite robust for rapid aiming tasks that have defined spatial and temporal goals, but it is unclear whether it extends to tasks that are more sensory driven and with no clear spatio-temporal goal, such as ball balancing. In this experiment, 24 young adults practiced balancing a ball on their thumb and forefinger either with or without vision. Performance was measured early in practice (after 40 min.) and late in practice (after 180 min.) in both conditions. Both groups improved their total balancing time from the early to late testing sessions. Transfer data from the late testing session revealed that all participants performed better with vision regardless of their practice condition. This suggests that vision is the dominant source of afferent information for this task and learning was not specific to the source of information available during practice. Thus, the specificity of practice hypothesis does not apply to this type of task.

CHAPTER 1.

INTRODUCTION

Producing a skilled movement involves cooperation between central planning and error correction mechanisms. With practice, the mover learns to use each of these mechanisms more efficiently but the relative importance of each is not well established at different stages of learning. One theory is that sensory information available for error correction is more important early in learning but becomes less important as the mover becomes more skilled. In this theory, a generalized motor program is established for the movement and once learned, can be executed with minimal dependence on sensory feedback (Schmidt, 1975; 2003). Another theory suggests just the opposite, that learning is specific to the source of information available during practice, and therefore becomes even more important later in learning (Proteau, Marteniuk, & Levesque, 1992; Proteau, Tremblay, & DeJaeger, 1998). This specificity of practice hypothesis is quite robust for rapid aiming tasks and gross motor tasks that have defined spatial and temporal goals; however, it is unclear whether it extends to less defined sensory-driven tasks.

The purpose of this study was to determine if the specificity of practice hypothesis could be extended to a fundamentally different task. The task, balancing a ball on the thumb and forefinger, cannot be executed without feedback. Since a generalized motor program with specific space-time parameters cannot be established for this task, the mover must integrate planning and error correction differently. To determine if sensory information becomes more or less important as one learns this task, 24 young adults were divided into two practice groups, one that practiced with vision and one that practiced without vision. Both groups practiced for 20 minutes, three times per week, for three and a half weeks totaling 180 minutes of practice. Each individual's performance was measured early in practice (after 40 minutes) and late in practice (after 180 minutes) in both practice conditions. The primary dependent variable was total balancing time. In order to assess strategy changes with learning the relative distance moved by the balancing hand and the number of peaks in the velocity profile were also measured.

Both groups learned the task as indicated by their improved total balancing time from the early to late testing sessions. However, the vision group was able to balance the ball for multiple minutes (fatigue was the major factor for dropping the ball) while the no vision group reached a plateau at about 30 seconds of balancing time. The number of velocity peaks decreased with practice in the vision group but not in the group that practiced without vision. This indicates that a strategy change of fewer abrupt adjustments is established with vision. The strategy change indicates that the participants learned to anticipate the movement of the ball and were better able to use feedforward control mechanisms later in practice. These data also suggest that vision is the dominant source of afferent information for this task.

In order to test the specificity of practice hypothesis, a transfer test was conducted at the late testing session to determine if the addition of vision had a detrimental effect on the performance of the group that practiced without vision (Proteau, 1992; 1998). Transfer data revealed that all participants performed better with vision regardless of their practice condition, thus suggesting that learning was not specific to the source of

information available during practice. It is concluded that the specificity of practice hypothesis does not apply to tasks such as ball balancing.

CHAPTER 2.

EXPERIMENT

Introduction

Researchers agree that practice is essential for learning a new motor skill. However, there are conflicting opinions about the role of sensory information after varying amounts of practice. Two contrasting ideas about motor learning are: (1) sensory information is more important early in practice and less important later in practice, and (2) sensory information is essential throughout practice, even increasing in importance after extensive practice.

The idea that the importance of sensory information decreases as one becomes more skilled at a task has historically been the basis of hierarchical motor control theories (eg. Keele, 1968; Adams, 1971; Schmidt, 1975). These theories suggest that with practice, movements can be executed without sensory feedback (Keele, 1968), control of movement shifts from closed-loop to open-loop (Adams, 1971), and an abstract representation of the movement is developed that can later be executed with minimal dependence on afferent information (Schmidt, 1975).

These theories continue to provide a basis for learning, retention, and transfer studies (e.g. Abrams & Pratt, 1993; Deakin & Proteau, 2000; Sekiya, Magill, Sidaway, & Anderson, 1994; Sekiya, Magill, & Anderson, 1996) especially those that incorporate feedback-based error correction (e.g. Franks & Romanow, 1993; Meyer, Smith, Kornblum, Abrams, & Wright, 1990). The abstract representation, or generalized motor program (GMP), is thought to control a group of movements that have common characteristics (Schmidt, 2003). Invariants, such as relative force and timing, are imbedded in the GMP, which can be adjusted based on the actual magnitude and timing of the desired movement. This theory is well supported for movements with defined spatial and temporal goals, such as discrete aiming (Schmidt, 1975; 2003; Robin, Toussaint, Blandin, & Vinter, 2004). With practice, the GMP is more firmly established and sensory feedback becomes less necessary.

In contrast, Proteau and colleagues (Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, Marteniuk, & Levesque, 1992) proposed that the neural representation developed during practice is specific to the source of sensory information available during practice and is therefore highly dependent on afferent information even late in practice. Proteau and colleagues (1992) found that practicing discrete aiming without vision for 1200 trials and then transferring to execution with vision actually disrupted performance. This was surprising given the importance of vision in rapid aiming (Elliot & Jaeger, 1988; Robin et al., 2004; Carlton, 1981; Hay & Beaubaton, 1986). These data suggest that sensory and motor information are strongly integrated with practice and adding or deleting afferent information after extensive practice disrupts performance more than after minimal practice.

The specificity of practice hypothesis is quite robust for discrete aiming movements (Proteau et al., 1987; 1992; Elliot & Jaeger, 1988; Temprado, Vieilledent, & Proteau, 1996), precision walking (Proteau, Tremblay, & DeJaeger, 1998), complex sequential limb positioning (Ivens & Marteniuk, 1997), and video-aiming (Abrams & Pratt, 1993). One common characteristic in all of these motor skills is that they have specific spatial and/or temporal goals. They are also movements for which a GMP can be established. Whether the specificity of practice hypothesis extends to movements that do not have these characteristics is unclear. Balancing a ball on one's fingers requires constant feedback and error correction. Since a generalized motor program with specific space-time parameters cannot be established for this task, the mover must integrate planning and feedback-based error correction differently. The purpose of this experiment was to better understand the role of afferent information in this type of skill.

We tested the specificity of practice hypothesis in ball balancing to determine whether, with practice, performance becomes more or less dependent on the sources of afferent information available during practice. This task was chosen because it is highly sensory-dependent and a generalized motor program with specific space-time parameters can not be established. If consistent with specificity of practice, it is hypothesized vision will be dominant after 40 minutes of practice but after 180 minutes of practice, participants will learn to use tactile cues more efficiently and transfer to vision will negatively affect performance. If this hypothesis is supported then the specificity of practice hypothesis will be extended to this type of sensory-driven task. If our hypothesis is not supported then we will have established a boundary to specificity of practice.

Method

Participants

Twenty-four neurologically healthy young adults (mean age = 22.8 years, SD = 3.17 years) participated in this study. Participants were stratified by gender and then randomly assigned to one of two practice groups: Full Vision (FV) (n=11, 6 men, 5 women) and No Vision (NV) (n=13, 7 men, 6 women). The university's Institutional

Review Board approved the study. Participants' consent was obtained according to the Declaration of Helsinki.

Task and Procedures

The task for this experiment was to balance a foam dodge ball (200mm diameter, 140g) on the pads of the thumb and forefinger of the dominant hand. Fingers were placed on pre-marked spots on the ball spaced 6 cm apart. All participants were instructed to attempt to balance it for as long as possible.

Practice. Participants were seated in a stationary chair throughout practice with the chairs positioned in a circle. The FV participants faced outward to minimize distractions and were specifically instructed to look at the ball during practice. They were instructed to re-position their fingers on the pre-marked spots whenever contact with the ball was lost. In the NV group vision was occluded with a blindfold, thus a researcher was paired with each participant to retrieve and repositioned the ball on the fingers when contact was lost. This ensured accurate finger placement without the removal of the blindfold. The NV participants faced inward in the circle to facilitate ball retrieval by the researchers. All participants were instructed to keep the ball in front of their shoulders while balancing.

Practice lasted for a total of 180 minutes divided into nine 20-minute sessions conducted on Mondays, Wednesdays, and Fridays for three and a half weeks. During pilot testing, we found that practice for longer than 5 minutes without rest caused substantial fatigue in the shoulders, arms, wrists, and fingers. Also, if participants balanced the ball continuously for more than 1 minute, subsequent attempts at balancing were blunted until the participant rested for 5 minutes. Therefore, during each practice session, participants were randomly divided into two groups that alternated 5 minutes of practice and 5 minutes of rest.

Testing. All participants were tested in both full vision and no vision conditions beginning with the participant's practice condition. Participants balanced the ball on the finger/thumb of their dominant hand and supported it with their non-dominant hand. Testing sessions occurred 2 days after the completion of 40 minutes of practice (early testing) and after the completion of 180 minutes of practice (late testing). Both testing sessions were identical and lasted for approximately 15 minutes. All participants were tested for 5 trials in each condition to assess time in balance. For each total time trial, balancing was terminated at 60 seconds in order to prevent fatigue on subsequent trials. None of the participants reached this cutoff in early testing but eight participants in the FV group tested with vision did so during late testing. For these trials, a balancing time of 60 seconds was used for analysis. Total time was measured using separate trials from kinematics due to a limitation in the duration of the kinematic sampling.

In addition to early and late testing, changes in performance across sessions were conducted on a subgroup of volunteer participants (FV group n = 4, NV group n = 4). We collected 10 trials of total time data after each practice session using the same method as testing sessions. No cut off time was used during these trials.

Movement of the hand was assessed through use of the Optotrak camera system (Model 3020, Northern Digital, Inc., Waterloo, Ontario, Canada) at a spatial resolution of 1 mm. Data were collected at 200Hz. One infrared light-emitting diode (IRED) was secured on the posterior of the first metacarpal just below the knuckle on the dominant (balancing) hand (see Figure 1). A second IRED was secured to the non-dominant wrist in order to record movement of the support hand (used to indicate the beginning of balancing). After a warning tone and start signal, participants were to move their support hand away from the ball as soon as they were comfortable doing so. Data were collected until the ball dropped, contacted another object, or balancing time exceeded 15 seconds, whichever came first. Each participant was given 1 practice trial and then 5 trials were collected in each condition. Mis-starts (i.e. losing the ball immediately after releasing, balancing lasting less than 2 seconds, or removing the support hand prior to the start signal) were replaced. Balancing time (up to 15 seconds) was also recorded using a stopwatch.

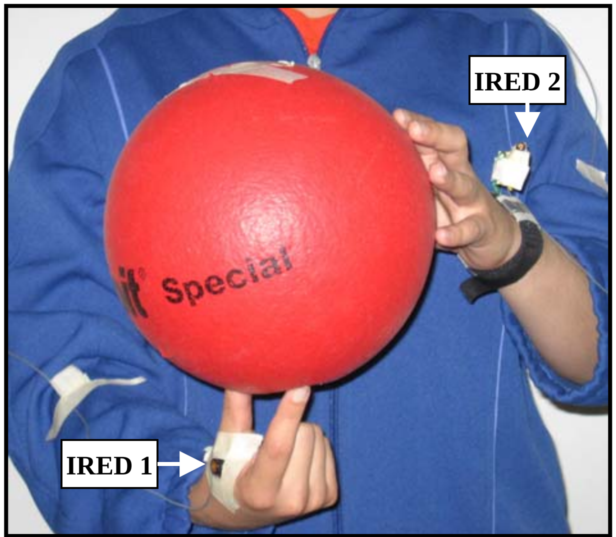

FIGURE 1. Ball balancing task. Pictured is the starting position. After the signal, participants removed their support hand (IRED 2) and balanced for as long as possible. The *x*, *y*, and *z* coordinates of the balancing hand (IRED 1) were recorded.

Dependent Variables

Total balancing time for each participant was measured using a stopwatch by the same trained researcher. Time was measured from the release of the supporting hand to either loss of contact between the ball and the dominant hand or the introduction of some other support (non-dominant hand or body).

Kinematic data collected with the Optotrak system included relative distance and peaks in the velocity profile (which measures the number of adjustments) of the balancing hand. All data were normalized by dividing by seconds because participants balanced the ball for different durations. Velocity peaks were defined as at least 5 data points in which the magnitude of tangential velocity increased followed by at least 5 data points where it decreased or vice versa.

Data Reduction and Analysis

Kinematic data were filtered with a second-order dual-pass Butterworth filter by using a 21-Hz low-pass cutoff frequency (Smith, 1989). We selected this cutoff frequency to optimally remove noise without eliminating important signal information (Winter, 1990). The start of balancing was defined as the first change in the non-dominant (support) hand’s velocity profile. The end of balancing was indicated by the ball blocking the IRED or by a sudden movement of the hand, and was confirmed by adding the balancing time, recorded by stopwatch, to the start time. The data for each dependent variable were reduced by calculating a mean across the 5 trials for each participant.

In order to determine if the participants became more efficient at using the sensory information available during practice, we conducted one-way analyses of variance (ANOVA) across acquisition sessions (early and late) for each of the dependent variables. Since it is not known how practice affects the kinematic variables measured on this task, we used the changes observed in the FV group performing with vision as representative of learning.

Specificity of practice was tested by comparing the acquisition and transfer performance of a group that practiced extensively under one set of afferent information. In order to compare acquisition and transfer within each group we conducted a Group (2) x Condition (2) ANOVA with repeated measures on the second factor for each variable at the late testing session. For comparison, we also conducted a Group (2) x Condition (2)

ANOVA with repeated measures on the second factor on the same variables for the early testing session. Variability around the mean is expressed as standard deviations in tables and confidence intervals in graphs. Alpha level was set at .05.

Effect sizes (ES) were also calculated to estimate the degree of improvement in standard deviation units to enable comparison across the dependent variables (Thomas, Nelson, & Silverman, 2005). An effect sizes greater than 0.8 is interpreted as a large and meaningful change.

Results

Total Balancing Time

As expected, both groups became more proficient at the task and were able to balance the ball longer after 180 minutes of practice. The one-way ANOVA for acquisition revealed a significant improvement in total balancing time for both the FV group, $F(1, 10) = 25.19$, $p = .001$, Effect Size (ES) = 1.87, and the NV group, $F(1, 12) = 19.99$, $p = .001$, ES = 1.65 (see Figure 2A and 2B). It is also apparent from the sub group data that the NV group reached a plateau in balancing time after practice session 6 (120 minutes of practice) (see Figure 3). This plateau is also evident when comparing the effect size for the NV subgroup from session 1 to session 6 (ES = 2.61) and session 6 to session 9 (ES = .06). The FV group did not reach a plateau in the 180 minutes of practice. Two of the participants in the FV sub group exceeded 7 minutes while collecting these data and one exceeded 3 minutes. For these three participants subsequent trials were all shorter than 45 seconds, presumably due to fatigue. It should be noted that, within the subgroup, the average time immediately after practice session 9 for both groups was longer than the averages in the late testing session (2 days after practice). The primary reasons for this difference are that the three best trials were selected from the 10 trials (thus biasing toward the best performance), and there were no time limitations.

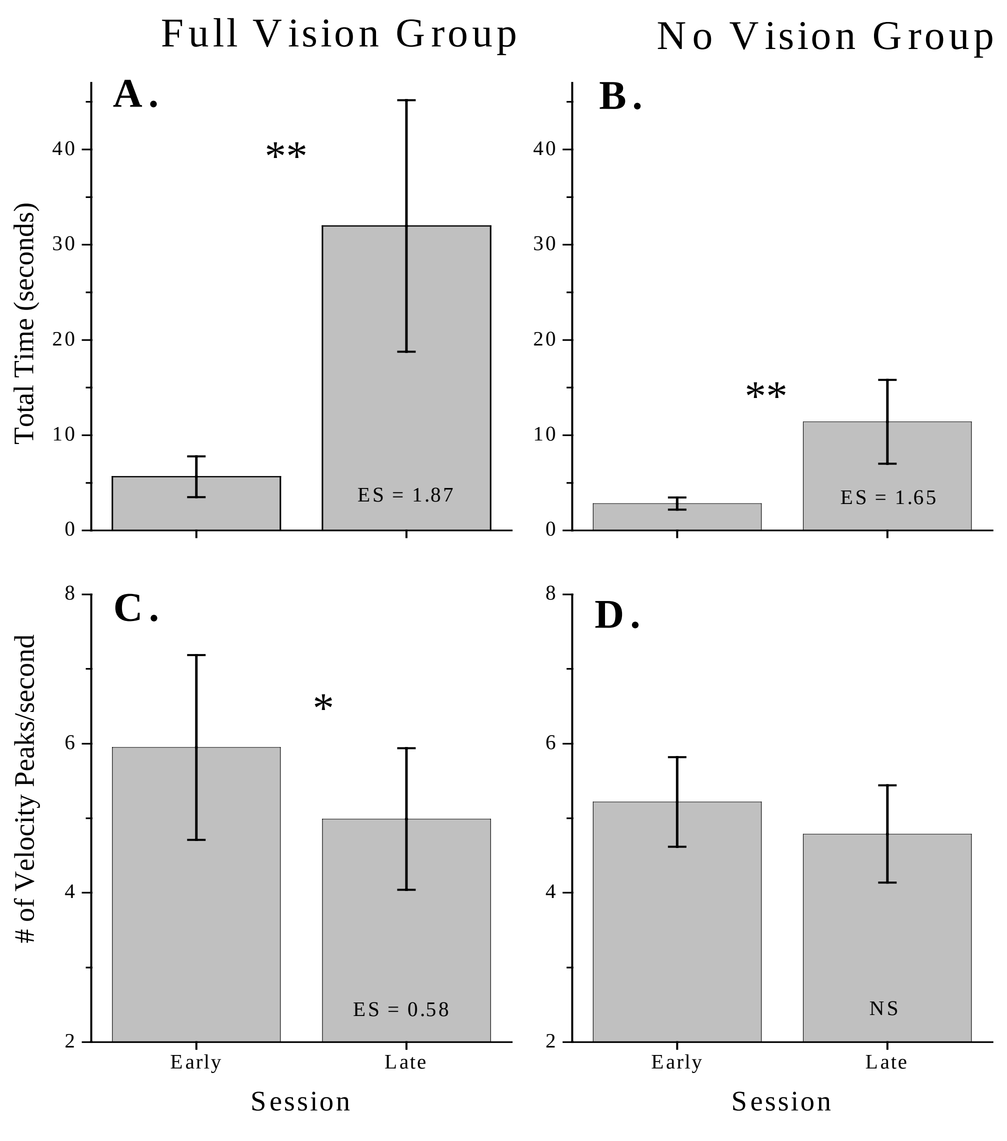

FIGURE 2. Acquisition from early to late testing. Total balancing time for the (A) Full Vision (FV) and (B) No Vision (NV) group. Number of velocity peaks per second for the (C) FV and (D) NV group. Error bars are 95% confidence intervals. ES = effect size. ** $p<.001$; * $p<.05$. NS = not significant.

To test specificity of practice, we compared acquisition and transfer of total time in the late testing session. The Group x Testing Condition ANOVA revealed an interaction, $F(1, 22) = 35.76$, $p = .003$, ES for NV = 0.65, ES for FV = 1.83 (see Figure 4A and 4B). This interaction shows that both groups balanced the ball longer in the vision condition thus revealing vision as the dominant source of afferent information in this task (see Table 1 for means and standard deviations on all dependent variables).

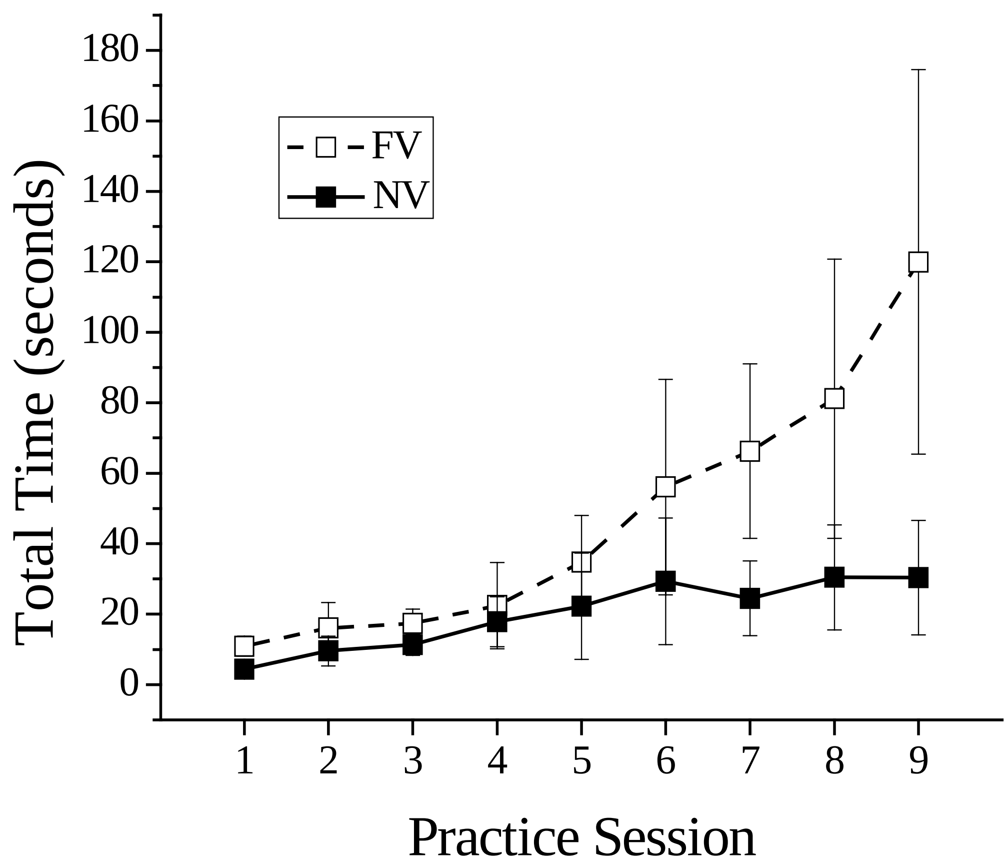

FIGURE 3. Performance curve for subgroups. Total time by practice session for FV and NV. Error bars are 95% confidence intervals.

Relative Distance

The relative distance moved by the FV group did not change with practice even though they were able to balance the ball for a longer time (see Table 1). This indicates that the strategy used to improve performance in this task does not include changing the

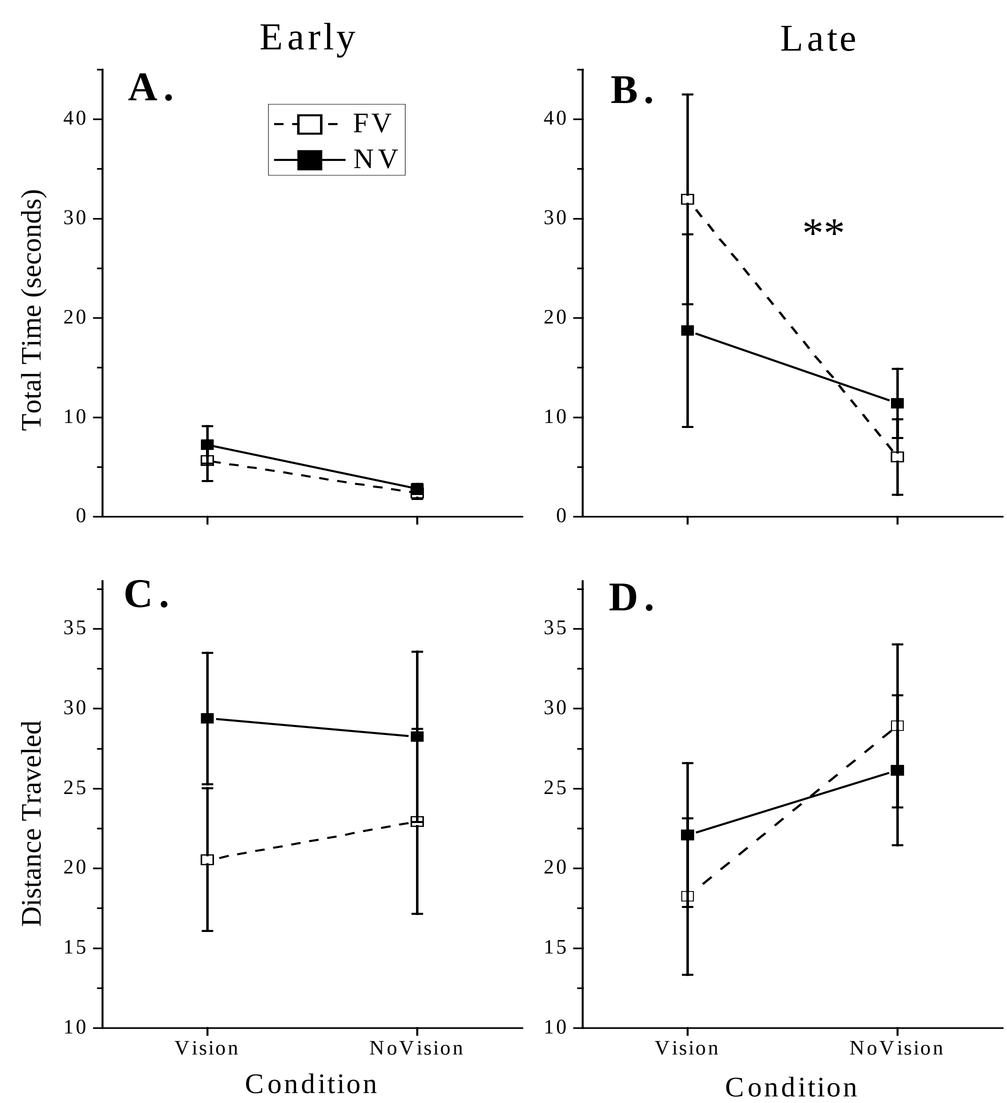

FIGURE 4. Acquisition and transfer within early and late sessions. Total time for (A) Early session and (B) Late session. Relative distance for (C) Early session and (D) late session. Error bars are 95% confidence intervals. **p<.003.

distance moved by the hand. No differences were found in relative distance for the NV group after practice. A significant main effect for Group was found in the early testing session, *F*(1, 22) = 16.03, p = .001, ES = 0.96, with longer relative distance in the no vision condition (Figure 4C). No differences were found for relative distance in the late testing session.

TABLE 1. Acquisition and Transfer in Early and Late Testing.

Variable	Group	EARLY		LATE	
		Acquisition	Transfer	Acquisition	Transfer
Total Time (s)	FV	5.64 (3.19)	2.38 (0.57)	31.96 (19.64)	6.02 (4.18)
	NV	2.82 (1.09)	7.24 (3.35)	11.41 (7.28)	18.74 (14.19)
Relative Distance (cm/sec)	FV	20.55 (6.75)	22.98 (7.44)	18.24 (5.32)	28.93 (7.11)
	NV	28.24 (10.54)	29.39 (7.46)	26.15 (8.95)	22.09 (9.43)
Velocity Peaks (#/sec)	FV	5.95 (1.85)	5.70 (1.09)	4.99 (1.42)	4.73 (0.99)
	NV	5.22 (0.99)	4.89 (0.82)	4.79 (1.07)	4.54 (1.53)

Velocity Peaks

The number of velocity peaks per second indicates how often the participant increased or decreased the speed of the balancing hand while balancing the ball, i.e., the number of adjustments. A significant main effect was found with the one-way ANOVA for acquisition of the FV group from early testing to late testing, *F*(1, 10) = 5.73, p = .038, ES = 0.58, with fewer velocity peaks per second late in practice. This indicates that a change in strategy is learned with practice that involves fewer changes in velocity. The NV group, however, did not show this effect. No differences were found in the Group x Testing Condition ANOVA for velocity peaks (Figure 2C and 2D).

Discussion

The specificity of practice hypothesis is tested by manipulating sensory information after extensive practice (Proteau et al., 1992; 1998). If this manipulation causes a decrease in performance then the specificity of practice hypothesis is upheld, indicating that the learner is more dependent on the specific source of afferent information that was available during practice. The specificity of practice hypothesis has primarily been tested in tasks with defined spatial and/or temporal goals. The purpose of this experiment was to determine if this hypothesis could be extended to a fundamentally different type of skill. The chosen skill, ball balancing, has several characteristics that are fundamentally different from a discrete aiming task. There is no specific space-time pattern associated with ball balancing and the task is sensory feedback-dependent. These characteristics make it difficult to establish a generalized motor program for this task and therefore learning is dependent on the mover's ability to integrate sensory information with the movement more efficiently. This could manifest in an increased ability to anticipate errors and use feed-forward control.

The data in this study indicate that this task represents a boundary to the specificity of practice hypothesis. Rather than the addition of vision disrupting performance after extensive practice, the addition of vision in the NV group improved performance (see Figure 4B). This is in contrast to Proteau et al. (1992) and thus does not support the specificity of practice hypothesis. Our data suggest that extensive practice of this skill does not integrate tactile information with the movement to the point that the addition of vision disrupted the movement. Our data also suggest that vision is the dominant source of afferent information in this task. After extensive practice, the total time balanced with vision by the FV group was significantly higher than the total time balanced without vision by the NV group. Even though both groups practiced the same amount of time in their practice condition, when vision was available, participants were able to balance the ball longer. Early in practice aiming tasks are performed more accurately with vision than without vision (Elliot & Jaeger, 1988; Robin et a., 2004; Carlton, 1981; Hay & Beaubaton, 1986; Proteau et al., 1992), specifically vision in the latter portion of the movement (Temprado, Vieilledent, & Proteau, 1996). In Proteau's study (Proteau et al., 1992), vision was dominant early in practice but after extensive practice without vision, participants were able to use proprioceptive cues more efficiently and were not dependent on vision. These results were not found in this experiment.

Specificity of practice can only be tested if both groups learn the task (Proteau et al., 1998). Our data revealed that both groups became more proficient at the task of balancing a ball after 180 minutes of practice. This is indicated in the large effect sizes found for total balancing time (1.87 and 1.65 in the FV and NV group, respectively), from early testing to late testing.

As the first study that has quantified strategy changes in ball balancing, the effects of learning on the kinematic variables tested are unknown. Therefore, data from the FV group were used as the standard. The kinematic data from this group may reveal strategy changes that improve performance for this task. The only kinematic variable that changed with practice in the FV group was velocity peaks, with fewer peaks later in practice. This may indicate that with practice participants learned to make fewer abrupt velocity changes, which could indicate greater anticipation and fewer reactive adjustments (Pew, 1966). Data for the NV group did not show any changes for velocity peaks from early to late in either condition. Reducing velocity peaks to improve performance appears to be a strategy that is learned only when vision is available during practice, thus indicating that vision is necessary for anticipation.

This research has established one clear boundary to the specificity of practice hypothesis. For a task that is highly feedback dependent with one source of afferent information that is dominant over others, the specificity of practice hypothesis does not apply. Although both groups were able to better use the sensory feedback that was available after practice, it is clear that this learning was not specific to the source of afferent information available during practice. Both groups performed significantly better with vision, even after extensive practice without vision.

CHAPTER 3.

CONCLUSION

It is logical that the removal of sensory information in a sensory dependent motor skill will disrupt performance. However, the addition of sensory information, specifically vision, has also been found to have a negative effect on performance (Proteau, Marteniuk, & Levesque, 1992; Proteau, Tremblay, & DeJaeger, 1998). This later conclusion is the result of a number of experiments on rapid aiming movements and other skills (eg. precision walking) that have defined spatial and temporal goals. For these skills, the same movement is repeated during practice and knowledge of results (for both space and time) is provided once the movement is complete. This information is used to establish a representation of the movement in which sensory and motor information is strongly integrated. When new sensory information is added to the system, that specific mechanism is no longer relevant and the movement will be more representative of a novice learner.

In this experiment, the specificity of practice hypothesis was not supported, i.e., sensory and motor information were not strongly integrated with practice. Late in practice, the addition of new sensory information did not disrupt performance, rather it enhanced performance. These data indicate that we found a boundary to the specificity of practice hypothesis.

The task of balancing a ball has unique features that rapid aiming and other space- and time-goal oriented skills do not. This task cannot be performed without sensory feedback. The movement of the ball dictates the movement of the hand and no two trials will be performed exactly the same. Before conducting this experiment, the relative contributions of visual and tactile information for this task were not known. The data clearly show that vision is the dominant source of afferent information for ball balancing. It is possible that specificity of practice is not applicable to tasks in which one source of sensory information is dominant. Although vision is important when aiming to a specific target, proprioceptive information can be effectively used in the absence of vision as seen in Proteau’s studies. The tactile feedback from contact between the ball and the fingertips does not seem to provide the same information as vision and therefore was not as effective in error correction. Additional studies in which tactile information is removed and participants practice with only visual feedback are needed to better understand the role of tactile feedback in this task.

Even though vision was dominant for this skill, the group that practiced without vision was still able to improve performance. This group improved for the first six practice sessions to more than four times their original balancing time but did not show any additional improvement during the last three practice sessions. The group that practiced with vision continued to increase their balancing time throughout the nine practice sessions and some participants were able to balance the ball for more than seven minutes after 180 minutes of practice. As revealed in the kinematic data, this group used a different strategy than the no vision group. The vision group had fewer velocity peaks per second in the late testing session. The number of velocity peaks is an indication of the development of anticipation. More velocity peaks per second are caused by quick changes in velocity without changing direction. It may be that this strategy is the reason that the vision group could balance the ball for a longer period of time than the no vision group. Changes in kinematics are indicative of strategy changes and should be studied further in sensory dependent tasks.

Additional work in this area may also include a better understanding of the feed-forward mechanisms used when balancing a ball. Information about the ball's movement in relation to the balancing hand would be necessary to study feed-forward control. It is also possible that with more practice the no vision group could establish similar strategies to the vision group and overcome the plateau. Kinematic testing after each practice session, especially during the plateau, could reveal this information.

Balancing a ball is a dynamic and unpredictable task that cannot be programmed and executed without sensory feedback. Rather than establishing a GMP, practice leads to strategy changes, such as fewer abrupt movements, to enhance performance. The movement of the ball provides direct feedback, both tactile and visual, to which the system must react in order to make the necessary adjustments. When practicing this task with vision, one is better able to use the sensory information received and make smoother adjustments. Further work is necessary to understand exactly how the sensory information is used in this task. Does use of this information shift from a feedback control system to a feedforward system? Can one better predict the ball's movement visually than from cutaneous receptors? Would more extensive practice without vision overcome the plateau seen in our data and allow these participants to balance as long as those in the FV group? These questions are beyond the scope of this research but are important to further develop the boundaries to the specificity of practice hypothesis.

It is clear that a boundary to the specificity of practice hypothesis has been established. When one source of sensory information is dominant, addition of this source will enhance performance even if one has already integrated motor output with another source of afferent information. For this task, motor learning was not dependent on the source of afferent information available during practice.

APPENDIX A.

REVIEW OF LITERATURE

The changes that occur in the human body when learning a new motor skill have been the subject of much research during the past fifty years. While almost all researchers agree that practice is essential for learning a new motor skill there are conflicting opinions about the role of sensory information after varying amounts of practice. Two major contrasting ideas have emerged from this research: (1) sensory information is more important early in practice and less important later in practice, and (2) sensory information is essential throughout practice, even increasing in importance after extensive practice.

The idea that the importance of sensory information decreases as one becomes more skilled at a task was first proposed by Keele (1968). His research suggested that experts were able to execute movements without sensory feedback. Later, Adams (1971) found that with practice, control of movement shifted from closed-loop to open-loop, where movements could be implemented without feedback. Adams also noted that afferent information was used primarily for error correction and thus was not needed as often when the movement could be performed with minimal errors. Schmidt (1975) further extended this idea in his schema theory, which places more importance on feedback early in practice than late in practice. He proposed that practice develops an abstract representation of the movement that can later be executed with minimal afferent information.

In contrast to Adams (1971) and Schmidt (1975), Proteau, et al. (1987; Proteau, et al. 1992) has proposed that the neural representation developed during practice is specific to the source of sensory information available during practice and is therefore highly dependent on afferent information even late in practice. This research suggests sensory and motor information are integrated strongly with practice. Therefore, adding or deleting afferent information after extensive practice will disrupt performance more than removal after less practice. Proteau (1992) refers to this as the specificity of practice hypothesis. Although the hypothesis is quite robust for discrete movements with specific spatial and temporal goals, it is not clear whether it extends to movements without specific spatial and temporal goals.

The purpose of this study is to explore the specificity of practice hypothesis using a continuous, sensory-dependent movement that does not have a specific spatial or temporal goal. The task chosen for this experiment is balancing a ball on the pads of the thumb and pointer finger. The goal is a performance goal: to prevent the ball from falling off the fingers for as long as possible. Participants will practice balancing the ball either with or without vision and will be tested under the opposite condition after a short and long amount of practice.

It is hypothesized that after extensive practice the group practicing without vision will experience a significant decline in performance when tested with vision available. One would expect performance to improve when more sensory information is made available, but if the specificity of practice hypothesis does extend to this type of movement then the neural representation formed from practice without vision will be disrupted when vision is added and performance will be negatively affected. If this hypothesis is correct, it will further our understanding of the role of sensory information in motor learning and possibly necessitate a new theory of how learned movements are represented in the brain.

Vision increases the accuracy of aiming tasks.

It is well established that early in practice aiming tasks are performed more accurately with vision than without vision. This conclusion is supported regardless of the nature of the aiming task. For example, Elliot and Jaeger (1988) had participants perform a spatial-temporal aiming task with either full vision, vision of only the target, and vision of only the target with movement starting two seconds after occlusion of full vision. In the initial test, and during practice, participants performed more accurately under the full vision condition.

Kelso and Frekany (1978) suggested that if the participant can control the endpoint of the aiming movement, vision is not necessary for accurate reproduction. However, Robin et al. (2004) disputed this idea by reporting fewer errors when vision was available in a participant-controlled pointing task. In this study, participants practiced moving a stylus to “self-defined” targets (participants chose any location within a 1/3 square meter area and then aimed for the same location in the next trial) with and without vision. Regardless of the amount of practice (up to 720 trials), fewer errors were found when participants performed with full vision. Also, although the participant’s “self-defined” target was not indicated by any visual means in the repeated trial, (the end point was stored mentally and then recalled), the occlusion of vision still hindered performance.

The necessity of vision also holds true for copying letters and shapes. Smyth (1989) reports data that rejects the notion of a grammar of action (with practice, similar shapes are always produced in the same way) and instead proposes that vision plays a major role in the sequence of shape production. Without vision, participants in this study used a strategy that minimized the number of relocations of the pen, thereby reducing spatial errors. When vision was available, almost all participants used a similar sequence of movements to copy the shape (namely left to right and top to bottom motions). Although fewer individual lines were used when vision was occluded, the overall shape was less accurate in this condition. These data also support the logical conclusion that vision is necessary for precise spatial movements.

The availability of vision improves spatial accuracy over conditions where vision is not available. Moreover, vision of the moving limb or cursor as well as vision of the target results in fewer errors than vision of the target alone. Carlton (1981) and Hay and Beaubaton (1986) proposed that vision of the target coupled with proprioceptive information from the moving limb are not sufficient to accurately contact the target. In both studies, although vision of the target was still available, accuracy of pointing was diminished when vision of the hand was occluded. Therefore, while vision of the target is more helpful than no vision at all, vision of the hand or stylus is necessary for optimal accuracy.

These conclusions have been replicated by Proteau in a number of studies (Proteau 1992; Proteau et al., 1987; Proteau & Cournoyer, 1990). During the acquisition phase for each experiment, performance by the groups that could see both their hand and the target was significantly more accurate than the groups that only had vision of the target. Even after 1200 practice trials full vision resulted in fewer errors (Proteau, 1992).

Therefore, for an aiming movement, vision of the entire task is important even after extensive practice.

It is logical that vision is important for an aiming task where a movement must be made precisely to a visual target and consequently there has been little debate over this theory. There is also support for the position that vision is necessary for gross movements that have more ambiguous endpoints. Bennett and Davids (1995, Experiment 1) found that vision was important for intermediate power lifters to perform a legal squat. With full vision (with a full length mirror positioned in front of the participant) participants performed more accurately than with ambient vision (focusing on a spot on the ceiling) or no vision. However, this gross movement does not have a precise end point as described in previous studies. A legal squat requires the participant to lower his or her body until the hips are just below the knees. Trained judges decide if a squat meets this standard by watching from a short distance. This kind of judging leads to ambiguity regarding the end point of the squat. Also, the movement was performed slowly, allowing the participant to adjust his or her endpoint before being judged.

The role of vision during different parts of the movement.

The above studies indicate that vision plays a vital role in aiming movements. They do not, however, describe when vision is important. Carlton (1981) demonstrated that withdrawing visual information during the first portion of an aiming movement had little effect on the accuracy of the movement. Participants performed an aiming task when vision of the hand was blocked by a barrier at various distances. Accuracy was not affected until more than 75% of the movement was occluded. Therefore, Carlton concluded that vision of the hand is not necessary until the final quarter of an aiming movement. Movement kinematics also revealed a slight sub-movement about 135ms after the hand became visible in this condition. These data suggest the use of vision for error detection and correction during the latter portion of the movement.

These results were replicated by some experimenters but the literature is still not clear on the issue. For example, the results from Carlton's (1981) study were disputed by Spijkers and Lochner (1994), who found that removing vision during the first half of the movement, rather than only the last quarter, had a detrimental effect on performance. They conducted a similar aiming task, blocking vision for the first 25%, 50%, and 90% of the movement. Participants performed more accurately in the 25% condition than either other condition leading the experimenters to conclude that the visual information available near the beginning of the movement was important to ensure spatial accuracy. No data were reported for a no-vision condition and the results at 50% and 90% were not significantly different.

However, the results from Carlton (1981) were replicated by Temprado, Vieilledent, and Proteau (1996). In this study, participants practiced the aiming task under either a full vision condition, vision during the first half, vision during the second half, or no vision conditions. As in Carlton (1981), accuracy was not inhibited by occlusion of the hand in the first half of the movement. During a transfer test where all participants performed the task without vision, accuracy was negatively affected only for the groups that practiced with full vision or with vision during the second half of the movement. This indicates that when vision is present for the second half of the movement, the mover uses a similar type of control to a full vision condition. Additionally, vision of the hand during only the first half of the movement results in similar accuracy to a no-vision condition, suggesting that vision during the first half of the movement is not critical for aiming accuracy. It should be noted, however, that these tasks all involved fast discrete movements. Slower movements seem to rely more heavily on vision during the entire movement (Beaubaton & Hay, 1986).

Support for Specificity of Practice

The above studies demonstrate a strong relationship between vision and control of motor skills. However, vision is obviously not the only control mechanism used to produce skilled movement. Since humans are able to move with some degree of accuracy without visual input, there must be other sources of afferent information to aid the control of movement. Attempts to understand how different types of afferent information are used to control movement abound in the second half of the twentieth century.

Fleishman and Rich (1963) concluded from their two-hand coordination study that reliance on vision (a seemingly dominant source of afferent information) diminishes with practice and is replaced by kinesthetic input. Years later, Cox and Walkuski (1988) attempted to replicate the study by Fleishman and Rich (1963) but failed to do so. Their results indicated that proprioceptive cues were not more important than visual-spatial cues later in learning. Rather, they found that kinesthetic inputs had no effect on the tasks (pursuit rotor and ball tossing) regardless of the amount of practice, and that vision was always dominant. These results were interpreted under the assumption that movements were a result of different types of afferent input. In a sense, they were considered complex reflexes.

In the early 1970’s, however, motor learning theories were based on the idea that movements were controlled centrally rather than reflexively and another theory emerged regarding the importance of afferent information for movement control. Adams (1971) concluded that with practice, control of movements transitions from closed loop to open loop control, thus diminishing the importance of all afferent information, not just vision. Schmidt’s schema theory (1975) also provided evidence for centrally represented motor programs. He found that practice enables motor programs to produce skilled movement without afferent input. He suggested that a shift occurs during learning from jerky feedback-dependent movements to smooth almost completely open-loop movements.

Abrams and Pratt (1993) conducted a study using a video-aiming task to better understand the diminishing role of afferent information. The results showed that practice led to an increase in the duration of the first portion of the movement (assumed to be the motor program) and a decrease in the time spent in the later part of the movement (corrective phase dependent on feedback). This could be interpreted as an increased dependence on the motor program (supporting Schmidt’s theory) and a decreased dependence on feedback. However, it can also imply that, with learning, participants were better able to use the afferent information to correct their movement (as suggested by Temprado et al., 1996). Almost all of the trials in this study exhibited at least one submovement indicating that there was still some reliance on afferent information to accurately contact the target.

Contrary to the previous studies, Proteau et al. (1992) proposed that visual feedback actually increases in importance with practice. Their participants completed 1200 trials of a rapid aiming task (80cm in 550ms) using a stylus. One group practiced all trials with full vision of the hand, stylus, and target. One group practiced in the dark with only the target lit and a third control group did not practice at all. All groups were subject to a pretest and two transfer tests in the full vision condition. The first transfer test occurred after 200 practice trials while the second was after all 1200 trials. As expected, participants in the full vision group performed more accurately (especially spatially) during the acquisition phase than the group that could only see the target. Both groups improved significantly over the 1200 trials indicating that learning did take place. The important finding from this study, however, is that the group that practiced with only the target visible did not produce any significant differences in the full lighting condition after 200 trials but significantly increased errors after 1200 trials (both spatially and temporally). These results indicated that with excessive practice, the specific afferent input used during practice becomes increasingly important for the accurate production of an aiming task. For the participants who practiced extensively without vision, the addition of visual feedback in the transfer task served as a hindrance to performance rather than a help.

These data support another motor learning hypothesis: specificity of practice. This hypothesis is centered around the idea that the specific information used during practice to control a movement actually increases in importance as learning occurs. Proteau and colleagues (1992; see also Proteau et al., 1998) suggest that the addition of vision in transfer actually interferes with what has already been learned without vision, confusing the system, and causing increased errors. Since these participants practiced without vision, they had not learned how to use the visual information efficiently. Therefore, practice must establish an integration between the sensory modality available during practice and the specific motor output.

In the Proteau et al. (1992) study, the performance detriment occurred after 1200 trials, but not after only 200 trials. Therefore, it seems that sufficient practice is needed to establish this sensorimotor integration. Once this integration is established, if the sensory information is removed, performance is hindered.

Proteau's experiments were based on earlier studies by Elliot and Jaeger (1988) where participants performed a spatio-temporal aiming task under similar conditions (vision and no vision). In this case, there was no control condition, but instead participants in this third group waited two seconds after the lights were turned out before beginning the movement. The delay did not cause any significant differences in accuracy. After practice, all participants were tested in transfer tasks in all three conditions. As expected, participants who practiced under the full vision condition made more errors when they transferred to either of the other conditions. Surprisingly, participants who practiced under the target-only or target-delay condition had more errors when performing with full vision. The researchers concluded that the participants who practiced without vision formed a sensori-motor pattern that integrated kinesthetic information with the desired outcome. When these participants received visual input during transfer their sensori-motor pattern was interrupted by the foreign information and thus produced more errors. This provides strong support for the specificity of practice hypothesis.

In another extension of Proteau's 1992 work (Ivens & Marteniuk 1997), three groups practiced a complex sequential positioning movement on a manipulandum. The movement was a series of flexions and extensions about the elbow joint that included four changes of direction at specific angles. Participants performed a pretest of ten trials with vision and then practiced for either 50 or 300 trials without visual feedback. A control group practiced 300 trials with vision. All participants were re-tested with vision post-practice. All groups improved with practice and, as expected, the full-vision control group was superior overall. While the high practice without-vision group (300 trials) did improve during acquisition, their pre and posttest performance (with vision) was not significantly different. The group that only practiced 50 trials without vision did experience a significant increase between pre and posttest accuracy. As in previous studies, these data indicate that the high practice group learned to use other forms of sensory information in the absence of vision, which produced a performance decrement when vision was added. These data support the specificity of practice hypothesis and extend it from a simple aiming movement to a sequential limb-positioning task.

A year later, Proteau et al. (1998) reported data on a gross motor skill that supports his earlier work regarding specificity of practice. In this study, participants practiced walking 20 meters along a line on the floor either with or without vision. After practice, both groups transferred to the no-vision condition. When vision was removed after participants had practiced extensively with vision (100 trials), performance significantly declined. Vision was the dominant source of afferent information during practice and when it was removed the participant had to rely on other forms of sensory information (ie. kinesthetic). The performance for this group in transfer was even worse than the baseline trials for the group that practiced without vision. Therefore, when performing without vision, it was more beneficial to not practice at all rather than practice extensively with vision. However, after only 20 trials, no significant differences were found in performance between practice with vision and without vision. This indicates that with only 20 trials of practice, participants had similar access to kinesthetic cues to correct performance regardless of visual input.

This study (Proteau, 1998) attempted to extend the specificity of practice hypothesis from a quick discrete aiming movement to a more continuous gross movement. The results also support the specificity hypothesis but the design of the study seems to mimic that of an aiming study rather than a continuous movement. The dependent variable was an outcome measure (the distance from the participant's ending point to the correct ending point) rather than a measure of performance. In this study, vision was not needed to guide the movement itself, but rather to ensure that the end of the movement was on target. Further work is needed in this area to determine if specificity of practice truly holds for continuous, sensory-dependent movements.

Proteau et al. (1998) propose that the information received during practice forms a sensorimotor representation that gets stronger with more practice under the same condition. Certain afferent information is expected during the motor task. If, after extensive practice, this afferent information is withdrawn, the sensorimotor representation is incomplete, which causes performance to deteriorate. The above studies lend support to the specificity of practice hypothesis. There are a number of researchers that attempted to further extend specificity of practice to other categories of movements but failed to replicate the above results and therefore rejected the notion of specificity of practice. However, Proteau and collegues (1998) suggest that many of these studies did not follow a paradigm that clearly tested specificity of practice. These procedural differences could be the reason the hypothesis was not supported.

Evidence that does not support specificity of practice

Published in consecutive years, Whiting and Savelsbergh (1992), Franks and Romanow (1993), Lidor and Singer (1994), and Bennett and Davids (1995 Experiment 2), all provided evidence that practice does not need to be specific to the testing condition in order for optimal performance to occur. A decade later, Robin (2004) also rejected this hypothesis. Before beginning a discussion on these studies, it is necessary to understand the testing paradigm for specificity of practice.

All learning paradigms cannot be used to test specificity of practice. Proteau et al. (1998) discuss some important conditions that must be addressed in order to properly test this hypothesis. First, the study must not use a novice-expert model. Although experts have practiced more than novices, their skill may be the result of a number of factors that do not involve vision. Therefore, when vision is removed, they can still rely on these other cues to achieve optimal performance. In studies that use a novice-expert model, it is not usually known under what specific conditions the expert acquired the skill. Although practice is high, the practice conditions are unknown and removing vision would not test specificity of practice.

The second condition for testing specificity of practice involves the use of knowledge of results (KR). If learning has truly occurred, performance should be stable without any KR. Therefore, the testing condition (often transfer of some kind) must be performed without any KR. For example, after each transfer trial the participants in Proteau's walking study (Proteau et al 1998) were led back to the starting point by an obscure route such that they would not know the accuracy of their performance. In a study done by Robertson et al (1994), participants walked on a balance beam without vision. Although these participants were not given any KR during transfer, they were able to evaluate their own performance from feeling the edge of the beam with their feet. This type of design is not optimal for testing learning specificity.

For the majority of the studies that reject the specificity of practice hypothesis, the movement performed was a gross motor skill rather than a simple aiming task as used in the previously described studies. Bennett and Davids (1995) investigated novice and skilled (extensive practice) power lifters performing a squat under three conditions: full vision, ambient vision (focusing on a spot on the ceiling), and no vision. Ninety percent of the skilled lifters reported practicing under full vision conditions yet they performed with a high level of accuracy across all conditions. The investigators report that these data fail to support the sensorimotor representation and the specificity of practice hypothesis. The experimenters suggest that there is a boundary to the hypothesis, restricting it to aiming movements, but more work could be done in this area using a design that does not incorporate the novice-expert model.

Whiting and Savelsbergh (1992) also studied the role of practice in gross movements. Their participants caught a ball in a fully lit condition or a dark room where only the ball was lit. The results indicate that despite the practice condition, participants performed with equal accuracy during the pre and posttest transfer conditions. Thus, transfer did not have a detrimental effect, once again rejecting the specificity of practice hypothesis. In this study, participants were awarded partial points (dependent variable) if they touched the ball but did not catch it. Under these conditions, the participant did not need to have a great deal of spatial accuracy to achieve a high score. This may have led to less convincing results than a task that needed more precision.

Similarly, Lidor and Singer (1994) used athletes to determine if training condition affected performance outcome. Participants threw a paddleball at a target during conditions of noise and quiet. Results indicated that there was no difference in error during transfer conditions. However, the novice-expert paradigm used in this study does not allow for a true test of specificity.

In a task similar to Ivens and Marteniuk (1997), Franks and Romanow (1993) had participants perform a tracking task using either a finger joystick or arm manipulandum. Performance was better under transfer conditions that were different from practice conditions rather than the reverse, as found by Proteau et al. (1992; 1998). As learning progressed, participants became increasingly independent from vision, which provides support for Schmidt's motor program theory.

More recently, Robin et al. (2004) replicated Proteau's work using "self-defined" targets. Participants aimed anywhere on a 300mm square surface and then attempted to repeat that same movement in the next trial. Groups were similar to previous studies: high practice (720 trials) and low practice (20 trials). Each group was then further divided into a vision group and a no-vision group. As expected, the groups that practiced with full vision of their own limb consistently performed better than those who performed the task in the dark. From the end of the acquisition phase to a posttest, withdrawal of vision from the groups that practiced with vision had a detrimental effect on the group that only practiced 20 trials but not on the extensive practice group. No differences were found from acquisition to post test when vision was added, thus contradicting specificity of practice. Motor learning for “self-defined” targets did not result in more efficient use of afferent information nor did adding vision necessitate a new sensorimotor representation.

The conflicting literature necessitates further study into the specificity of practice hypothesis. Specifically, research in this area lacks insight about sensory-dependent continuous movements that do not have a defined spatial or temporal goal. An example of this type of movement is balancing a ball on two fingers. The movement necessitates sensory feedback yet does not have specific spatial or temporal parameters. Does the specificity of practice hypothesis extend to this type of movement? The present study is designed to answer this question.

APPENDIX B.

INFORMED CONSENT DOCUMENT

Title of Study: The manipulation of vision and cutaneous proprioception during practice of a continuous task.

Investigators: Christy Reed, BS (cgoggin@iastate.edu); Ann Smiley-Oyen, PhD (asmiley@iastate.edu)
Contact Information: Motor Control and Learning Laboratory, 178S Forker Building, Department of Health and Human Performance, Iowa State University, Ames, IA 50011
Phone: 515-294-3288

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This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

It is common knowledge that learning any motor skill takes practice. However, there are many different theories about exactly how a person should practice in order to minimize time and maximize performance gains. The purpose of this study is to further understand how specific kinds of practice affect learning a new movement. The results will be useful to teachers, coaches, athletes, and anyone else interested in learning motor skills. You are being invited to participate in this study because you are a student at Iowa State University and have little or no experience with the motor skill to be learned.

DESCRIPTION OF PROCEDURES

Before participating in this study, you will obtain a medical release from your current physician for the use of 2% topical lidocaine. If this release is not obtained or if your physician indicates that you are allergic to or currently using lidocaine you will not be able to participate in this study. If you agree to participate in this study, your participation will last for three weeks and will consist of three visits to the Motor Control and Learning laboratory each week for approximately 45 minutes per visit. During the study you may expect the following study procedures to be followed. You will be asked to balance a rubber kickball on your thumb and index finger for as long as possible under three different conditions: 1) with both vision and touch, 2) with only touch (you will be blindfolded during this condition), and 3) with only vision (you will be apply a small amount of a topical numbing cream (2% lidocaine) to the pads of your finger and thumb. You will be asked to practice in the lab under only one of the above conditions multiple times per week with no more than 30 minutes of practice per day. You will then come into the lab again for a testing session in which the investigators will record the amount of time you can balance the ball on your fingers in the three conditions mentioned above. During the testing sessions you will also be videotaped and data regarding the position of your hand and the ball will be recorded so the investigators can better analyze your movement.

RISKS

There are no known risks to your health or well being associated with participation in this study. You will experience numbing of the index finger and thumb during the vision only condition. This numbing will last throughout the condition and remain for a short time afterwards but you will regain feeling within several minutes.

BENEFITS

If you decide to participate in this study you will learn a new motor skill. There are no other direct benefits to you. However, it is hoped that the information gained in this study will benefit society by providing a more thorough understanding of the most efficient ways to practice a motor skill.

COSTS AND COMPENSATION

You will not have any costs from participating in this study. You will not be paid to participate in this study.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled. At any time during the study, you may withdraw your consent to participate for any reason and without consequence.

RESEARCH INJURY

Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, all data will be coded numerically by subject and no names, initials, or other identifying characteristics will be reported in publication or presentation. Hard copies of all data will be kept in a locked file cabinet in the Motor Control and Learning Laboratory and computer files of data will be stored on a password protected computer. Videos will not contain any identifying information. If the results are published, your identity will remain confidential.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during this study.

- For further information about the study please contact Christy Reed (294-3288) or Dr. Ann Smiley-Oyen (294-8261).

- If you have any questions about the rights of research participants or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, Office of Research Assurances (515) 294-3115.

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PARTICIPANT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

____ ________________________
(Participant's Signature) (Date)

INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

____ ________________________
(Signature of Person Obtaining Informed Consent) (Date)

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