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**Divided Attention During Adaptation to Visual-Motor Rotation in an Endoscopic Surgery Simulator**

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# DIVIDED ATTENTION DURING ADAPTATION TO VISUAL-MOTOR ROTATION IN AN ENDOSCOPIC SURGERY SIMULATOR

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**Abstract**

The goal of this research was to understand how cognitive demand affects the process of acquiring adaptive hand-eye coordination. Endoscopic surgery, during which surgeons operate using video cameras and long, thin surgical tools, is an example of a situation that requires adaptive hand-eye coordination. In endoscopic surgery the normal mapping between the hands and the eyes is distorted, presenting a perceptual-motor challenge for surgeons and potentially causing a disruption in coordination. Besides having to adapt to altered perceptual-motor conditions surgeons also have to deal with many other simultaneous demands, such as monitoring vital signs. Having to perform other simultaneous tasks during endoscopic surgery may divert attention that is necessary for the complex movements demanded by the surgery. The specific aim of this study was to investigate whether adaptive performance in an endoscopic surgery simulator suffers under dual-task conditions. I investigated the effects of a concurrent short-term memory (STM) task on adaptation to visual-motor distortions encountered in an endoscopic simulator. Participants completed a peg transfer task in a low-fidelity endoscopic surgery simulator. In the *pre-exposure* and *post-exposure* phases participants moved small foam stars between pegs with endoscopic forceps while directly viewing the pegboard. In the *exposure* phase participants completed the peg transfer task while indirectly viewing the pegboard through a camera and monitor with a 90° clockwise visual rotation of the pegboard. A control group completed the experiment as described whereas an experimental group performed the STM task (mentally rehearsing a random string of digits) during the exposure phase. Performance was significantly disrupted under altered perceptual-motor conditions during early exposure-phase performance. The STM task caused an additional initial performance decrement,

but experimental group performance quickly converged on control group performance.  The results provide greater support for the single than the multiple resource model of attention.

# Table of Contents

# List of Figures

# Divided attention during adaptation to visual-motor rotation in an endoscopic surgery simulator

## Chapter I

## Introduction

Advances in technology have dramatically changed the way surgeries are performed today. In the past surgeons usually had to make large incisions to reach organs, and they could directly view and manipulate the operating field. Today certain surgeries can be performed using much less invasive procedures, termed endoscopic (or laparoscopic) procedures. In endoscopic surgery a small camera and long, thin surgical tools are inserted into the body through small incisions. Images of the surgical field obtained by the camera (endoscope) are transmitted through a video monitor to the surgeon. Minimally invasive techniques cause less tissue damage and, therefore, patients heal more quickly. With those advantages endoscopic surgery has grown in popularity. Today, 80% of all gallbladder removals are performed endoscopically, and this figure is expected to increase in the future (Berci & Forde, 2000). Endoscopic surgery can also be applied to joints, the gastrointestinal tract, the chest, the abdomen, and coronary arteries.

### *Perceptual-Motor Challenges of Endoscopic Surgery*

Despite the advantages of endoscopic surgery, there are also problems. A fundamental problem associated with endoscopic surgery is the perceptual and motor demand placed on the surgeon. Because of the minimally invasive nature of endoscopic surgery, surgeons have to deal with perceptual-motor demands that are different from those required by traditional open surgery. For instance, in endoscopic surgery the normal mapping between the hands and the eyes is distorted—the mapping between the hands and eyes is different from traditional open surgery. Because of the altered hand-eye mapping instruments may appear to move in a direction different than the actual direction of movement. That situation presents a perceptual-motor challenge to surgeons and may cause a disruption in surgical performance (Holden, Flach, & Donchin, 1999). Moreover, the three-dimensional view in traditional open surgery is replaced by a two-dimensional image on a video monitor. This results in losses of depth information, resolution, contrast, and color fidelity (Reinhardt-Rutland, Annett, & Gifford, 1999). The use of long, thin surgical tools and a reduction of degrees of freedom also limit haptic feedback (MacFarlane, Rosen, Hannaford, Pellegrini, & Sinanan, 1999). Though the problems associated with the video image and the loss of haptic feedback may be substantial, the primary focus of this study was the distorted hand-eye mapping.

As part of their training in endoscopic surgical procedures, surgeons have to learn new perceptual-motor skills. It can take anywhere from 3 months to 2 years of simulator and animal training during this time and up to about 25 actual supervised procedures to gain a level of proficiency required for unsupervised operations on patients (Hawes, Lehman, Hast, O'Connor, Crabb, Lui, & Christiansen, 1986). However, even after extensive training the perceptual motor-conditions of the endoscopic environment are still demanding. One reason is that the altered hand-eye mapping is not consistent from surgery to surgery or even within a given surgery. During the course of a procedure, the camera may be moved and/or rotated, or the surgeon may have to change position from one side of the patient to the other. Holden et al. (1999) found that simulator performance was disrupted when the camera was moved relative to surgical instruments and when surgeons changed position relative to the camera. However, when the camera and surgeon positions were changed together (when a consistent mapping between the camera and motor orientation was maintained) performance did not decline.

Based on those findings and other findings from sensory rearrangement studies, it seems that adaptation to a distorted hand-eye mapping requires that the distortion remains constant (Bingham & Romack, 1999; Gibson, 1969; Howard, 1982; Redding & Wallace, 1996; Welch, 1978). Since experienced surgeons are able to maintain relatively high levels of performance under changing hand-eye mappings, it remains a question whether or not performance becomes immune to changes in the mapping once a certain amount of experience has been attained, or whether surgeons are capable of maintaining multiple adaptive perceptual-motor states (Cunningham & Welch, 1994; Lackner, 1993; Stanney et al., 1998).

These problems associated with endoscopic surgical performance are related to fundamental perception-action issues studied by experimental psychologists and human factors specialists (e.g., skill learning, perceptual-motor adaptation). In addition to the issues of skill learning and perceptual-motor adaptation, another fundamental constraint on perception-action and topic of considerable interest to human factors was studied in the present research—the performance costs of dual-tasking.

*Cognitive Constraints During Surgical Performance*

The endoscopic performance environment is challenging not only because of the altered perceptual-motor conditions, but also because surgeons have to cope with many simultaneous cognitive demands during endoscopic surgery. For instance, surgeons must monitor vital signs in addition to performing the complex movements demanded by the surgery. *Divided attention* occurs when performers are required to perform two or more tasks at the same time and attention is required in order to perform each of the tasks. In many divided attention or dual-task conditions performance on at least one of the tasks suffers. There is a general consensus that humans have a limited cognitive capacity and when tasks are performed concurrently the limited capacity can be deleterious to task performance. The capacity limitation issue is often expressed in terms of attentional or cognitive resources. In this view (Kahneman, 1973; Wickens, 1984), attention is treated as a limited resource to be allocated between different perceptual, cognitive, or motor tasks. Performance of any given task (depending on level of practice of the task and the nature of the task itself) requires some of those resources. The inability to successfully perform two tasks concurrently might be due to the fact that resources are limited (single resource theory; Kahneman, 1973) or that different activities demand different types of resources and interference occurs when the same pool of resources is accessed by more than one task (multiple resource theory; Wickens, 1984).

Kahneman's (1973) model of resource theory assumes that attention exists as a single, limited pool of resources that can be flexibly allocated among concurrent tasks up to the point that all attention has been allocated. There are three characteristics of resources that are relevant to dual-task performance: Scarcity, allocation, and task difficulty. With regard to scarcity, this theory assumes there is a limited supply of resources. If the limited resource supply is divided between tasks and is exceeded one or both tasks will receive insufficient resources and, therefore, performance on one or both tasks will suffer. This is regarded as the basic dual-task performance decrement. With regard to allocation, this theory assumes that resources can be continually and voluntarily allocated among tasks in a graded quantity. Resources can be allocated between two tasks in different proportions. Resource tradeoffs can be made if there are insufficient resources to perform two tasks. More resources can be allocated to achieve successful performance on one task but at the cost of decrementing performance on the other task. With regard to task difficulty, this theory assumes difficult tasks will require more resources to maintain a high level of performance. If this is the case there will be fewer resources available to allocate to a concurrent task and performance on the concurrent task will suffer. If the resources allocated to the concurrent task remain fixed, a discrepancy between required and allocated resources will increase, and performance on the primary task will deteriorate.

The single resource theory of attention has been challenged. One problem with the theory is that sometimes people successfully perform highly demanding tasks simultaneously (Navon, 1984). Resource theory cannot account for highly demanding tasks that can be performed together without interference. In reponse to such criticisms, hierarchical models of cognitive processing were proposed (Broadbent, 1971; Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977a; Schneider & Shiffrin, 1977b) suggesting at least two levels of cognitive processing. The higher level is typically responsible for novel tasks that require substantial cognitive attention in spite of increasing experience. The lower level is generally considered responsible for well-learned tasks that can be performed without much cognitive involvement (e.g., bicycle riding, typing). With extensive practice dual-task interference can be reduced or eliminated (Peterson, 1969; Shaffer, 1975; Spelke, Hirst & Neisser, 1976). Practice may reduce the need for resources, allowing for successful performance of two highly demanding tasks (Schneider & Shiffrin, 1977a). Tasks that have been practiced sufficiently come to be performed more quickly and accurately and also no longer impose capacity demands. Over the course of practice performance shifts from a resource demanding stage (controlled processing) to a stage that requires few or no resources (automatic processing).

Tasks can eventually be performed simultaneously without interference from, or producing interference with, other concurrent tasks.

Resource theory has also been challenged by the observation that modality changes in one task can affect performance on the other task (Wickens, 1984). When tasks are performed in the same sensory modality (e.g., both visual) it is often harder to perform those tasks than to perform a task combination in different sensory modalities (e.g., one visual, one auditory). Based on those observations, it has been proposed that the dual-task decrement results from structural interference between similar processes rather than a lack of resources (Wickens, 1984). Structural interference between two tasks results from competition for the same mental or neurological structures.

These challenges resulted in the generalization of the original single-pool resource theory to a multiple resource model (Wickens, 1984). Wickens' theory assumes there are multiple pools of resources and performance decrements occur only when the same pool of resources is accessed by more than one concurrently performed task. The different resource pools are differentiated according to information processing stages (encoding and central processing versus responding), processing codes (spatial versus verbal), and perceptual modality (for example, auditory versus visual). The resources used for encoding and central processing appear to be the same and are separate from the resources used for the selection and execution of responses. Thus, an individual should be able to divide attention between information processing stages. Similarly, the resources used for spatial processing codes are presumed to be different than the resources used for verbal processing codes. Individuals should thus be able to divide their attention between spatial and verbal tasks better than between two tasks that require the same processing code. Finally, the resources used for vision, for instance, are supposedly different from the resources used for hearing. Individuals can divide their attention between perceptual modalities, and should be able to divide their attention between visual and auditory tasks better than between two visual tasks or two auditory tasks. Different tasks may require different resources along any of those three dimensions. If the demands imposed by two tasks do not overlap, performance of both tasks should not suffer.

*The Present Study: Perceptual-Motor and Cognitive Constraints on Endoscopic Performance*

One of the aims of this study was to quantify adaptive performance changes in an endoscopic surgery simulator. The other, and primary, aim of this study was to investigate whether adaptive performance in an endoscopic surgery simulator would suffer under dual-task conditions. Very little is known about how simultaneous cognitive demands affect the process of acquiring adaptive hand-eye coordination. In the experiment participants completed a peg-transfer task in a low-fidelity endoscopic surgery simulator. In the *pre-exposure* and *post-exposure* phases of the experiment participants moved small foam stars between pegs with endoscopic forceps while directly viewing the pegboard. In the *exposure* phase participants completed the peg transfer task while indirectly viewing the pegboard through a camera and monitor with a clockwise visual rotation of 90°. Peg transfer tasks have been shown to correlate strongly with *in vivo* performance (Derossis, Fried, Abrahamowicz, Sigman, Barkun, & Meakins, 1998; Fried, Derossis, Bothwell, & Sigman, 1999). A control group completed the experiment as described whereas an experimental group performed an additional, secondary cognitive task during the exposure phase. At the start of the experiment, experimental group participants' digit spans (a measure of short-term memory [STM] capacity) were tested using a digit memory test (Turner & Ridsdale, 1997). Experimental group participants were verbally presented a random string of digits, one less than their measured maximum digit span, at the beginning of each trial and were instructed to mentally rehearse the numbers while performing the peg task. At the end of each trial participants recited the digits aloud to the experimenter. Time to complete the task, number of errors (drops of the foam stars), and STM task performance were recorded.

Performance (operationalized in terms of two measures, movement time and number of errors) was expected to be significantly disrupted (time to complete the task and errors would increase) when participants switched from directly viewing the pegboard to indirectly viewing the pegboard. This disruption was expected because the normal mapping between the hands and eyes was altered by the visual rotation. During the exposure phase, a main effect of trial was expected—performance was expected to improve over trials. This effect has been demonstrated in previous research (e.g., Holden et al., 1999; Rosser, Rosser, & Savalgi, 1999; Scott et al., 2001).

Of particular interest in this study was the effect of the STM task on performance during the exposure phase. Single resource theory and multiple resource theory make different predictions in this regard. Single resource theory predicts, first of all, that experimental group performance would be significantly worse on the first exposure phase trial, relative to control group performance, because experimental group participants performed a secondary cognitive task in addition to dealing with altered perceptual-motor conditions. Presumably concurrent performance of those tasks would exceed the performer's resource capacity. Single resource theory predicts, moreover, that the dual-task performance decrement should persist (i.e., a main effect of group will accompany the main effect of trial—the experimental group will always perform worse than the control group, although performance will improve across trials for both groups), although if with practice the peg transfer task came to require fewer resources, experimental group performance might become comparable to control group performance after some number of trials (i.e., a group × trial interaction).

Wickens' (1984) multiple resource theory, on the other hand, would predict no dual-task performance decrement. The tasks differ in terms of processing stage (encoding/central processing for the STM task versus responding for the peg transfer task), processing codes (verbal for the STM task versus spatial for the peg transfer task), and perceptual modality (auditory for the STM task, since the digits are presented auditorily, versus visual for the peg transfer task). Thus, according to Wickens' model there should be no group effect or group × trial interaction.

An aftereffect was expected in the post-exposure phase, when participants returned to normal visual conditions. An aftereffect means that on the first few trials of the post-exposure phase participants will perform worse than during the pre-exposure phase. This result is expected on the basis of similar results found in prism adaptation studies (see Welch, 1978). In prism adaptation, aftereffects are present upon return from distorted visual conditions to normal visual conditions. Finally, the two groups were expected to perform equivalently in pre- and post-exposure phases.

# Chapter II

# Method

*Participants*

Thirty-four undergraduate students (18 males and 16 females) from the University of Cincinnati voluntarily participated in this experiment to fulfill a requirement for an Introductory Psychology course. All participants reported a right-hand preference, no history of neurological, neuromuscular, or skeletal disabilities/disorders, and no broken or severely injured body segments in the past year. All participants had normal uncorrected vision or corrected-to-normal vision by glasses or contact lenses. All participants signed an informed consent form approved by the University of Cincinnati Institutional Review Board prior to beginning the experiment.

*Apparatus*

The low-fidelity endoscopic surgery simulator (see Figure 1a) consisted of a small box of dimensions 45.72 × 34.29 × 10.50 cm that rested on a 60 cm table. The box was covered by an opaque, removable top. Two holes, located 7.11 cm apart horizontally, were cut in the center of the removable top to hold a set of two Ethicon Endosurgery 5 mm grasping forceps. A pegboard (see Figure 1b) was located in the bottom-center of the box. The pegboard consisted of three rows with two pegs in each row. Vertical separation between rows was 2.54 cm and horizontal separation between pegs in a row was 7.62 cm. The pegboard also contained two electrical contact buttons, located 3.30 cm to the left and right sides of the pegs. The two electrical contact buttons enabled a buzzer and started and stopped a timer upon contact. A color video camera (Panasonic AG-460) was mounted on a stand at a fixed height (99.06 cm) to the left of the box.

The camera was used to rotate visual feedback 90º during certain phases of the experiment. Visual feedback was projected onto a 48.26 cm Panasonic color television monitor. The monitor was mounted at a fixed height (132.84 cm) located directly in front of the participant. A light source (25 watts) was located between the video camera and the pegboard.

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Insert Figure 1 here

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*Procedure*

The experiment consisted of four phases: Practice (practice data were not analyzed), pre-exposure, exposure, and post-exposure (the pre- and post-exposure phases were identical). The experimenter read instructions describing the four phases to each participant at the beginning of the experiment. Participants were randomly assigned to one of two groups; they received different experimental treatments only during the exposure phase. During the exposure phase, the *experimental group* performed a secondary cognitive task while concurrently performing the peg transfer task whereas the *control group* did not perform a secondary cognitive task while performing the peg transfer task.

Data collection began on a given trial when the participant pressed the appropriate contact button to start the timer, and ceased when the participant completed the peg transfer task and pressed the other contact button to stop the timer. The complete experiment consisted of 53 trials (practice: 3 trials; pre-exposure: 10 trials; exposure: 30 trials; post-exposure: 10 trials), and lasted approximately 60 to 90 minutes.

*Digit Memory Test.* This test was used to obtain a measure of experimental group participants' (control group participants were not tested) STM (Turner & Ridsdale, 1997). Digit spans were tested forward and backward. For the forward test participants were presented random strings of digits (generated using the "rand" function in *Microsoft Excel*) and instructed to repeat the digits in the same order as presented. Digits were presented auditorily by the experimenter at a rate of one digit per second. Digits were non-repeating. The experimenter attempted to eliminate variation in pitch of voice during digit presentation. Two trials of each digit string length were administered. The digit strings increased in length by one digit (beginning with a length of 2 digits) after each pair of trials. The test terminated when participants failed to recall both trials of a pair of digits. The backward test was administered and scored exactly the same as the forward test, except that participants were instructed to repeat the numbers backwards. Overall digit span was calculated by averaging the digits-forward and digits-backward scores (mean digit span = 5.71 digits; range = 5 – 6 digits).

*Peg transfer task.* During every trial of the experiment all participants performed a peg transfer task. A similar peg transfer task has previously been shown to strongly correlate with *in vivo* performance (Derossis et al., 1998; Fried at al., 1999). Participants were asked to transfer three foam stars (1.5 mm thick, 1 cm center hole diameter, and 0.23 g) in a certain order from the pegs on one side of the pegboard to the pegs on the other side. Foam stars were transferred from the left side to the right side and vice versa, starting with either the top or bottom star, and transferred in successive order. Participants started with either the top-left, bottom-left, top-right, or bottom-right star (starting positions were randomized). The forceps were placed by the experimenter on the contact buttons prior to the start of every trial. As an example of the participant's task on a given trial, consider a participant starting with the top-left star. The participant began a trial by pressing the left contact button, thereby starting the timer and sounding the buzzer, with a surgical forcep controlled by the left hand. The participant picked up the top star from the left side using the left forcep, transferred it in the air to a forcep held by the right hand, and then placed the star on the top peg on the right side of the pegboard. The participant then transferred the middle and bottom foam stars from left to right as just described. If the participant dropped a foam star he or she had to pick it up with the same forcep from which it was dropped. Once all three foam stars were successfully transferred, participants pressed the right contact button with the forcep controlled by the right hand to stop the timer and sound the buzzer. The experimenter recorded the time taken to complete the task and number of errors (drops) and then reset the foam stars, the forceps, and the timer.

*Practice phase.* The practice phase was conducted to familiarize participants with the endoscopic graspers and the peg transfer task. The peg transfer task was demonstrated by the experimenter, and each participant was given three practice trials while directly viewing the pegboard (i.e., not through the camera and monitor — the opaque top was removed). This phase took approximately 5 minutes to complete.

*Pre-Exposure phase.* The pre-exposure phase was conducted to obtain a baseline measure of performance. During this phase participants completed 10 trials of the peg transfer task while directly viewing the pegboard (i.e., not through the camera and monitor). This phase took approximately 10 minutes.

*Exposure phase.* At the beginning of this phase the experimenter placed the opaque top on the box and turned on the light, monitor, and video camera. Participants completed 30 trials of the peg transfer task while indirectly viewing the pegboard through the monitor with a clockwise visual rotation of 90º. The opaque top prevented direct vision of the pegboard.

During this phase experimental group participants were asked to complete the secondary digit-span (STM) task. The experimenter verbally presented to those participants a random string of digits, one less than their maximum digit span, at the beginning of each trial. Participants were instructed to mentally rehearse the numbers while performing the peg transfer task. That task presumably engages the phonological loop component of Baddeley and Hitch's (1974) working memory model. Participants were instructed to divide their attention as equally as possible between both tasks, giving precedence to 100% accurate performance of the STM task at the expense of the peg transfer task. At the end of each trial participants were prompted to recite the digits to the experimenter. Accurate performance constituted all digits in the correct order with no intrusions. Overall STM task performance was 93% accurate. Control group participants performed the peg transfer task as described but did not perform the STM task. This phase of the experiment lasted approximately 30 to 60 minutes. Time to complete the peg transfer task, number of drops (errors), and STM task performance were recorded.

*Post-Exposure phase.* The post-exposure phase was identical to the pre-exposure phase. The opaque top was removed and participants completed 10 trials of the peg transfer task while directly viewing the pegboard. Experimental group participants did not perform the STM task in this phase. This phase took approximately five minutes. When the experiment was completed, participants were debriefed and the effects of the visual rotation were explained.

*Methodological Issues*

There are some important methodological issues that need to be addressed when assessing human motor skill performance under dual-task conditions (Abernethy, 1988). One issue involves the selection of the primary and secondary tasks. The primary task is usually determined by the nature of the motor skill being examined. The primary laboratory task should be the same movement task as required by the normal, real world activity. The peg transfer task used in this experiment has previously been shown to strongly correlate with *in vivo* performance (Derossis et al., 1998; Fried et al., 1999). Decisions also have to be made regarding secondary task selection—whether the secondary tasks should be continuous or discrete and whether the secondary task should intentionally create or avoid structural interference. In this experiment the secondary STM task was continuous and was not intended to create structural interference. Using a continuous secondary task was advantageous because cognitive demands are more likely to remain at a constant level throughout the course of a trial whereas participants may opt to use greater degrees of attentional switching between tasks when a discrete secondary task is used.

# Chapter III

# Results

Performance was measured by time to complete the peg task and by number of errors (drops). Separate analyses were conducted on movement time and error data. Bonferroni and Huynh-Feldt corrections were applied as necessary to correct for inflated Type I error rates when making multiple comparisons and for violations of the analysis of variance (ANOVA) assumption of homogeneity of variance, respectively.

*Initial Effects of Visual Rotation and Digit Task*

To determine whether performance was disrupted when participants switched from directly to indirectly viewing the pegboard a *t*-test was used to compare movement time performance on the last pre-exposure trial to the first exposure trial. When participants switched from directly viewing the pegboard (mean time = 21.61 s) to indirectly viewing the pegboard (mean time = 129.51 s) performance (averaged across groups) significantly declined, i.e., movement time increased, $t(33) = -9.97$, $p < .01$. To further determine whether performance was disrupted when participants switched from directly to indirectly viewing the pegboard a *t*-test was used to compare the number of errors committed on the last pre-exposure trial to the first exposure trial. When participants switched from directly viewing the pegboard (mean number of drops = 0.09) to indirectly viewing the pegboard (mean number of drops = 2.15) performance (averaged across groups) significantly declined, i.e., the number of errors increased, $t(33) = -5.49$, $p < .01$.

A *t*-test was used to determine whether experimental group performance (mean time = 144.06 s) was significantly different on the first trial of the exposure phase, relative to control group performance (mean time = 114.96 s). There was no significant difference in performance between groups on the first exposure phase trial, $t(16) = -1.26$, $p > .05$. However, even though the difference was not statistically significant the difference between groups on this trial was quite large (29.15 s).

A *t*-test was also used to determine whether experimental group errors (mean number of drops = 2.35) was significantly different on the first trial of the exposure phase, relative to control group errors (mean number of drops = 1.94). There was no significant difference in errors between groups on the first exposure phase trial, $t(16) = -6.47$, $p > .05$.

*Performance of Groups over Exposure Trials.*

An ANOVA with groups (control vs. experimental) as a between factor and trials (1 – 30) as a within factor was conducted on movement time data to determine whether a main effect of group, a main effect of trial, and a group × trial interaction were present during the exposure phase. A main effect of trials and a significant group × trial interaction were found. As expected, performance (averaged across groups) significantly improved over trials, $F(29,928) = 31.99$, $p < .01$. Performance improved from a mean time of 129.51 s on trial 1 to a mean time of 39.63 s on trial 30. The interaction, $F(29,928) = 2.03$, $p < .05$, indicated that the experimental group took longer to complete the task initially but both groups performed equivalently in later trials (see Figure 2). A *t*-test was used to compare experimental and control group performance on the last trial of the exposure phase. Experimental (mean time = 40.60 s) and control (mean time = 38.66 s) groups did not perform differently on the last trial of the exposure phase ($p >$ .05).

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Insert Figure 2 here

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An ANOVA with groups (control vs. experimental) as a between factor and trials (1 – 30) as a within factor was also conducted on the error data to determine whether a main effect of group, a main effect of trial, and a group × trial interaction were present during the exposure phase. A main effect of trials was found. As expected, performance of both groups significantly improved (errors declined) over trials, $F(29,928) = 4.12$, $p < .01$. Performance improved from a mean of 2.15 drops on trial 1 to a mean of 0.76 drops on trial 30 (see Figure 3). The effect of group and group × trials interaction were not significant ($p > .05$).

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Insert Figure 3 here

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*Pre- and Post-Exposure Performance*

An ANOVA with phase (pre-exposure vs. post-exposure) and trials (1 – 10) as within factors and groups (control vs. experimental) as a between factor was conducted on movement time data to determine whether group performance differed in pre- and post-exposure phases and to determine whether an aftereffect was present in the post-exposure phase (i.e., a temporary decline in performance upon return to normal visual conditions). Performance did not differ between groups ($p > .05$) for either phase ($p > .05$ for the interaction). An aftereffect was not present in the exposure phase—instead, performance was significantly *better* in the post-exposure phase (mean time = 19.97 s) than in the pre-exposure phase (mean time = 22.92 s), $F(1,32) = 19.12$, $p < .01$. Performance as measured by errors did not differ between groups ($p > .05$) or phase ($p > .05$). The interaction was also not significant ($p > .05$).

# Chapter IV

## Discussion

The general purpose of this study was to explore the phenomenon of divided attention during performance in an endoscopic surgery simulator. Specifically, I wanted to determine the effects of a concurrent STM task on adaptation to visual-motor distortions induced by the endoscopic surgery simulator. Competing hypotheses regarding exposure phase performance—hypotheses derived from single resource theory (Kahneman, 1973) and multiple resource theory (Wickens, 1984)—were evaluated in this study. Single resource theory predicted that experimental group performance would be significantly worse than control group performance during the exposure phase, even though performance would improve across trials for both groups. Single resource theory could also have accounted for experimental group performance becoming comparable to control group performance over the course of the exposure phase, if the demand imposed by the peg transfer task decreased with practice (Schneider & Shiffrin, 1977a) or if participants learned to effectively time-share the use of attentional resources (Kahneman, 1973; Welford, 1980; Wickens, 1980). Multiple resource theory predicted that experimental and control group performance would not differ, since the tasks did not compete for the same resource pools.

A number of other predictions were evaluated. Performance was expected to be significantly disrupted for all participants upon switching from the pre-exposure phase to the exposure phase. Performance was expected to improve over exposure phase trials. Also, an aftereffect was expected in the post-exposure phase (which marked a return to normal visual conditions). Such a pattern of results across the three phases of the experiment is characteristic of situations involving imposed perceptual-motor discrepancies (e.g., Howard, 1982; Welch, 1978). Finally, both groups were expected to perform equivalently in the pre- and post-exposure phases, since during those phases the experimental group did not perform the STM task.

*Effects of Visual Rotation*

Performance was significantly disrupted under altered perceptual-motor conditions during early exposure-phase performance but improved over trials for both groups. Those results confirmed the findings of Derossis et al. (1998), Holden et al. (1999), Rosser et al. (1997), and Scott et al. (2001) and were generally consistent with findings from sensory rearrangement studies (e.g., Bingham & Romack, 1999; Harris, 1965; Kohler, 1964; Redding & Wallace, 1996; Welch, 1978).

No aftereffect was observed in the post-exposure phase. An aftereffect was expected on the basis of similar results found in prism adaptation studies (see Harris 1965; Howard, 1982; Redding & Wallace 1996; Welch, 1978). Participants did not perform worse on the first few trials of the post-exposure phase than during the pre-exposure phase. Instead, performance was significantly better for both groups in the post-exposure phase than in the pre-exposure phase. As expected, the two groups performed equivalently to each other in the pre- and post-exposure phases.

*Concurrent Perceptual-Motor and STM Task Performance*

*Single resource theory*. The peg-transfer performance data obtained during the exposure phase were generally consistent with Kahneman’s (1973) single resource theory. A significant group × trial interaction was found during the exposure phase. Although experimental group performance was not significantly worse than control group performance on the first exposure phase trial according to the *t*-test, the interaction seen on the movement time data (see Figure 2) indicated an initial dual-task performance decrement for the experimental group. That decrement did not persist during the exposure phase—experimental group performance quickly converged on control group performance.

Single resource theory (Kahneman, 1974) would account for those results as follows. The altered perceptual-motor conditions presumably were relatively cognitively demanding, requiring a large amount of cognitive resources for successful performance. The addition of the STM task placed demands that taxed experimental group participants' attentional resource capacity, causing a greater initial disruption in performance for them. With practice, the perceptual-motor task came to require fewer resources or participants may have learned to effectively time-share the use of their cognitive resources. Therefore, control and experimental group participants were able to perform at an equivalent rate in later exposure-phase trials.

Schneider and Shiffrin's (1977a) theory of automaticity states that well-practiced tasks are not only performed more quickly and accurately but also no longer impose capacity demands on the performer. Over the course of practice task performance shifts from a resource demanding stage (controlled processing) to a stage that requires few or no resources (automatic processing). Thus, tasks can eventually be performed simultaneously without interference from, or producing interference with, other concurrent tasks. Over trials performance of the peg transfer task may have shifted from controlled processing to automatic processing, thus allowing for successful performance of both tasks. However, extensive practice is required before a task comes to be performed automatically. For instance, Schneider and Shiffrin (1977b) found that it took 2100 trials for a target search task to become automatic. Spelke et al. (1976) trained two people over months to transcribe oral dictation while reading stories for detailed comprehension. Performance became automatic after training one hour a day, five days a week, for six months (see also Levy & Pashler, 2001; Ruthruff, Johnston, & Van Selst, 2001; Schumacher, Seymour, Glass, Kieras, & Meyer, 2001). In the present experiment, which involved substantially less practice than either of those studies, performance of the peg transfer task likely did not reach a truly automatic stage.

Bahrick, Noble, and Fitts (1954) found, however, that motor tasks possessing some degree of repetitiveness and that are continually practiced quickly become less susceptible to interference from another task. Participants in their experiment either received 3 or 15 practice trials on a random or repetitive visual-motor task alone prior to performing 3 trials of the visual-motor task and a mental arithmetic task concurrently. Participants who received greater amounts of practice (15 trials) and who performed the repetitive visual-motor task experienced less dual-task interference than participants in other conditions. The amount of practice those participants received was less than but comparable to the amount of practice participants received in the present experiment. The peg transfer task in my experiment was repetitive and continually practiced. Based on the results of Bahrick et al., it is conceivable that in my experiment practice of the peg transfer task rendered it less susceptible over the course of the exposure phase to interference from the STM task, even though the practice period was relatively brief compared to the studies of Schneider and Shiffrin (1977b) and Spelke et al. (1976).

*Multiple resource theory.* The data obtained during the exposure phase did not confirm the prediction derived from multiple resource theory (Wickens, 1984). That theory predicted there should have been no dual-task performance decrement. However, the data indicated an initial dual-task decrement for the experimental group. Given that the tasks differed in terms of processing stage (encoding/central processing for the STM task versus responding for the peg transfer task), processing codes (verbal for the STM task versus spatial for the peg transfer task), and perceptual modality (auditory for the STM task, since the digits are presented auditorily, versus visual and haptic for the peg transfer task) there should not have been dual-task interference, since the tasks did not compete for the same resource pools. Overall, the results of this study are more consistent with single (Kahneman, 1973) than multiple resource theory.

*Future Directions*

*Effects of performer's skill level.* Future research can be conducted to determine whether amount of experience has an effect on adaptive performance in an endoscopic surgery simulator under dual-task conditions. Grantcharov, Bardram, Funch-Jensen, and Rosenberg (2003) found differences in simulator performance between surgeons with different amounts of laparoscopic experience. Not surprisingly, experienced surgeons demonstrated the best simulator performance, followed by surgeons with intermediate experience, and then by beginning surgeons. Based on those results and the results from this experiment, one might expect that dual-tasks effects may differ for people with different skill levels. This experiment demonstrated that with practice the dual-task effect was reduced or eliminated. Thus, highly experienced surgeons may experience little or no dual-task interference compared to surgeons with less experience.

Perceptual-motor skills develop in a manner consistent with Schneider and Shiffrin's (1977a) theory of automaticity. Fitts and Posner (1964) identified three stages of motor-skill development (cf. Berstein, 1996). Motor skills develop from a *cognitive stage* to an *associative stage* and then to an *autonomous stage*. The first stage, the cognitive stage, is characterized by an attempt to understand the nature of the movement task. The level of cognitive involvement demanded by this stage is high and learners typically make numerous, gross errors. The second stage, the associative stage, is characterized by a transition from a slow and deliberate use of knowledge to a more direct representation of how to perform the skill. During this stage learners begin to modify and/or adapt movement patterns as needed and skills become more fluid and error free. The third stage, the autonomous stage, is characterized by skills becoming more automatic. During this stage skills require less cognitive involvement and learners are able to carry out tasks with minimal interference from other simultaneous activities. Based on those theoretical stages of motor learning different types of interference can be expected depending on the surgeon’s stage of learning. The Fitts and Posner theory would predict that concurrent cognitive activity would have a greater effect during the cognitive stage of the skill learning process.

*Effects of type of cognitive activity*. Currently there is little research on what cognitive systems are involved in adaptation to perceptual-motor distortions. Future research can be conducted to determine the role of specific working memory systems in adaptation to perceptual-motor distortions. Eversheim and Bock (2001), in a preliminary study, used dual-task conditions that engaged different computational resources during a perceptual-motor task and found evidence for different processing stages involved in adaptation to perceptual-motor distortions. Dual-task conditions that engage different components of Baddeley and Hitch’s (1974) model of working memory can be used to further explore that issue. That model of working memory consists of a controlling attentional system, referred to as the central executive, which supervises and coordinates two slave systems, the phonological loop and the visuo-spatial sketch pad (Baddeley, 1997). The STM task used in this study engaged the phonological loop. In future research the roles of the central executive and visuo-spatial sketch pad can be assessed by employing different cognitive tasks.

Another strategy may be to mirror the methodologies used in classical studies of memory and divided attention. For instance, simulator performance could be compared when participants are faced with a concurrent memory task that involves either encoding or retrieval processes. When attention is divided between memory (encoding or retrieval) and a secondary task memory performance is substantially reduced when attention is divided during encoding (Baddeley, Lewis, Eldridge, & Thomson 1984; Baddeley, 1966) but only marginally reduced when attention is divided at retrieval (Baddeley et al., 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Guez, & Dori, 1998). Furthermore, when attention is divided between memory and a secondary task, secondary task performance declines marginally during encoding and dramatically during retrieval (Anderson, Craik, & Naveh-Benjamin, 1998; Craik et al., 1996; see Naveh-Benjamin, 2002 for a review). When the difficulty of the secondary task is increased during encoding memory performance is inversely related to secondary task difficulty (Anderson & Craik, 1974) but the same effect is not observed during retrieval. It was further demonstrated (Craik et al., 1996; Anderson et al., 1998) that instructions to control attention—to emphasize the memory task, the secondary task, or both tasks equally—also produced asymmetric results. When secondary task performance was emphasized there were greater declines in memory performance for divided attention at encoding than divided attention at retrieval, whereas emphasis on the memory task resulted in similar declines in memory performance for divided attention at both encoding and retrieval.

Those results suggest that encoding processes are consciously controlled and attentionally demanding whereas retrieval processes are automatic and require few processing resources. An experiment could be conducted to evaluate the effects of divided attention at encoding and retrieval during concurrent performance of a memory task and the peg transfer task. That experiment could have practical implications regarding surgical performance and theoretical implications regarding memory and differences between encoding and retrieval processes.

*Effects of varying the hand-eye mapping*. Future research can also be conducted to examine effects of varying the hand-eye mapping on adaptive performance in an endoscopic surgery simulator. The hand-eye mapping is not always consistent during a given surgery because during the course of a procedure the camera may be moved and/or rotated or the surgeon may move. Holden et al. (1999) found that simulator performance was disrupted when either the camera's position or the surgeon's position changed. However, performance did not decline when the camera and surgeon positions were changed together. Future research can examine whether people are capable of maintaining multiple adaptive perceptual-motor states and whether or not performance becomes immune to changes in the mapping once a certain amount of experience has been attained (Cunningham & Welch, 1994; Lackner, 1993; Stanney et al., 1998).

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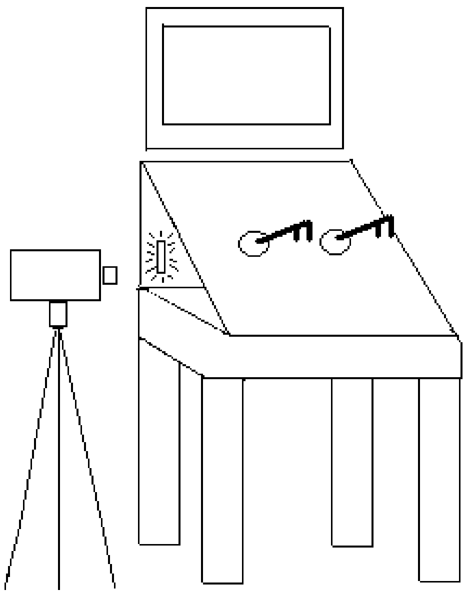
a



b

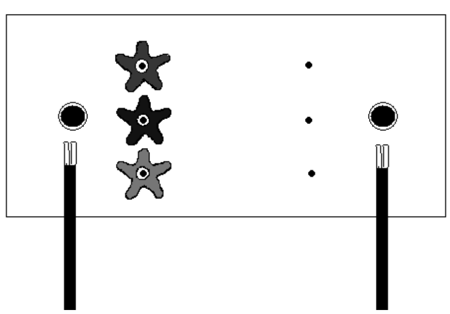


*Figure 1a*. Low-fidelty endoscopic surgery simulator.
*Figure 1b.* Pegboard located in bottom-center of simulator.

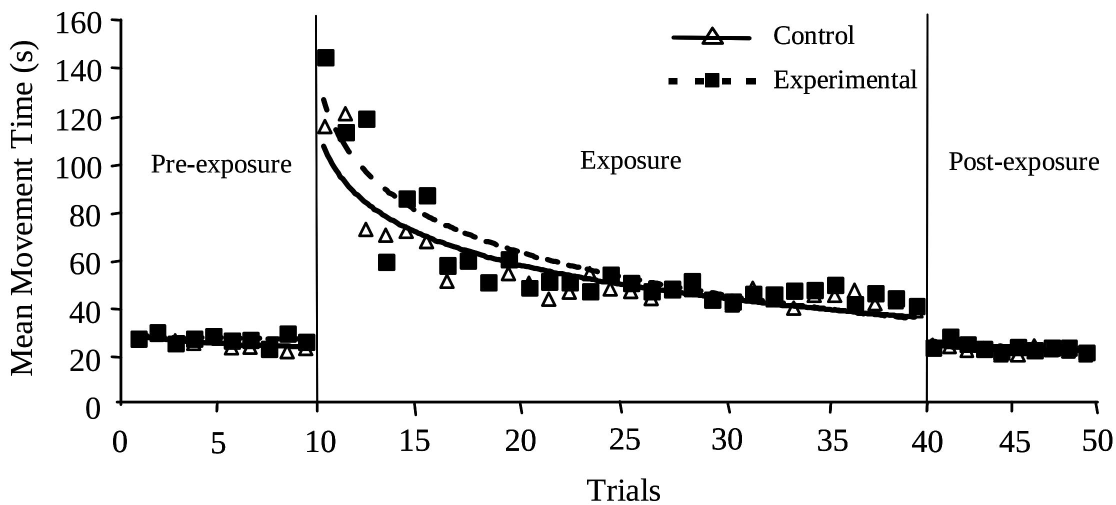



*Figure 2.* Mean movement time as a function of experiment phase, trials, and group. The trend lines represent the logarithmic lines of best fit. For the exposure phase, control group movement time = -26.78 (Trials) + 125.78, $R^2$ = .82, and experimental group movement time = -20.90 (Trials) + 106.43, $R^2$ = .82.

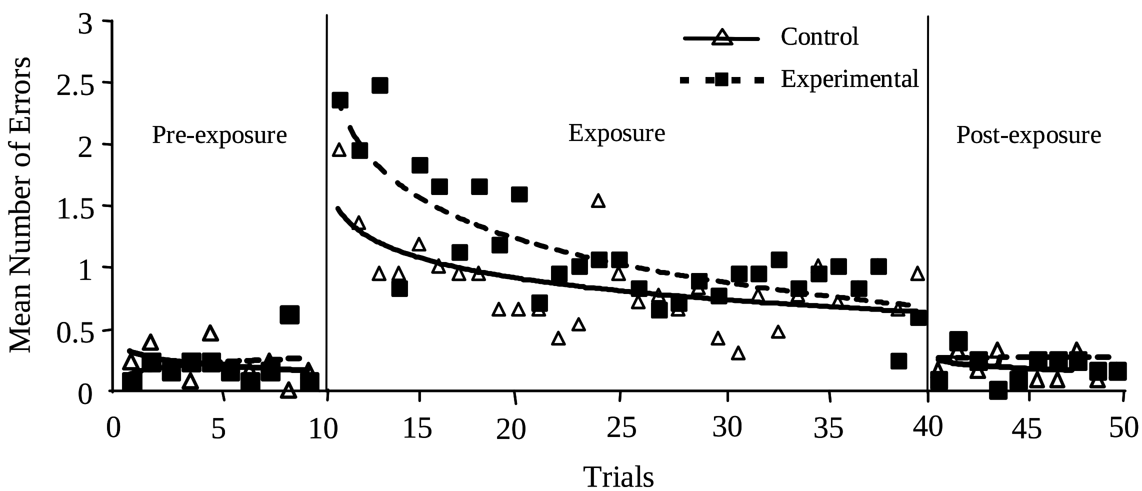



*Figure 3.* Mean number of errors as a function of experiment phase, trials, and group. The trend lines represent the logarithmic lines of best fit. For the exposure phase, control group errors = -0.2456 (Trials) + 1.4563, $R^2 = .67$, and experimental group errors = -0.4944 (Trials) + 2.348, $R^2 = .82$.