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THE EFFECT OF DEPTH JUDGMENTS ON MENTAL WORKLOAD IN LAPAROSCOPY MEASURED BY A VISUAL-SPATIAL SECONDARY TASK

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ABSTRACT

THE EFFECT OF DEPTH JUDGMENTS ON MENTAL WORKLOAD IN LAPAROSCOPY MEASURED BY A VISUAL-SPATIAL SECONDARY TASK

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Old Dominion University, 2011
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Performing laparoscopic surgery is more attentionally demanding than traditional surgery. One challenge results from the surgeon operating in 3D space while referencing a 2D display that has limited and distorted depth cues. The goal of the present study was to compare two versions of a secondary task for measuring the mental workload associated with laparoscopic depth and nondepth movements. Twenty six undergraduate students at Old Dominion University performed a laparoscopic threading task in three separate orientations: X plane, Y plane, and Z plane. The threading task was performed in single-task conditions and dual-task conditions where it was paired with a visual-spatial secondary task to measure workload. It was expected that workload would be highest when threading in the Z plane orientation, reflecting challenges for making depth judgments based on a 2D display. The primary task results showed that participants indeed had difficulty performing the threading task when depth judgments were required. The secondary task was sensitive to overall laparoscopic workload, but was not found to be sensitive to the specific differences in workload for threading orientation. There were also no performance differences between versions of the secondary task. The findings suggest that laparoscopic surgery is attentionally demanding and surgical training should emphasize practicing movements in the depth plane.

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CHAPTER 1

INTRODUCTION

Laparoscopy, sometimes referred to as minimally invasive surgery, is a type of surgery where surgeons perform operative procedures from outside the body cavity through small openings. Long handled surgical instruments with similar functions to traditional instruments are inserted through the openings. The image of the operating site is captured by a small video camera that transmits the video image from the operating site to a large display monitor where it is viewed by the surgeon.

The patient-related benefits of minimally invasive surgery include less pain, faster recovery time, fewer infections, and smaller surgical scars. Laparoscopy has become an increasingly common technique since laparoscopic cholecystectomy (gallbladder removal) was first performed in 1987 (Way, Bhoyrul, & Mori, 1995). Afterward, an explosion in popularity occurred due to advances in modern imaging equipment. As of 1995, hospitals reported that as many as 50 percent of abdominal operations were performed laparoscopically (Way, Bhoyrul, & Mori, 1995).

From the surgeon's perspective, however, laparoscopic procedures are a departure from traditional surgical methods in ways that make laparoscopy more difficult to perform. Unlike traditional open surgery, the operating site in laparoscopy is viewed indirectly via a remote display and the operation is performed with long handled instruments. Although expert surgeons with extensive experience can perform a laparoscopic procedure comfortably while also performing other tasks concurrently (e.g., communicate with assistants, anticipate complications), novice surgeons may be unable to multitask. If a surgeon is unable to divide attention among several tasks, the patient's safety could be at risk.

The present study addressed the concept of mental workload and how it applies to laparoscopic surgery. Important factors that contribute to laparoscopic workload, specifically, the effect of making depth judgments, are discussed. The purpose of the present study was to develop a method to measure mental workload for a simulated laparoscopic task. By successfully measuring mental workload, a person's ability to multitask during a laparoscopic task can be predicted.

CHAPTER 2

MENTAL WORKLOAD

Historical Background

Generally, workload can be thought of as the amount of effort required for a person to perform a task. The amount of effort required depends on the difficulty of the task itself as well as factors like the skills, abilities, and stress level of the operator. It is important to understand workload in order to design tasks and equipment with human capabilities in mind. Workload can be physical (e.g., lifting heavy boxes) or cognitive (e.g., air traffic controllers directing flight traffic). The cognitive aspect of workload is called mental workload.

Mental workload is based on the relationship between attentional capacity of an operator and the attentional demand of a task. An important premise of mental workload is that human attention has a limited capacity. This is based on a model of information processing where processing occurs in a series of stages, and although many perceptual and cognitive processes are carried out rapidly and preattentively, some processes are selected and attended to by the operator. Attention is represented in this model as having a limited number of resources (Kahneman, 1973; Moray, 1967; Norman & Bobrow, 1975). An operator allocates attentional resources according to the needs of the task, with more resources allocated to a difficult task than a simple task. As the demands of a task increase and more resources are used, fewer resources are available for other tasks.

Historically, researchers considered attention to be one undifferentiated pool of resources. Kahneman's (1973) original single resource theory suggested that processing is limited by the total amount of attentional resources available. According to this theory, if a task demands more resources than an operator possesses, it simply cannot be performed. In subsequent modifications of this theory (Navon & Gopher, 1979; Wickens, 1980, 1984) researchers argued that attention was comprised of multiple resources, that is, specific pools of resources separated by processing structure (Wickens, 1980, 1984). According to multiple resource theory, processing is not only limited by total amount of resources available, but it is further limited by demand for specific types of resources.

Wickens (2002) suggested that the pools of resources are distinguished by three main dimensions: processing stages, processing codes, and processing modalities. The first dimension, processing stages, is dichotomized into perceptual/cognitive and response resources. This dimension dictates that "perceptual/cognitive" resources, such as working memory, are distinctly separate from "response" resources, which are used to make a response or perform an action. The second dimension describes processing codes and distinguishes between verbal and spatial resources. Verbal resources are used for tasks involving language, and spatial resources are used for making judgments about distance or position. The third dimension refers to the processing modalities, and distinguishes between auditory and visual resources. This auditory/visual dichotomy is attributable to separate sensory systems that are physiologically unique and allows parallel processing of visual and auditory information.

Further, resources for the visual processing modality are separated into two visual channels: focal and ambient/peripheral vision (Wickens, 2002). Focal vision is responsible for high acuity information, and ambient vision is responsible for detecting movement patterns. Focal vision and ambient vision are processed along physiologically separate pathways from the retina to separate structures in the cortical visual areas of the brain; focal vision follows the parvocellular pathway and peripheral vision follows the magnocellular pathway through the brain (Goldstein, 2009). These distinct pathways enable a person to focus on specific information foveally while monitoring locations and movements in the surrounding environment from peripheral areas of the retina. These separate visual channels are processed in parallel and allow focal and ambient vision to operate simultaneously at all times.

Based on the four described dichotomies, multiple resource theory is useful for predicting how well an operator can multitask, or time share between two tasks (Wickens, 2002). Specifically, because each dimension is dichotomized into distinctly separate pools of attentional resources, the extent to which two tasks differ along these dimensions dictates the ability to time share between the tasks. Consequently, two tasks that are similar and pull from the same pool of resources would interfere with one another and result in an increase in mental workload.

The degree to which two tasks are similar along a dimension is also referred to as resource overlap. Accordingly, knowing the degree to which resources "overlap" is a predictor of dual task compatibility, or the degree to which two tasks can be performed simultaneously. Two other predictors of dual task compatibility are the total demand for resources required by both tasks and the operator's resource allocation policy (Wickens, 2008). It is useful to consider attentional resources as supply and the task as demand. The total demand for resources affects dual task compatibility because the combined demand for both tasks may exceed the available supply and reduce multitasking capabilities. A resource allocation policy, which is a strategy for sharing resources between tasks, also affects dual task compatibility. Commonly, the operator prioritizes between concurrent tasks and focuses more attention on the "important" task at the expense of the other (O'Donnell & Eggemeier, 1986).

Ideally, the resources demanded by a single task should not exceed the supply of resources available. Any unused resources can then be allocated to additional tasks. However, if the total demand for resources exceeds those available, or if both tasks compete for the same resources, the result is task "overload" and deterioration in performance (Wickens & Hollands, 2000). In the work environment, operators are often required to divide attention among two or more tasks, which can increase workload to the point of overload.

Measuring Mental Workload

The most direct way to measure mental workload is to measure performance on the task of interest itself, called the primary task. Variations in primary task performance intuitively reflect variations in workload. However, there are instances where there may be underlying differences in workload, but there is little variation in performance. If a task is very easy or very difficult, primary task performance may not reflect any differences in workload because performance will always be very good or very poor.

If primary task performance is not an appropriate measure of mental workload, then a secondary task may provide a better measure. A secondary task is performed concurrently with the primary task, and the operator is instructed to perform the primary task to the best of his or her ability and to allocate any remaining attention to the secondary task. Secondary task performance therefore reflects the amount of unused attentional resources (Ogden, Levine, & Eisner, 1979). It is inferred that variations in secondary task performance reflect differences in primary task demand. As a primary task increases in difficulty, fewer residual resources are available to allocate to the secondary task and secondary task performance declines. Thus, a secondary task provides a way to measure and compare workload among primary tasks.

In order for a secondary task to be considered an accurate measure of mental workload, the secondary task must be sensitive to the primary task. This means that the secondary task must reflect changes in the same resource demands required by the primary task (O'Donnell & Eggemeier, 1986). Tasks that are similar along any of the four previously mentioned dichotomies (i.e., processing stages, processing codes, processing modalities, and visual channels) compete for the same resources. For example, an auditory secondary task would be sensitive to an auditory primary task, but not to a visual primary task. A second important criterion for a secondary task is that it should not be obtrusive (Wierwille, Rahimi, & Casali, 1985), meaning the secondary task should not interfere with primary task performance. An obtrusive secondary task would not provide an accurate measure of primary task workload because it would measure the amount of resources that are pulled away from the primary task rather than the amount that is unused by the primary task.

There are also other ways to measure mental workload besides using a secondary task. Physiological indicators such as heart rate variability and pupil diameter can provide a continuous record of workload as tasks are performed (Wickens & Hollands, 2000). Subjective measures, such as rating scales and questionnaires can also be given to the operator and used to generate a mental workload score. Subjective rating scales are common because they are easy to administer and have high face validity (Wickens & Hollands, 2000).

CHAPTER 3

WORKLOAD IN LAPAROSCOPY

There are several aspects of laparoscopic surgery that make it more attentionally demanding (i.e., higher in workload) than traditional open surgery. Three characteristics that contribute to this demand are reduced tactile feedback, location of the display, and impoverished depth cues from the 2D display.

Reduced Tactile Feedback

The first factor that impacts workload in laparoscopy is the reduction in tactile feedback. In open surgery, the surgeon can use his or her hand (albeit gloved) to directly touch and feel tissue which provides a good impression of its temperature, consistency, and texture (Westebring-Van Der Putten, Goossens, Jakimowicz, & Dankelman, 2008). The surgeon can also accurately judge how much pressure he or she is exerting on tissue with traditional surgical instruments. In laparoscopic surgery, however, the length of laparoscopic instruments combined with the greater number of mechanical parts between the surgeon's hand and the patient's tissue leads to a loss in tactile sensation (Tendick, Bhoyrul, & Way, 1997). The loss of this type of feedback may cause an inexperienced surgeon to exert greater forces than desired, possibly damaging the tissue (Way, Bhoyrul, & Mori, 1995). Consequently, workload may increase because the surgeon must estimate actual forces exerted in the context of reduced tactile feedback. With practice, surgeons learn to compensate for the limited tactile feedback, but novice surgeons may not have acquired this ability (Bholat et al., 1999).

Display Location

A second factor that may increase workload concerns the remote location of the laparoscopic display. The physical separation between the display and the operating space makes the task more difficult than a task where the space is directly visible, especially for spatial judgments. This issue was investigated by Wu, Klatzky, and Stetten (2010). Specifically, they compared in-situ displays (viewed directly above the operative site) and ex-situ displays (viewed via a remote screen, as in laparoscopy) for a spatial task. Participants were asked to judge the pitch, yaw, or both of a virtual rod. The researchers found that even in a simple task, ex-situ viewing significantly impaired accuracy of spatial judgments. Judgments were even less accurate on the ex-situ display when participants were judging multiple spatial dimensions (pitch and yaw) at once. In laparoscopy, judging distances in multiple dimensions is crucial. The findings by Wu, Klatzky, and Stetten suggest that using a remote laparoscopic display may impair spatial judgments at the operative site.

Limited Depth Cues

The third factor that contributes to laparoscopic workload is more complex than the first two. Mental workload is increased because a two dimensional (2D) display is used for a three dimensional (3D) spatial task. Judgments of relative and absolute distances are almost always poorer when a 3D volume of space is presented two dimensionally (Gregory, 1977). Depth is difficult to estimate in laparoscopy for two reasons.

First, many natural depth cues are absent in any 2D display because the screen is flat. Depth can still be estimated in a flat image, but perhaps judgments are less accurate or the observer experiences more difficulty making judgments. The observer must rely on monocular depth cues. Monocular depth cues do not depend on binocular vision.

Monocular or pictorial cues provide information about depth in 2D images. Some pictorial cues that may provide depth information are texture gradients, relative height, relative size, and perspective convergence (Goldstein, 2010). Texture gradient is a cue based on textures appearing more densely packed as distance from the observer increases. Relative height refers to the height of an object in the field of view increasing as depth increases, and relative size refers to objects that are physically the same size appearing smaller when farther from view. Perspective convergence refers to parallel lines appearing to converge as depth increases. Complementary and redundant depth information provided by multiple pictorial cues contributes to the perception of relative and absolute distance of objects in the image.

Besides pictorial cues, two other types of depth cues are oculomotor and binocular cues. These cues are totally absent from a 2D display. Oculomotor cues are generated by the muscle movements responsible for changing eye position and lens shape. Convergence and divergence are oculomotor cues caused by the movement of the eyes toward each other when looking at nearby objects and away from each other when viewing farther objects. Accommodation is a second oculomotor cue based on the change in lens shape. When looking at close objects, the lens becomes thicker to shorten the focal length (Goldstein, 2010). The eyes do not converge, diverge, or accommodate when looking at different sources of information on a 2D display because the display itself is flat and at a uniform distance from the eyes.

Binocular cues are the third type of depth cue and result from viewing the environment with two eyes. In binocular vision, each eye sees a slightly different image which produces retinal disparity. The amount of disparity provides information about depth. Binocular vision is also not useful when viewing a 2D display because all information on the display is at a fixed distance and does not create any retinal disparity.

Although stereoscopic displays exist (which enable binocular vision by presenting slightly different images to each eye), they are still not yet widely used. Further, there is some evidence suggesting stereoscopic displays may not provide measurable benefits in laparoscopy (Crosthwaite, Chung, Dunkley, Shimi, & Cuschieri, 1995; Tendick, Bhoyrul, & Way, 1997). Also, 3D video imaging systems often cause users to experience headaches, dizziness, or other side effects, and their superiority to normal 2D systems has not been substantiated (Pietrzak, Arya, Joseph, & Patel, 2006). For these reasons, only the traditional 2D display is considered in this study.

Two-dimensional displays limit the use of many natural depth cues, making depth judgments difficult. However depth is also difficult to estimate in laparoscopy because a wide-angle lens is used in the laparoscope to expand the viewing area within the operating space. The wide-angle lens distorts distances and shapes, thereby increasing the difficulty of making accurate depth, size, and distance judgments.

An inherent characteristic of wide-angle lenses is that they show extreme, exaggerated perspective (Wentink, Fischer, Dankelman, Stassen, & Wieringa, 2002). Objects closer to the lens, compared to those farther away, appear larger than usual given their actual relative distance. A wide-angle lens distorts the appearance of information which alters the relationship between perceptual and motor events (Hegarty, Keehner, Cohen, Montello, & Lippa, 2007).

The difficulty in making accurate judgments from a distorted 2D image is further compounded when the operator must interact with the 3D environment. Fitts' law (Fitts, 1954) is a model for predicting movement time toward a target in a pointing task within a single dimension. According to Fitts' law, the movement time to a target is a function of the target width and the distance to the target, whereby time to point to a target increases as size of the target decreases and distance to the target increases. An extension of Fitts' law to 3D pointing tasks also incorporates direction of movement, where increases in the angle from directly in front of a person results in increases in movement time to a target (Cha & Myung, 2010).

Estimating depth from a 2D display has been shown to affect workload and performance in applied settings. Pilots rated subjective mental workload higher in 3D views on a 2D cockpit display than 2D planar views on the same display (Alexander, Wickens, & Merwin, 2005). In a location judgment task on a 2D display, elevation of a target is generally overestimated, and more so for a narrow field of view (McGreevy & Ellis, 1986). Depth judgments from a 2D display may require the use of visualization processes to mentally manipulate or correct the given image.

Visualization and Workload

The laparoscopic surgeon must effectively translate a 2D representation of the operating space into a mental representation of the 3D environment with voluminous objects. The construction of a mental representation requires visualization processes. Visualization is defined as the mental manipulation of objects in a 3D space (McGee, 1979). Rescaling and mental rotation are two types of visualization processes that are used to better understand the 2D image in relation to 3D space.

Rescaling is a visualization process that may be used to mentally resize a representation of space so that it reflects the actual environment. Rescaling is required in laparoscopy to "shrink" the large display of the operative site into smaller actual movements. The scale of the image displayed onscreen differs in size from the operative area. The image is magnified about 15 to 20 times so that it can be seen clearly (Milsom, Böhm, & Najajima, 1996). Referencing an enlarged display requires the surgeon to rescale onscreen sizes and distances into a much smaller representation to make appropriate instrument movements. During a laparoscopic procedure, rescaling must also be implemented whenever the camera is zoomed in and out. When the focal length of the zoom lens changes, the displayed size relative to actual size also changes and must again be rescaled.

A second visualization process used in laparoscopy is the process of mental rotation. Surgeons view the procedure from via the laparoscope, which can rotate within the operating site causing the image on the display to rotate as well. Thus, surgeons may need to mentally rotate the image on the display to facilitate spatial judgments. Researchers have provided evidence for mental rotation by showing participants a pair of perspective drawings and asking them to determine whether the two images are the same or different shapes. The amount of time it takes to make a decision is linearly related to the difference in their orientations (Shepard & Metzler, 1971). This finding suggests that the representation of one of the shapes is mentally rotated to match the second shape.

Familiar 3D objects viewed from an unfamiliar angle may also be mentally rotated so that they are easier to recognize. A body of evidence (Tarr & Pinker, 1989, 1990) suggests that the recognition time for objects depends on the orientation in which they are presented. Certain views of familiar objects, generally the views seen most often (i.e., canonical views), are consistently easier to recognize. If an object is presented in a significantly different orientation, the viewer may impose a mental transformation on the object (i.e., mental rotation) in order to match it to the specific representation stored in visual memory.

The finding that canonical views are more quickly identified than noncanonical views suggests that our ability to recognize or identify 3D objects depends on our experience viewing objects from specific angles. Recognizing objects that greatly deviate from canonical views takes more time. After practice, however, observers can learn to "rotate" objects faster, meaning observers can make judgments faster (Leone, Taine, & Droulez, 1993). This finding suggests that the ability to mentally rotate can be improved with training.

Mental rotation is sometimes required in laparoscopy because the camera presents an image that may change during procedures. As the degree of camera rotation increases, time and accuracy of a simple laparoscopic procedure are significantly degraded (Gallagher, Al-Akash, Seymour, & Satava, 2009). Further, because an assistant is often responsible for holding the laparoscope, the image may change if the camera is unintentionally moved or rotated during the procedure, requiring the surgeon to readjust by mentally rotating the objects viewed onscreen. The surgeon may also mentally rotate objects because the directions of movement onscreen are not consistent with actual movement. The fulcrum effect refers to the fact that when the surgeon moves his or her hand in one direction, the working end of the laparoscopic instrument moves in the opposite direction on the monitor (Gallagher, Al-Akash, Seymour, & Satava, 2009). This perceptual-motor relationship is strongly counterintuitive and requires practice to overcome.

Mental rotation may also be necessary if the orientation displayed onscreen deviates from the surgeon's perspective (Hegarty, Keehner, Cohen, Montello, & Lippa, 2007). Misalignment between the display and the operator means the surgeon must mentally rotate the image before he or she can successfully navigate within the operating environment. In a similar task requiring teleoperation, it was shown that as the misalignment between the operator and the display increased, performance on a tracking task decreased (Macedo, Kaber, Endsley, Powanusorn, & Myung, 1998). Misalignment could also affect spatial judgments and negatively impact performance in laparoscopic tasks. Keehner, Wong, and Tendick (2004) asked participants to perform a laparoscopic maze drawing task and found that performance deteriorated as the camera angle deviated from 0 degrees.

The use of visualization processes has been investigated with ultrasound tasks, which in some respects are perceptually similar to laparoscopy. Ultrasound imaging is created by high frequency sound waves via a transducer and converted into a 2D image. The operator references the display while moving the transducer. Ultrasound displays are similar to laparoscopic displays in that the ultrasound image is remote from the location being scanned, is shown from different viewpoints depending on where the transducer is moved, and shown at different scales depending on the zoom. While looking at ultrasounds, the operator may use spatial cognitive processes such as mental rotation, translation, and rescaling to successfully use the display as a reference (Klatzky, Wu, & Stetten, 2008). Although each of these cognitive processes can be performed relatively quickly, they each contribute to workload (DeJong, Colgate, & Peshkin, 2004).

Measuring Workload in Laparoscopy

There are few standardized training and evaluation methods for surgery (Tendick, Downes, Goketekin, Cavusoglu, Feygin, et al., 2000). Methods to evaluate laparoscopic skills include time measures and surgical technique, but there is currently no standard method of measuring mental workload in laparoscopy. Performance assessment is usually done without regard to the attentional resources used.

Physiological mental workload measures are not ideal for laparoscopic measurement because the required equipment may impose physical constraints on the surgeons' ability to move freely. Subjective measures would rely on the surgeon's own judgment of task difficulty rather than measuring performance characteristics directly. This is also not ideal because subjective ratings could be intentionally or unintentionally distorted by the surgeon.

Perhaps the ideal workload measure in the context of laparoscopy is the secondary task. A secondary task that competes for the same resources needed to perform laparoscopy could effectively measure residual resources. This means that a task with a spatial component as well as a visual component would be sensitive to laparoscopy; that is, the tasks will compete for the same attentional resources. Specifically, laparoscopy requires visual-spatial resources to make depth and distance judgments while the surgeon navigates in 3D space referencing a 2D display. The secondary task could be paired with a simulated laparoscopic task to not impose danger to patients during an actual procedure.

Stefanidis, Scerbo, Korndorffer Jr, and Scott (2007) used a visual-spatial secondary task to differentiate performance between surgeons who otherwise were indistinguishable using traditional primary task measures. The primary task was laparoscopic suturing and knot tying and the secondary task required participants to monitor images of squares and respond with a foot pedal to a specific pattern. The task called for spatial judgments in a single dimension and appeared on a monitor located close to the primary task display. Although performance did not differ between novices and experts on the primary task, experts were faster and more accurate on the secondary task, suggesting that expertise allows the same task to be completed using fewer attentional resources. Further, a second study (Stefanidis, Scerbo, Sechrist, Mostafavi, & Heniford, 2008) revealed that secondary task performance improved as a function of practice. However, this improvement occurred only after novices had mastered the primary task. Zheng, Cassera, Martinee, Spaun, and Swanström (2010) found similar results using a visual detection secondary task. Following the success of Stefanidis et al., the present study will use a novel visual-spatial secondary task to investigate workload in simulated laparoscopy.

Simulation as a Training Tool

Training for laparoscopic surgery, as with traditional surgery, is principally based on an apprenticeship model where residents observe and assist more senior surgeons in the operating room (Tendick, Downes, Goketekin, Cavusoglu, Feygin, et al., 2000). Residents gradually assume greater responsibility for patient care over time and after repeated practice in a supervised environment. However, there are many benefits to supplementing apprenticeship training with simulation.

When training with simulators, trainees can learn at their own pace and tasks can be broken up into smaller parts (Verdaasdonk, Dankelman, Lange, & Stassen, 2007). Simulation training can also be done at a lower cost than training in the operating room and without the additional consequence of slowing down an operation (Tendick et al., 2000). Further, and perhaps most important, trainees can repeatedly practice skills without imposing any risk to actual patients (Hegarty, Keehner, Cohen, Montello, & Lippa, 2007).

Simulator training is especially useful in laparoscopy compared to traditional surgery because surgeons can practice the spatial skills and visualization processes associated with making depth and distance judgments. Spatial skills are crucial for successful laparoscopic performance. Risucci, Geiss, Gellman, Pinard, and Rosser (2001) reported significant correlations between skill in simulator-based performance and spatial tests, such as mental rotation.

Laparoscopic surgeons may also benefit from simulator training because they can learn to adapt to the spatial distortions created by the wide-angle lens of a laparoscope. Researchers have studied how spatial distortions affect the ability to make visual motor adaptations by having participants wear prism glasses that inverted the image of the world (Morton & Bastian, 2004). In a large clinical study, Frassinetti, Angeli, Meneghello, Avanzi, and Ladavas (2002) found that after a two-week program in which participants wore the glasses 20 minutes a day for five days a week, accuracy in pointing tasks while wearing the glasses improved to the same levels exhibited by control participants not wearing prism glasses. Therefore, simulation may be an effective way to acclimate surgeons to distortions inherent in laparoscope displays.

Simulators for laparoscopic training have indeed been shown to benefit surgeons. Keehner, Lippa, Montello, Tendick, and Hegarty (2006) found that after 12 days of practice on a laparoscopic simulator, simulator performance was comparable for novices and experts. More important, training using simulation has been shown to successfully transfer to the operating room. In a study by Seymour, Gallagher, Roman, O'Brien, and Bansal, et al. (2002), surgical residents were randomly assigned to learn a laparoscopic gallbladder procedure either with standard programmatic training or with the standard training in addition to virtual reality (VR). After training, all residents performed the simulated laparoscopic procedure.Those who trained on the VR simulator performed the procedure 29% faster and were less likely to make errors, suggesting that VR training can transfer to the operating room.

Although simulator training allows novices to achieve proficiency on surgical skills that transfer to surgical procedures, novices often do not perform as well as experts during genuine surgery (Korndorffer et al., 2005). This suggests that novices may still be experiencing higher workload. A secondary task may be needed to uncover differences in workload between novices and experts and ensure that novices have achieved skill proficiency without exhausting attentional resources.

CHAPTER 4

PRESENT STUDY

Although Stefanidis et al. (2007, 2008) had some success measuring workload with a visual-spatial secondary task for a laparoscopic primary task, there are a few limiting factors that could be improved. First, the task used by Stefanidis et al. (monitoring white squares) required judgments in only the X plane, but laparoscopy involves spatial judgments in all three planes (X, Y, and Z). Therefore, a spatial task requiring depth judgments is expected to be more sensitive to the depth resources used during a laparoscopic task. Additionally, using a spatial task that can isolate depth judgments from nondepth judgments can allow performance to be examined separately along each dimension.

A second limiting factor is that the Stefanidis et al. task was presented on a separate display from the primary task display. One possible consequence of that configuration is that separate displays may have forced participants to switch their gaze between the tasks, meaning participants may not have engaged in true multitasking. A second possible consequence of separate displays is that participants were able to monitor the secondary task peripherally while viewing the laparoscopic monitor foveally. Recall that foveal and ambient/peripheral vision are separate visual channels requiring separate attentional resources. Therefore, Stefanidis et al. may have limited the sensitivity of their secondary task because the tasks used different visual channels and did not compete for the same resources.

To address the limitations of the Stefanidis, et al. task, a new secondary task was created. In the new secondary task, participants observe successive images of four balls in a 2D representation of a 3D tunnel. After each image is presented, participants must respond to whether the balls changed position from a standard configuration. Changes in ball position occur either around the tunnel circumference or in depth within the tunnel. This task, referred to as the "ball-and-tunnel task," was designed to require the same visual-spatial resources needed for laparoscopy.

The ball-and-tunnel task provides two improvements over the Stefanidis et al. task. First, it requires viewers to judge depth differences because responses are made about the balls' locations within a 3D "tunnel." Second, to address the limitation that the Stefanidis et al. task was presented on a separate display, the ball-and-tunnel task is superimposed over the laparoscopic display at 50% transparency. This eliminates the need to shift gaze between tasks. It was expected, therefore, that because the ball-and-tunnel task requires depth judgments and is superimposed over the primary task display, it will be more sensitive to differences in laparoscopic workload than the Stefanidis et al. task.

In a previous study, Scerbo, Kennedy, and Anderson (2011) used the ball-and-tunnel task to measure workload for undergraduate students performing a laparoscopic tracing task. It was expected that ball-and-tunnel task performance would be worse when the laparoscopic task required movement in the depth (or Z) plane than in the X and Y planes, reflecting greater difficulty for depth judgments. Results showed that performance on the primary task was indeed worse in the depth condition; however, the ball-and-tunnel task was not sensitive enough to reflect workload differences. Ball-and-tunnel task performance showed a ceiling effect: participants made very few errors, and average response times were not significantly different from those obtained when the ball-and-tunnel task was performed alone.

Several problems with the ball-and-tunnel task identified in the Scerbo et al. study were addressed in the present study. In the Scerbo et al. study, the stimuli were presented and remained visible on the screen until a response was made. However, this presentation style made the task too easy. Errors were low and response times were lengthy (i.e., 2.6 s), suggesting that participants may have taken extra time to direct attention away from the primary task and to the ball-and-tunnel task to make an accurate response. In the present study, the stimuli were presented briefly (1 s), thereby limiting the time available to scan the image and instead requiring participants to rely on visual memory. Therefore, if primary task workload is high, participants should not have enough residual resources to attend to the ball-and-tunnel task stimuli when presented. This change in presentation style was expected to allow ball-and-tunnel task performance to better reflect workload differences.

A second problem with the ball-and-tunnel task in the Scerbo et al. (2011) study was that significantly more errors were made in the circumference condition than in the depth condition. This is in direct contrast to what was hypothesized, given the assumption that depth judgments would be more difficult to perform than nondepth judgments. This unexpected finding may also be attributed to the presentation style; that is, because participants were given unlimited time to inspect stimuli and respond they had less difficulty detecting a change in ball depth than a change in circumference. This is best understood by considering that a depth change was the result of changes in both physical size and position of the ball, whereas a circumference change resulted from a change in position only. The magnitude of change was greater for depth changes, making them easier to identify.

In the present study, the problem of nonequivalent depth and nondepth conditions was addressed by adjusting the physical magnitude of changes and psychophysically equating the stimuli in a pilot study. The standard position of the balls in the tunnel was set back "farther" in the tunnel and the changes in the depth condition were made less conspicuous. Eleven pilot participants performed the ball-and-tunnel task in both conditions. A paired samples t-test indicated that performance between the depth ($M = .98$, $SE = .03$) and nondepth ($M = .96$, $SE = .04$) conditions was not statistically significant, $t(1,11) = 1.60$, $p = .140$. Therefore, after adjusting the magnitude of changes, depth changes were not significantly harder or easier to detect than nondepth changes. Changes for both versions were psychological equivalent.

The primary task used in the Scerbo et al. (2011) study was a laparoscopic tracing task. Participants traced the outline of figures with one hand, using a laparoscopic instrument with a marker affixed to the end. The tracing task was chosen because it is a continuous task that can be performed easily by participants with no laparoscopic experience. In the present study, the primary task was a threading task requiring both hands. The threading task is similar to laparoscopic tasks commonly used by surgeons in the operating room.

The present study aimed to use a more sensitive version of the ball-and-tunnel task by changing the presentation style of the stimuli and using psychophysically equated depth and nondepth stimuli changes. The goals of the study were to assess the sensitivity of the modified ball-and-tunnel task when paired with a laparoscopic primary task and to use the ball-and-tunnel task to investigate the workload differences between depth and nondepth primary task judgments on a 2D display.

Hypotheses

A visual-spatial secondary task was paired with a laparoscopic primary task. The primary task had three conditions: movement isolated to either the X plane, Y plane, or Z plane. Additionally, there were two secondary task conditions: depth and nondepth.

Recall that absent and distorted depth cues on a laparoscopic display make depth judgments difficult. Thus, the conditions where laparoscopic movement was required in the depth plane were expected to be more difficult than conditions where movement was required only in the X and Y planes. The first hypothesis was that primary task performance would be poorer for the depth condition because movement and judgment in the Z plane is more difficult.

If a secondary task is an accurate workload measure, secondary task performance would be expected to decline when primary task workload increases. The second hypothesis was that secondary task performance would decline when the primary task was performed in the Z plane. This decline in secondary task performance should reflect increased attentional resources required by the primary task.

The third hypothesis was that the dual-task decrement predicted by the second hypothesis would be more prominent when both tasks require depth judgments; that is, secondary task performance should be poorest when the primary task was performed in the Z plane and the secondary task was performed in the depth version. For these trials, the same visual-spatial resources would be demanded by both the primary and secondary tasks and there would be even fewer residual resources to allocate to the secondary task.

Primary task performance was not expected to differ when performed alone or in conjunction with the secondary task, because the secondary task should not disrupt primary task performance. Therefore, the fourth hypothesis was that the presence of the secondary task would not significantly affect performance on the primary task.

CHAPTER 5

METHOD

Participants

A power analysis was conducted to determine the appropriate number of participants required to achieve the same effect size found in the previous study by Scerbo. Kennedy, and Anderson (2011, partial $\eta^2 = .342$), which resulted in a suggested sample size of 9. This number was exceeded to be sure that more moderate effects could be detected. A total of 30 undergraduate students at Old Dominion University participated in the study to fulfill a course requirement or to receive extra credit. Data for 26 participants were used after the data for four participants were removed because of technical difficulties. Participants were at least 18 years of age, with a mean age of 23. Twenty were female (76.92%) and six were male (23.08%). All participants had normal or corrected to normal vision and no prior experience with laparoscopic simulation or laparoscopy. Fifteen participants (57.69%) reported that they played video games, and the average reported hours per week playing video games was 2.69.

Primary Task

The primary task used in this study was a laparoscopic threading task. The task required participants to maneuver a needle through three eyelets on a wooden block using laparoscopic instruments with grabbers. The threading task was chosen because it is a complex task, requires both hands, and is similar to movements required for laparoscopic suturing. Additionally, although ecologically valid, it is also a task that can be done by undergraduate students with no surgical experience. The wooden block containing the eyelets can be oriented either in an upright or prone position so that the threading can occur in the X, Y, or Z planes. Figure 1 displays diagrams and camera screenshots for each orientation.

All trials were video recorded to facilitate performance assessment. Primary task dependent measures were based on total time to complete threading and accuracy of threading. Threading accuracy was assessed by the number of times the needle was dropped and the number of unsuccessful attempts to pass the needle through the eyelets. The two accuracy variables were measured by watching the videos and counting the number of instances that each occurred.

The number of unsuccessful attempts was calculated by counting the number of times a participant attempted to pass the needle through the eyelet but missed. Needle movement was considered an unsuccessful attempt whenever the participant moved the needle forward and past the location of the eyelet but the needle did not go through the eyelet. For simplicity, the term "forward" refers to movement toward the eyelet to pass it through, although the actual direction differed among conditions. Successive attempts were counted when the needle was pulled back so that the needle was in front of the eyelet and then again pushed forward and past the eyelet. If the participant pushed the needle forward and missed the eyelet, but then dropped the needle, it was also counted as an unsuccessful attempt.

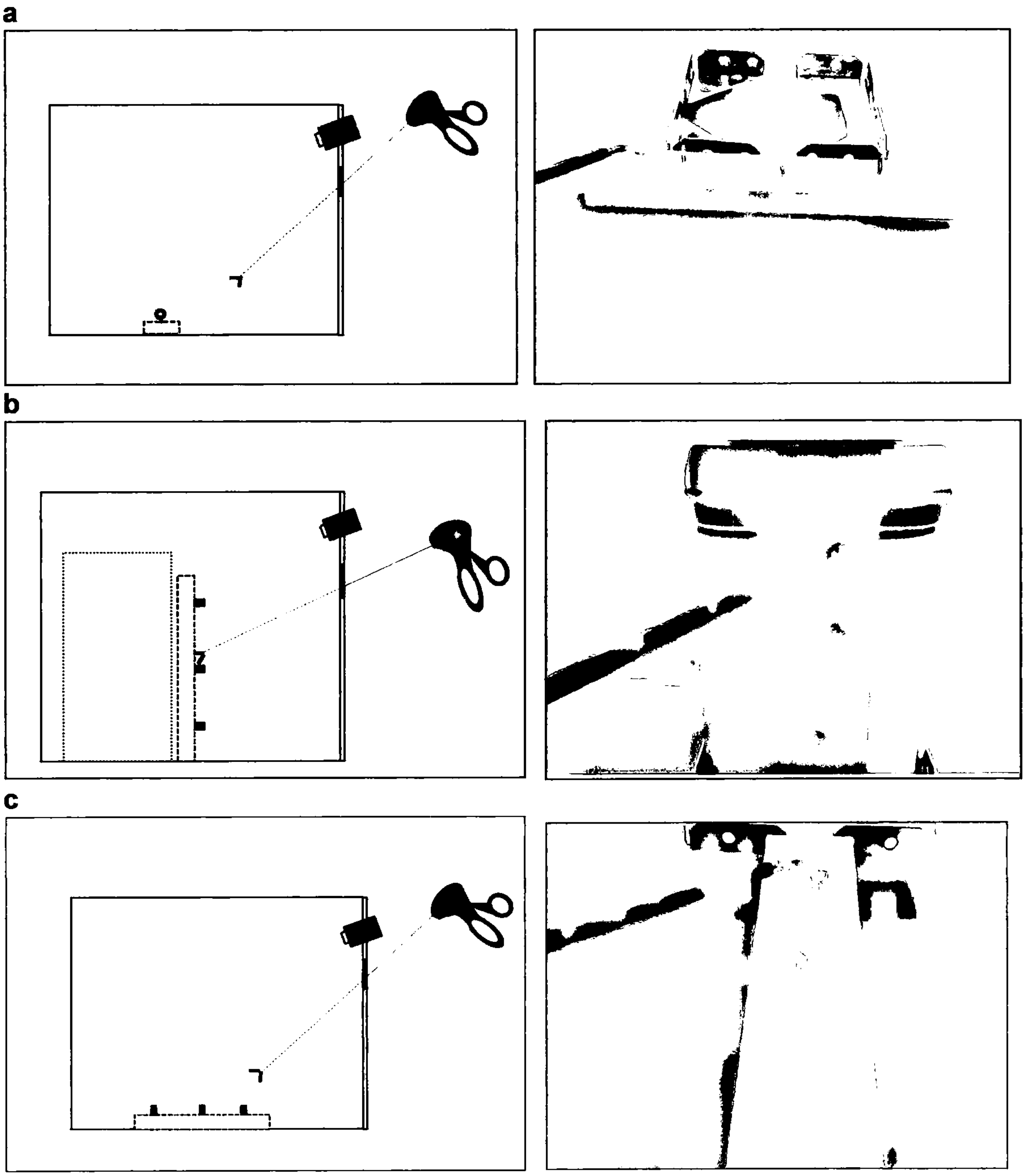

Figure 1. Threading configurations and camera views for the X (a), Y (b), and Z (c) plane threading orientations.

Secondary Task

The secondary task was the ball-and-tunnel task. The task contains the 2D image of four spheres ("balls") in a representation of a 3D tunnel. Depth perspective is conveyed in the tunnel using small dots that decrease in size and relative distance toward the center of the image. Participants monitor successive images to determine whether any of the balls has "moved" from a standard configuration. In the standard configuration, the balls measure 1.9 cm and are placed at the 12, 3, 6, and 9 o'clock positions within the tunnel (see Figure 2a). Images are presented for 1 s, after which the participant indicates whether the image was the same or different from the standard by pressing a left or right foot pedal, respectively. There is a delay of 4 s between image presentations.

Changes in ball position occur either in depth or nondepth. In either case, only one of the four balls changes in location and the other three remain in the standard positions. The condition also remains consistent within each set of trials, so observers only look for one type of change (depth or nondepth) at a time. In the depth condition, a change from the standard configuration consists of one ball appearing to move either closer or farther in the tunnel (see Figure 2b). Depth changes are represented by a change in the ball's diameter and a location shift (see Table 1 for size and location change values). For nondepth changes, a ball remains the same size but moves either plus or minus 26 degrees around the circumference of the tunnel from its standard location (see Figure 2c).

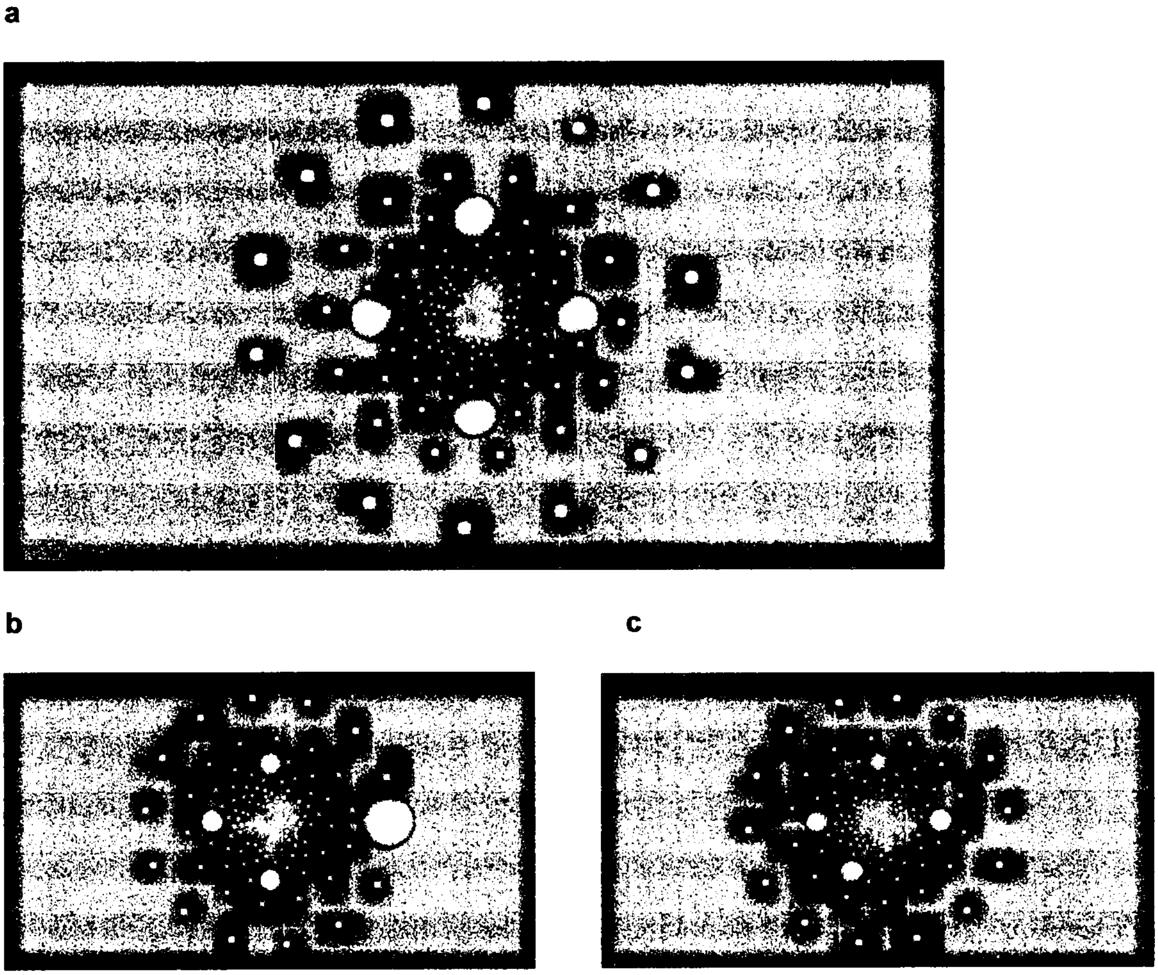

Figure 2. Three images from the ball-and-tunnel task. The top image (a) is the standard configuration to which all stimuli are compared. The bottom two images are examples of changes from the standard; on the left (b) is an example of a depth change and on the right (c) is an example of a circumference change.

Performance on the ball-and-tunnel task was assessed using average response time (RT), proportion of correct responses, and proportion of "No Response" trials. All response times were automatically recorded by the ball-and-tunnel task software. A response time of "0" indicated that no response was made and these were times were excluded from analysis.

Correct answers to the ball-and-tunnel task are hits and correct rejections, whereas incorrect responses are misses, false alarms, and No Response trials. No Response trials indicate a failure to make a response during the 4s delay before a new image is presented. Participants were instructed to perform the threading task to the best of their ability and to respond to the ball-and-tunnel task only if they felt they were able to do so.

Equipment

The primary task was placed inside a plastic box with a drawer measuring approximately 42 cm x 36 cm x 25 cm. The box ensured that participants' direct vision was obstructed. A Microsoft LifeCam VX-5000 video camera was placed at a fixed location inside the box and the camera was connected to a 13 inch iMac that displayed the camera image. The ball-and-tunnel task was run on a separate Dell laptop and the images of the task were captured from the Dell with an Epiphan, Inc. VGA2USB signal grabber and superimposed at 50% transparency using BoinxTV software on the iMac.

Table 1.
Onscreen changes in ball size and position

Ball Orignial Size	Perceptual Change	New Size	New position
26 mm	Closer in tunnel	53 mm	53 mm shift away from center
26 mm	Farther in tunnel	11 mm	11 mm shift toward center

In the dual-task conditions, participants were instructed to direct attention to the primary task and to make the ball-and-tunnel task their second priority. The order of the combinations of orientations, directions, and secondary task conditions were counterbalanced through random assignment. Upon completion of the experimental trials, participants were debriefed and thanked for their participation.

CHAPTER 6

RESULTS

Thirty undergraduate students took part in the study. The data for four participants were not used because of equipment recording errors, leaving a total of twenty six participants with analyzable data. To assess primary task performance, a 3 Orientations (X, Y, and Z plane) x 2 Directions x 3 Secondary Task Conditions (no secondary task, depth secondary task, nondepth secondary task) repeated measures analysis of variance (ANOVA) was performed. There were three dependent measures for primary task performance: threading time, number of times the needle was dropped, and number of unsuccessful attempts to pass the needle through the eyelets.

All dependent measures for the primary task were assessed for orientation and secondary task condition, but differences in direction were not of interest to this study. Participants performed each orientation in both possible directions, but to analyze these differences is not informative. Rather, interest lies with the six levels of direction and orientation combinations.

Also, separate analyses were conducted to assess the primary task and secondary task differences under single- and dual-task conditions (i.e., collapsed across depth and nondepth versions of the secondary task). The purpose was to determine whether performance was affected by the presence of the secondary task.

Post hoc analyses were used to further analyze the data. Simple main effects were complemented with t-tests to compare pairs of means and analyzed with Bonferroni-corrected degrees of freedom. Statistical significance for all the other data was assessed at the .05 significance level unless otherwise noted.

Primary Task Results

Threading time. Lower threading times indicate better performance. The mean threading time per trial for all conditions was 113.07 s. A separate repeated measures ANOVA was performed to compare threading times in the single- and dual-task trials. Threading time was significantly longer when performed in dual-task conditions than single-task conditions, $F(1, 25) = 4.51, p < .05$, partial $\eta^2 = .153$. The means and standard errors for single- and dual-task threading time are displayed in Table 2.

Table 2
Means and Standard Errors of Threading Times for Single- and Dual-Task Conditions

Secondary Task Condition	Mean	SE
Single Task (No Secondary Task)	107.19 *	19.19
Dual Task		
Depth Version	115.93	5.85
Nondepth Version	116.10 *	5.41
Dual Task Mean	116.01	27.12

Note: * indicate significantly different means.

The ANOVA for threading time is displayed in Table 3. There was a significant main effect of threading time for orientation. The means for all three orientations were significantly different from one another (see Table 4). Threading times were shortest in the Y plane orientation and, as predicted, longest in the Z plane orientation.

Table 3

Results of the Analysis of Variance for Threading Time

Source	SS	df	MS	F	p	partial η^2
Orientation (O)	81031.76	2	40515.88	13.58	.000 *	.352
Error	149135.51	50	2982.71			
Direction (D)	1220.62	1	1220.62	.47	.501	.018
Error	65444.07	25	2617.76			
Secondary Task (S)	8103.87	2	4051.94	2.82	.069	.101
Error	71936.85	50	1438.74			
O x D	8285.34	2	4142.67	1.71	.192	.064
Error	121441.41	50	2428.83			
O x S	1366.51	4	341.63	.27	.897	.011
Error	126674.02	100	1266.74			
D x S	3937.39	2	1968.70	1.80	.176	.067
Error	54777.70	50	1095.55			
O x D x S	13722.00	4	3430.50	3.53	.010 *	.124
Error	97102.07	100	971.02			

Note. * $p < .05$

Table 4
Means and Standard Errors of Threading Times for X, Y, and Z Plane Orientations

Orientation	Mean	SE
X plane	113.75 *	6.53
Y plane	96.63 *	5.14
Z plane	128.84 *	5.44

Note: * indicate significantly different means.

There was also a significant three-way interaction among orientation, direction, and secondary task for threading time (see Figure 2). To probe this interaction further, a separate ANOVA was run for each of the six possible orientation and direction combinations. Three of the six ANOVAs were statistically significant, indicating significant simple main effects for secondary task condition. The significant ANOVAs were for the X plane in the left to right direction, the Y plane in the bottom to top direction, and the Z plane in the back to front direction.

For the three simple main effects that were significant, pairwise comparisons were performed to determine which secondary task condition means within each orientation and direction combination differed significantly. Dependent measures t-tests were performed with a Bonferroni-corrected alpha level of .017 to correct for inflated family-wise error for the three means compared. The results indicated that the no secondary task condition was significantly lower than the nondepth secondary task for the Y plane in the bottom to top direction and the Z plane in the back to front direction. The no secondary task condition was significantly lower than both the nondepth and depth secondary task conditions for the X plane in the left to right direction.

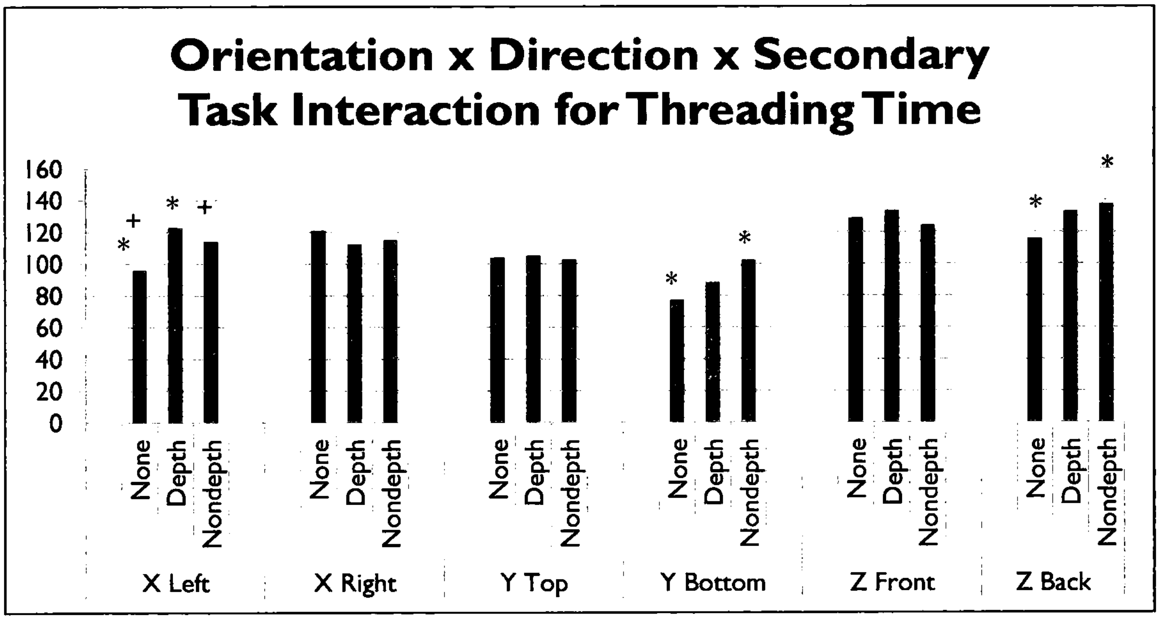

Figure 3. Threading times for orientation and direction for each secondary task condition. Simple main effects were significant for three combinations: X left, Y bottom, and Z back.

Note: * and + indicate significantly different means within that orientation and direction combination.

Number of needle drops. Table 5 displays the results of the ANOVA for number of needle drops. The mean number of drops was .99 across all conditions, or about once per trial. The mean number of drops was not significantly different between single-task ($M = .93$, $SE = .66$) and dual-task trials ($M = .97$, $SE = .43$), $F(1, 25) = .07$, $p = .787$.

There was a significant main effect for orientation. The means and standard errors for number of needle drops for each orientation are displayed in Table 6. The needle was dropped significantly fewer times while threading in the Y plane than the other two orientations. It was hypothesized that primary task performance would be poorest in the Z plane orientation. The number of needle drops was indeed highest while threading in the Z plane, but this was not statistically higher than number of drops in the X plane.

Table 5
Results of the Analysis of Variance for Mean Number of Needle Drops per Trial

Source	SS	df	MS	*F*	*p*	partial η^2
Orientation (O)	32.12	2	16.06	7.58	.001*	.233
Error	105.10	50	2.12			
Direction (D)	3.25	1	1220.62	3.25	.176	.072
Error	65444.07	25	2617.76			
Secondary Task (S)	3.35	2	1.68	1.14	.329	.043
Error	71936.85	50	1438.74			
O x D	15.59	2	7.80	3.03	.057	.108
Error	121441.41	50	2428.83			
O x S	4.83	4	1.21	1.11	.354	.043
Error	108.39	100	1.08			
D x S	.462	2	.231	.23	.797	.009
Error	54777.70	50	1095.55			
O x D x S	2.18	4	.55	.43	.787	.017
Error	127.04	100	1.27			

Note. * $p < .05$

Table 6
Means and Standard Errors for Number of Needle Drops per Trial for X, Y, and Z Plane Orientations

Orientation	Mean	SE
X plane	.99 *	.13
Y plane	.65 * +	.09
Z plane	1.28 +	.15

Note: * and + indicate significant differences.

Number of unsuccessful attempts to pass the needle. There were significantly more unsuccessful attempts to pass the needle through eyelets when participants threaded in dual-task conditions ($M = 6.83$, $SE = .57$) than single-task conditions ($M = 5.72$, $SE = .58$), $F(1, 25) = 6.26, p < .05$, partial $\eta^2 = .200$. Table 7 displays the ANOVA results for number of unsuccessful attempts to pass the needle. There was a significant main effect for orientation; however, the assumption of sphericity was violated according to Mauchly's test so a Greenhouse-Geisser correction was used, $F(1.63, 40.85) = 15.44, p < .05$, partial $\eta^2 = .382$. The means are displayed in Table 8. Specifically, there were significantly more unsuccessful attempts in the X plane orientation than the Y and Z plane orientations. This finding does not support the hypothesis that threading is most difficult in the Z plane.

There was also a significant secondary task x direction interaction for number of unsuccessful attempts. However, this was not investigated further because, as previously mentioned, threading direction was not a variable of interest.

Table 7

Results of the Analysis of Variance for Number of Unsuccessful Attempts to Pass the Needle through Eyelets

Source	SS	df	MS	*F*	*p*	partial η^2
Orientation (O)	945.50	1.63	472.75	15.44	.000 *	.382
Error	1530.94	40.85	37.48			
Direction (D)	18.09	1	18.09	.57	.456	.022
Error	787.69	25	31.51			
Secondary Task (S)	132.27	1.97	66.06	2.96	.062	.106
Error	1119.18	49.31	22.70			
O x D	226.70	1.85	122.80	2.00	.150	.074
Error	2834.86	46.15	61.43			
O x S	32.00	3.26	9.81	.38	.786	.015
Error	2122.56	81.51	26.04			
D x S	184.08	1.50	122.86	3.98	.038 *	.137
Error	1155.14	37.46	30.84			
O x D x S	203.37	2.41	84.34	2.32	.097	.085
Error	2196.08	60.29	36.43			

Note. * $p < .05$

Table 8
Means and Standard Errors for Mean Number of Unsuccessful Attempts per Trial for X, Y, and Z Plane Orientations

Orientation	Mean	SE
X plane	8.47 * +	.83
Y plane	5.56 *	.57
Z plane	5.53 +	.47

Note: * and + indicate significant differences.

Secondary Task Results

Data for secondary task performance were analyzed with a 3 Orientations x 2 Directions x 2 Secondary Task Conditions (Depth and Nondepth) repeated measures ANOVA. Secondary task dependent measures were response times (RT), the proportion of correct responses, and the proportion of No Response trials (NR trials; i.e., trials where participants failed to respond with the foot pedal).

A correct response was defined as the correct identification of either the standard ball configuration or a change in ball position. Proportions of correct responses were used rather than number of correct or incorrect responses because the total number of stimuli presented depended on how long it took the participant to perform the primary task.

Response time (RT). The mean RT was 1.85 s ($SE = .07$) and was significantly faster when the task was performed as a single task baseline measure ($M = 1.18$, $SE = .23$) than when paired with the primary task ($M = 1.85$, $SE = .37$), $F(1, 25) = 133.98, p < .05$, partial $\eta^2 = .843$. Table 9 displays the results of the ANOVA for response times (RT) to ball-and-tunnel task stimuli. A Greenhouse-Geisser correction was used.

Table 9

Results of the Analysis of Variance for Secondary Task Response Times

Source	SS	df	MS	*F*	*p*	partial η^2
Orientation (O)	.50	1.42	.33	2.65	.101	.096
Error	4.44	35.48	37.48			
Direction (D)	.01	1	.01	.11	.742	.004
Error	1.37	25	.05			
Secondary Task (S)	.00	1	.00	.12	.735	.005
Error	.63	25	.03			
O x D	.18	1.48	.12	1.66	.209	.062
Error	2.64	36.96	.07			
O x S	.05	2	.03	.83	.441	.032
Error	1.59	50	.03			
D x S	.01	1	.01	.40	.549	.015
Error	.56	25	.02			
O x D x S	.18	2	.09	2.41	.100	.088
Error	1.83	50	.04			

The means for ball-and-tunnel task RT are displayed in Table 10. It was hypothesized that RT would be longer for the Z plane orientation, but there was no significant main effect for orientation. Although the main effect was not significant, there was a trend for longer RTs in the X plane orientation than both the Y plane and Z plane orientations.

Table 10
Means and Standard Errors for Secondary Task Response Times for X, Y, and Z Plane Primary Task Orientations

Orientation	Mean	SE
X plane	1.91	.08
Y plane	1.82	.07
Z plane	1.83	.07

It was also hypothesized that RTs would be longer for the depth version of the ball-and-tunnel task. However, there was no significant difference between the depth ($M = 1.85$, $SE = .07$) and nondepth ($M = 1.85$, $SE = .07$) conditions.

Proportion of correct responses. The proportion of correct responses was significantly higher when the task was performed alone ($M = .95$, $SE = .01$) than when performed in dual-task conditions ($M = .59$, $SE = .03$), $F(1, 25) = 122.65$, $p < .05$, partial $\eta^2 = .831$.

Table 11 displays the results of the ANOVA for proportion of correct responses for the ball-and-tunnel task. There were no significant main effects.

Table 11
Results of the Analysis of Variance for Secondary Task Proportions of Correct Responses

Source	SS	df	MS	*F*	*p*	partial η^2
Orientation (O)	.24	2	.11	2.66	.080	.096
Error	2.10	50	.04			
Direction (D)	.01	1	.01	.55	.464	.022
Error	1.37	25	.05			
Secondary Task (S)	.04	1	.04	2.09	.161	.077
Error	.53	25	.02			
O x D	.06	2	.03	.82	.447	.032
Error	1.75	50	.04			
O x S	.06	2	.03	2.31	.110	.084
Error	.65	50	.01			
D x S	7.21	1	7 .21	.01	.924	.000
Error	.20	25	.02			
O x D x S	.04	2	.02	.84	.440	.032
Error	1.12	50	.02			

Table 12 displays the mean proportion of correct responses for each orientation. The proportion of correct responses was hypothesized to be lowest for the Z plane orientation; however, this was not supported. There was no significant main effect of orientation on proportion correct responses orientation. Also, there was no significant difference in proportion correct responses between the depth (*M* = .59, *SE* = .03) and nondepth (*M* = .57, *SE* = .03) versions of the task.

Table 12
Means and Standard Errors for Proportions of Correct Responses in the X, Y, and Z Plane Threading Orientations

Orientation	Mean	SE
X plane	.54	.04
Y plane	.62	.04
Z plane	.59	.04

Proportion of no response (NR) trials. In the single-task condition, there were very few NR trials (*M* = .01, *SE* = .01). When performing the task under dual-task conditions, mean proportion of NR trials increased to .38 (*SE* = .18) and was significantly higher $F(1, 25) = 121.25, p < .05$, partial $\eta^2 = .829$. Table 13 displays the results of the ANOVA for proportion of NR trials.

Table 13
Results of the Analysis of Variance for Secondary Task Mean Proportions of No Response Trials

Source	SS	df	MS	*F*	*p*	partial η^2
Orientation (O)	.35	1.56	.22	3.62	.047 *	.136
Error	2.21	35.82	.06			
Direction (D)	.03	1	.03	1 .03	.322	.043
Error	.63	23	.03			
Secondary Task (S)	7.71	1	7.71	.00	.995	.000
Error	.40	23	.02			
O x D	.00	1.79	.00	.02	.976	.001
Error	1.79	41.21	.04			
O x S	.03	1.89	.01	.74	.474	.031
Error	.83	43.45	.02			
D x S	.00	1	.00	.01	.910	.001
Error	.27	23	.01			
O x D x S	.03	1.69	.02	.91	.397	.038
Error	.82	38.84	.02			

Note. * $p < .05$

There was a significant main effect of proportion of NRs for threading orientation. Mauchly's test indicated that the assumption of sphericity was violated for orientation so a Greenhouse-Geisser correction was used, $F(1.56, 35.82) = 3.62, p < .05$, partial $\eta^2 = .136$. The means are displayed in Table 14. There were significantly more NR trials in the X plane orientation than the Y plane and the Z plane orientations.

There was no significant difference between the depth ($M = .39$, $SE = .04$) and nondepth ($M = .39$, $SE = .04$) conditions. In fact, the proportion of NR trials was basically identical in both conditions.

Table 14
Means and Standard Errors for Proportions of No Response Trials in the X, Y, and Z Plane Threading Orientations

Orientation	Mean	SE
X plane	.44 * +	.04
Y plane	.36 *	.05
Z plane	.37 +	.04

Note: * and + indicate significant differences.

CHAPTER 7

DISCUSSION

The purpose of the present study was to use a laparoscopic task to investigate the effects of making 3D spatial judgments while viewing task movements on a 2D display. Specifically, a visual-spatial secondary task was used to measure spare attentional capacity during a laparoscopic threading task in the X, Y, and Z plane orientations. Participants performed each threading orientation with the depth and nondepth versions of the secondary task.

Primary Task

It was predicted that primary task performance would be poorer for the Z plane compared to the X and Y planes, indicating that laparoscopic movements in depth are difficult to perform because of impoverished depth cues on a 2D display. This hypothesis was partially supported. Participants took significantly longer to thread in the Z plane than the other two orientations. Also, participants dropped the needle significantly more times in the Z plane orientation (and X plane orientation) than in the Y plane orientation. However, there were significantly more unsuccessful attempts to push the needle through eyelets in the X plane, with a mean of about 8.5 per trial compared to 5.5 in both the Y and Z planes.

Poorer threading accuracy in the X plane does not provide immediate support for the hypothesis that threading in the Z plane would be most difficult. However, a closer inspection of the task reveals that poor X plane performance may have actually resulted from participants' difficulty with depth judgments. First, the higher number of unsuccessful attempts to pass the needle in the X plane orientation actually demonstrates errors related to poor depth judgments. In the X plane orientation, the eyelets were rotated 90 degrees away from the camera for participants to thread the needle in the left and right directions (refer to Figure 1a). Participants could not clearly see the location of the eyelet holes on the display, so errors in passing the needle for this configuration may have been related to compromised depth perception. Not only did participants have difficulty ascertaining the location of the eyelets, but they also had difficulty adjusting their movements once they had made an unsuccessful attempt. Participants often moved the needle behind the hole instead of through the hole. If the task were performed under normal viewing conditions, binocular depth cues would have been available and aided participants in adjusting movements until they successfully passed the needle through the eyelet. This explanation provides some support for the idea that missing and distorted depth cues impacted laparoscopic performance, though it was not predicted at the outset of the study.

Although the X plane condition was more difficult than anticipated, the Z plane condition may also have been easier for two unexpected reasons. First, the eyelet holes were directly facing the camera in the Z plane orientation so visibility of the eyelet holes was very clear (refer to Figure 1c). In the other two orientations the eyelets were perpendicular to the camera, making the location of the eyelet holes more ambiguous. However, visibility of the eyelet holes in the Y plane was better than in the X plane because the camera placement at the top of the box allowed a better view of the bottom two eyelet holes (refer to Figure 1b).

The second reason that the X plane was more challenging than anticipated is that it lacked many depth cues that were actually more prominent in the Z plane orientation. As noted earlier, examples of pictorial cues that provide depth information in 2D images include the texture gradient, relative height, relative size, and perspective convergence (Goldstein, 2010). Texture gradient was more prominent in the Z plane than in the X or Y planes. The texture of the wooden board could be seen more clearly for the parts of the board closer to the camera. Additionally, the relative height and relative size depth cues could be used in the Z plane where the eyelets appeared higher in the field of view and smaller as depth increased. Participants knew that all eyelets were the same size, so they could use the size of the eyelets onscreen to gauge how far they were from the camera. In the X plane, however, the eyelets appeared at the same height in the field of view and appeared to be the same size because they were relatively equally distant from the camera. Last, the eyelets were screwed into a thin wooden board that provided perspective convergence depth cues in the Z plane (i.e., the edges of the wooden board appeared to converge toward each other as depth increased) that were less prominent in the X and Y planes.

It was also hypothesized that that primary task performance would be unaffected by secondary task performance, providing evidence that the ball-and-tunnel task was an unobtrusive secondary task. For secondary task measures to be pure, the primary task should be unaffected by the secondary task. This hypothesis was not supported. Threading time was significantly longer and there were significantly more unsuccessful attempts to pass the needle for dual-task trials. Although participants were instructed to focus on the primary task, the results suggest that this was not the case. Participants switched attention between the primary and secondary tasks because they may have had difficulty with the primary task. The threading task was difficult for the participants to perform. However, the skills of the undergraduate students who participated in the study are similar to those of novice surgeons, and the task is generalizable to the kinds of tasks performed by novice surgeons.

In sum, the hypothesis for poorer primary task performance in the Z plane was partially supported. Threading time was significantly longer for the Z plane orientation, which supports the idea that laparoscopic movements in depth are more difficult than nondepth movements. Participants dropped the needle significantly more times in the Z plane than the Y plane orientation, which provides further support; however, participants also dropped the needle significantly more times in the X plane than the Y plane. There were also significantly more unsuccessful attempts to push the needle through eyelets in the X plane. Although poor X plane performance does not provide immediate support for the hypothesis, it does suggest that the increased errors in the X plane orientation were due to unanticipated depth-related difficulties. The hypothesis that primary task performance would be unaffected by the presence of a secondary task was unsupported. Participants devoted resources to the secondary task, despite instructions telling them emphasize the primary task.

Secondary Task

The second hypothesis was that secondary task performance would also decline for Z plane primary task conditions, which would provide evidencing for the higher attentional demand by the primary task. The third hypothesis was that performance on the secondary task would decline further when both the primary and secondary tasks were performed in the depth conditions. Such a finding would indicate a competition for the same depth resources. Neither hypothesis was supported.

Performance was significantly better for the ball-and-tunnel task under single as compared to dual-task conditions. This provides evidence that there was a competition for attentional resources under dual-task conditions.

For orientation, there were no significant differences in RT or proportion of correct responses. However, there were significantly more NR trials in the X plane than the Y or Z plane orientations. This does not directly support the hypothesis that Z plane threading would require the most resources, but as discussed previously, it might reflect higher difficulty in the X plane because of other difficulties with depth judgments.

There were almost no performance differences between the depth and nondepth versions of the secondary task. Recall that a pilot study was performed to psychophysically equate the depth and nondepth ball changes in the ball-and-tunnel task. In the present study, performance remained equivalent for depth and nondepth even under dual task conditions.

The lack of performance differences suggests that the ball-and-tunnel task was not a sensitive measure of differences in workload associated with the orientations. One possible explanation is that the ball-and-tunnel task stimuli did not contain enough depth cues for participants to rely on depth judgments. Depth perspective was conveyed using small dots that decrease in size and relative distance toward the center of the image to convey a 3D tunnel, but another cue could be added. Shadows of the balls could also be placed on the "wall" of the tunnel to help provide an addition cue to their implied location in the tunnel.

An alternative explanation may be that the depth task did not actually draw upon depth spatial resources, meaning both versions of the task used the same resources. Recall that to imply a change in depth within the tunnel, a ball differed in size and location from the standard configuration. The stimuli were two dimensional and participants may have perceived them as such, meaning that when a ball changed from the standard location, participants may have simply noticed that it differed in *appearance* rather than depth. Thus, additional research may be needed to examine the appearance and location perceptions of stimuli used to depict depth in 2D displays.

Theoretical Implications

Overall, the findings are consistent with Multiple Resource Theory (Wickens, 1980, 1984). There was a dual task performance decrement in both tasks when performed simultaneously, which suggests that attention is a limited resource and that both tasks competed for similar attentional resources. The mean proportion of correct responses for the ball-and-tunnel task dropped from .95 under the single-task conditions to .59 under dual-task conditions. This suggests that, as expected, the attentional resources required for the ball-and-tunnel task were allocated to the primary task.

Poor laparoscopic performance in the Z plane and X plane provides evidence that making depth judgments by referencing a 2D display is challenging. Consistent with work by Klatzky, Wu, and Stetten (2008) who used ultrasound images, the results of the present study suggest that participants used spatial visualization processes to translate the

2D display into 3D movements, and that these processes contributed to higher mental workload.

However, it was also expected that primary task performance would be unaffected by the presence of a secondary task, but this was not the case. Compared to the single-task baseline, threading time under dual-task conditions was longer and there were significantly more unsuccessful attempts to pass the needle through eyelets. This suggests that despite instructing participants to emphasize the primary task, the ball-and-tunnel task distracted participants somewhat from threading, or participants felt like they needed to perform *both* tasks at the expense of the primary task.

Poor primary task performance in the Z plane (for threading time and number of false attempts to pass the needle) and X plane (for number of false attempts to pass the needle) was possibly related to participants' difficulty with making depth judgments. Therefore, it seems that the theoretical basis for the study is correct but the task was flawed. However, a second possibility is that the theoretical basis of the ball-and-tunnel task itself is incorrect. It may be that no unique depth-related attentional resources beyond those conveying 2D displays are actually used during laparoscopic tasks. This could explain why performance differences in depth and nondepth secondary task conditions were not observed.

Limitations

An unanticipated problem in the present study was that the three orientations of the threading task were inherently different. The current methods were based on a prior study (Scerbo, Kennedy, & Anderson, 2011) where the primary task was a laparoscopic tracing task. In the tracing task, participants used a laparoscopic instrument to trace the outline of a figure printed on a piece of paper. In the current study, the threading task differed from the tracing task in three major ways that resulted in unexpected variations among conditions.

First, the box simulator imposed unexpected ergonomic strain on participants. In the Scerbo et al (2011) study, the tracing task required continuous hand and arm movement to trace the figure to completion without lifting the instrument. Second, the tracing task required the use of one hand at a time and participants alternated which hand was being used between trials. Fatigue had not been reported by participants during or after performing the tracing task. In the present study, the threading task required more static arm and hand positioning to pass the needle through eyelets and from one hand to the other. Third, in the previous study it took an average of 35 s to complete each laparoscopic tracing, allowing frequent rests between figures. By contrast, the mean threading time in the current study was about 113 s.

As a result of static arm and hand positions, constant use of both hands, and longer completion times, the threading task was more physically demanding than the tracing task. The implications of ergonomics strain were less pronounced in the Y-plane orientation, because threading the needle in the up and down direction required less wrist movement than threading laterally in the X plane or forward and back in the Z plane (see Figure 3).

Also, the placement of the holes for instrument insertion on the box was unnatural in the X and Z plane orientations. In the Scerbo et al. (2011) study, there were separate holes on the box for instrument insertion for the depth and nondepth tracing conditions.

The instruments were inserted at the front of the box for the nondepth condition and the top of the box for the depth condition. Consistent placement of the instruments in the present study ensured a constant camera angle among all threading conditions. However, this procedure introduced a different confounding variable. The ideal placement for instrument insertion in the X and Z planes would have been on top of the box trainer. Therefore, differences in ergonomic comfort among the three orientations was a confounding variable.

Thus, it was expected that performance would be similar for threading in the X plane and Y plane because they were both considered "nondepth" conditions. However, the better performance (lower threading time, fewer needle drops, and fewer unsuccessful attempts) found for the Y plane may have been due to the placement of the holes and physical task characteristics rather than visual-spatial information.

Future Work

Many changes could be implemented to improve the methods used in the present study. The ball-and-tunnel task was not sensitive to differences in primary task performance. To remedy this, the threading task could be changed to ensure that depth attentional resources are required. Artificial depth cues, such as converging lines to convey perspective convergence, could be displayed in the X and Y plane orientations to make up for the cues more naturally present in the Z plane orientation. The ball-and-tunnel task could also have an additional depth cue of balls' shadows on the wall of the tunnel.

A modification of the secondary task itself could also be useful. The ball-and-tunnel task is currently presented as a series of static images. Alternatively, the task could be made more dynamic by presenting continuously moving balls and requiring the participant to respond when the balls reach a certain position. This change would make it more difficult for participants to switch attention between the primary and secondary tasks because participants would need to focus on both tasks to provide accurate responses. In the present study, participants could have responded to the ball-and-tunnel task by relying on their visual memory after the stimuli were briefly presented. This suggests that participants could switch attention between tasks whenever convenient. However, by using continuous primary and secondary tasks, participants would be required to actively attend to both tasks to make correct responses.

There were also many problems with the laparoscopic threading task. Rather than participants performing a continuous threading task, a task could be used requiring participants to rapidly point to real or simulated objects in 3D space. The difference between these two types of tasks is that the threading task is a closed-loop task where spatial judgments are constantly adjusted as small movements are made, whereas a pointing task is a ballistic task that may provide a purer measure of quick spatial judgments. By pairing a pointing task with the ball-and-tunnel task as a secondary task, differences in attentional demand may be better observed.

CHAPTER 8

CONCLUSION

In the present study, a laparoscopic threading task was paired with a visual-spatial secondary task to measure residual attentional resources and mental workload. It was expected that secondary task performance would reflect differences in workload when performing depth or nondepth laparoscopic movements.

Poor laparoscopic performance in the Z plane and X plane can be attributed to difficulty in making depth judgments, providing support for the main hypothesis that laparoscopic depth movements are challenging. The ball-and-tunnel task was sensitive to high workload imposed by the primary task, but it was not sensitive to the differences in threading orientation. The fact that secondary task performance was much poorer under dual-task compared to single-task conditions supports the idea that laparoscopy is attentionally demanding. Primary task performance was also negatively affected by the presence of the secondary task, meaning participants' mental workload was high when they had to perform both tasks simultaneously.

The ball-and-tunnel task was developed to be a more sensitive measure of laparoscopic mental workload than the secondary task used by Stefanidis et al. (2007, 2008). There were two improvements with the ball-and-tunnel task over the squares task used previously. First, the secondary task was superimposed directly over the primary task display. Although there were no performance differences between the depth and nondepth versions of the ball-and-tunnel task, the fact that the task was superimposed over the laparoscopic display is an important methodological improvement. Recall, that Wickens' (2002) dichotomy of visual attentional resources is divided into focal and ambient/peripheral vision. Therefore, two tasks located in foveal vision should compete for similar resources. In the studies by Stefanidis et al. one cannot rule out the possibility that participants switched their gaze between two displays. In the present study, however, both tasks were located in participants' foveal vision. Thus, participants could not perform the secondary task as well in dual-task conditions as single-task conditions, suggesting the differences are due to attention and not one's visual fixation point.

The second improvement with the ball-and-tunnel task is that a depth component was added through the use of an implied tunnel. The purpose of this modification was to create a task that required the same type of depth resources that would compete with resources used in laparoscopy to make depth judgments. However, the results of the present study do not provide evidence that the resources required for the depth version of the secondary task differed from those used in nondepth version of the secondary task.

The general implications of the results are that performing laparoscopic surgery is clearly attentionally demanding. Participants had difficulty performing a laparoscopic threading task and had even more difficulty when asked to simultaneously perform a secondary task. Further, a major reason that laparoscopy is attentionally demanding is that it requires users to make 3D judgments and movements by referencing a 2D display. The use of visual-spatial resources to translate the displayed images 3D movements may be the reason that laparoscopic judgments in depth are more challenging.

To ensure that surgeons perform laparoscopic procedures without exhausting attentional resources, surgeons must be given sufficient practice to achieve proficiency. In accordance with the three phases of skill learning proposed by Fitts and Posner (1967), trainees should practice until they have reached the autonomous phase in which they are capable of carrying out procedures with little conscious effort. This would allow the surgeon to perform the procedure and still have spare attention. Further, training should be emphasized for laparoscopic depth movements so that spatial judgments can be made more quickly and accurately during genuine laparoscopic procedures.

REFERENCES

Alexander, A.L., Wickens, C.D., & Merwin, D. H. (2005). Perspective and coplanar cockpit displays of traffic information: implications for maneuver choice, flight safety, and mental workload. *International Journal of Aviation Psychology, 15*, 1 – 21. doi:10.1207/s15327108ijap1501_1

Bholat, O.S., Haluck, R.S., Murray, W.B.; Gorman, P.J., & Krummel T.M. (1999). Tactile feedback is present during minimally invasive surgery. *Journal of the American College of Surgeons, 189*, 349 – 55.

Cha, Y. & Myung, R. (2010). Extended Fitts' law in 3-D pointing tasks. *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*. (pp. 972 – 976). Santa Monica, CA: Human Factors and Ergonomics Society.

Crosthwaite, G., Chung, T., Dunkley, P., Shimi, S., & Cuschieri, A. (1995). Comparison of direct vision and electronic two- and three-dimensional display systems on surgical task efficiency in endoscopic surgery. *British Journal of Surgery, 82*, 849 – 851.

DeJong, B.P., Colgate, E. & Peshkin, M.A. (2004). Improving teleoperation: Reducing mental rotations and translations. *Proceedings of the IEEE International Conference on Robotics and Automation*, 3708 – 3714.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47,* 381 – 391.

Fitts, P. M., & Posner, M. I. (1967). *Human performance.* Belmont, California: Brooks/Cole.

Frassinetti, F., Angeli, V., Meneghello, F., Avanzi, S., & Làdavas, E. (2002). Longlasting amelioration of visuo-spatial neglect by prism adaptation. *Brain, 125*, 608 – 623.

Gallagher, A., Al-Akash, M., Seymour, N., & Satava, R. (2009). An ergonomic analysis of the effects of camera rotation on laparoscopic performance. *Surgical Endoscopy, 23*, 2684 – 2691. doi:10.1007/s00464-008-0261-x

Goldstein, E.B. (2009). *Sensation and perception, eighth edition.* Belmont CA: Wadsworth, Cengage Learning.

Gregory, R.L. (1977). *Eye and brain: The psychology of seeing.* London: Wiedenfeld and Nicolson.

Hegarty, M., Keehner, M., Cohen, C., Montello, D.R., & Lippa, Y. (2007). The role of spatial cognition in medicine: Applications for selecting and training professionals. In G. Allen (Ed.), *Applied spatial cognition* (pp. 285 – 315). Mahwah, NJ: Lawrence Erlbaum Associates.

Kahneman, D., & Tversky, A. (1973). On the psychology of prediction. *Psychological Review, 80,* 237 – 251.

Keehner, M., Lippa, Y., Montello, D.R., Tendick, F., & Hegarty, M. (2006). Learning a spatial skill for surgery: How the contributions of abilities change with practice. *Applied Cognitive Psychology, 20*, 487 – 503. doi:10.1002/acp.1198

Keehner, M., Wong, D., & Tendick, F. (2004). Effects of viewing angle, spatial ability, and sight of own hand on accuracy of movements performed under simulated laparoscopic conditions. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 1695 – 1699). Santa Monica, CA: Human Factors and Ergonomics Society.

Klatzky, R.L., Wu, B., & Stetten, G. (2008). Spatial representations from perception and cognitive mediation: The case of ultrasound. *Current Directions in Psychological Science, 17,* 359 – 364. doi: 10.1111/j.1467-8721.2008.00606.x

Korndorffer Jr, J.R., Dunne, J.B., Sierra, R., Stefanidis, D., Touchard, C.L., & Scott, D.J. (2005). Simulator training for laparoscopic suturing using performance goals translates to the operating room. *Journal of the American College of Surgeons, 201,* 23 – 29. doi: 10.1016/j.jamcollsurg.2005.02.021

Leone, G., Taine, M.C., Droulez, J. (1993). The influence of long-term practice on mental rotation of 3-D objects. *Cognitive Brain Research, 1,* 241 – 255.

Macedo, J.A., Kaber, D.B., Endsley, M.R., Powanusorn, P.A., & Myung, S. (1998.) The effect of automated compensation for incongruent axes on teleoperator performance. *Human Factors, 40,* 541 – 553.

McGee, M.G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 86,* 889 – 918.

McGreevy, M.W., & Ellis, S.R. (1986). The effect of perspective geometry on judged direction in spatial information instruments. *Human Factors, 32,* 299 – 317.

Milsom, J.W., Böhm, B., & Najajima, K. (1996). Laparoscopic Anatomy of the Abdominal Cavity. In Milsom, J.W. (Ed.), *Laparoscopic Colorectal Surgery* (pp. 97 – 110). New York: Springer Science+Business Media, Inc.

Moray, N. (1967) Where is capacity limited? A survey and a model. In A. Sanders (Ed.), *Attention and performance* (pp. 84 – 92). Amsterdam: North-Holland.

Morton, S.M., & Bastian, A.J. (2004). Prism adaptation during walking generalizes to reaching and requires the cerebellum. *Journal of Neurophysiology*, *92*, 2497 – 2509.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review*, *86*, 214 – 253.

Norman, D.A., & Bobrow, D.G. (1975). On data-limited and resource limited processes. *Cognitive Psychology*, *7*, 44 – 64.

O'Donnell, R.D., & Eggemeier, F.T. (1986). Workload Assessment Methodology. In K. Boff, L. Kaufman & J. Thomas (Eds.), *Handbook of perception and human performance, vol. II: Cognitive processes and performance* (pp. 421 – 429). New York: Wiley Interscience.

Ogden, G., Levine, J., & Eisner, E. (1979). Measurement of workload by secondary tasks. *Human Factors, 21*, 529 – 548.

Pietrzak, P., Arya, M., Joseph, J.V., & Patel, H.R.H. (2006). Three-dimensional visualization in laparoscopic surgery. *British Journal of Urology International*, *98*, 253 – 256. doi: 10.1111/j.1464-410X.2006.06287.x

Risucci, D.A., Geiss, A., Gellman, L., Pinard, B., & Rosser, J.C. (2001). Surgeon-specific factors in the acquisition of laparoscopic surgical skills. *The American Journal of Surgery, 181*, 289 – 293.

Scerbo, Kennedy, & Anderson (2011, Jan.). *Evaluation of a secondary attentional task for laparoscopy.* Poster presented at International Meeting of Simulation in Healthcare, New Orleans, LA.

Seymour, N.E., Gallagher, A.G., Roman, S.A., O'Brien, M.K., Bansal, V.K., Andersen, D.K., & Satava, R.M. (2002). Virtual reality training improves operating room performance: Results of a randomized, double-blinded study. *Annals of Surgery, 236*, 458 – 464.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, New Series, 171*, 701 – 703.

Stefanidis, D., Scerbo, M.W., Korndorffer Jr, J.R., & Scott, D.J. (2007). Redefining simulator proficiency using automaticity theory. *The American Journal of Surgery, 193*, 502 – 506. doi: 10.1016/j.amjsurg.2006.11.010

Stefanidis, D., Scerbo, M.W., Sechrist, C., Mostafavi, A., & Heniford, B.T. (2008). Do novices display automaticity during simulator training? *The American Journal of Surgery, 195*, 210 – 213. doi:10.1016/j.amjsurg.2007.08.055

Tarr, M. J., & Pinker, S. (1989). Mental rotation and orientation–dependence in shape recognition. *Cognitive Psychology, 21*, 233 – 282.

Tarr, M. J., & Pinker, S. (1990). When does human object recognition use a viewer–centered reference frame? *Psychological Science, 1*, 253 – 256.

Tendick, F., Bhoyrul, S., & Way, L. (1997). Comparison of laparoscopic imaging systems and conditions using a not tying task. *Computer Aided Surgery, 2*, 1.

Tendick, F., Downes, M., Gogtekin, T., Cavusoglu, M. C., Feygin, D., Wu, X., Eyal, R., Hegarty, M., & Way, L.W. (2000). A virtual testbed for training laparoscopic surgical skills. *Presence, 9*, 236 – 255. doi:10.1162/105474600566772

Verdaasdonk, E.G.G., Dankelman, J., Lange, J.F., & Stassen, L.P.S. (2007). Transfer validity of laparoscopic knot-tying training on a VR simulator to a realistic environment: A randomized controlled trial. *Surgical Endoscopy, 22,* 1636 – 1642. doi:10.1007/s00464-007-9672-3

Way, L. W., Bhoyrul, S., & Mori, T. (1995). *Fundamentals of Laparoscopic Surgery.* New York: Churchill Livingstone.

Wentink, M., Fischer, H., Dankelman, J., Stassen, L.P.S., & Wieringa P.A. (2002) The perspective effect due to wide-angle lenses in endoscopes. *Journal of Laparoscopic & Advanced Surgical Techniques, 12, 4*61 – 465. doi:10.1089/109264202762252776

Westebring-Van Der Putten, E.P., Goossens, R.H.M., Jakimowicz, J.J., & Dankelman, J. (2008). Haptics in minimally invasive surgery – a review. *Minimally Invasive Therapy, 17,* 3 – 16. doi:10.1080/13645700701820242

Wickens, C.D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and performance VIII* (pp. 239 – 257). Hillsdale, NJ: Erlbaum.

Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman & D.R. Davies (Eds.), *Varieties of attention* (pp. 63 – 102). New York, NY: Academic Press.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3,* 159 – 177. doi:10.1080/14639220210123806

Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance.* Upper Saddle River, NJ: Prentice Hall.

Wierwille, W.W., Rahimi, M., & Casali, J.G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing meditational activity. *Human Factors*, *27*, 489 – 502.

Wu, B., Klatzky, R. L., & Stetten, G. (2010). Visualizing 3D objects from 2D cross sectional images displayed *in-situ* versus *ex-situ*. *Journal of Experimental Psychology: Applied, 16*, 45 – 59.

Zheng, B., Cassera, M.A., Martinec, D.V., Spaun, G.O., & Swanström, L.L. (2010). Measuring mental workload during the performance of advanced laparoscopic tasks. *Surgical Endoscopy, 24*, 45 – 50. doi: 10.1007/s00464-009-0522-3

APPENDIX A

INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: **Assessment of Mental Workload during Laparoscopic Skill Acquisition on a Virtual Reality Simulator**

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The title of this research study is Project LapSkill. This research is being conducted in partial fulfillment of the requirements for the degree of Ph.D. in Human Factors Psychology.

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DESCRIPTION OF RESEARCH STUDY

Laparoscopic surgery is a type of surgery that is performed by inserting a small camera and surgical instruments through small incisions in the body. This technique is generally safer for the patient, but often more difficult for the surgeon to perform. Therefore, computer-based simulators are now being used to help surgeons acquire laparoscopic skills.

If you decide to participate, then you will be one of approximately 80 undergraduate students involved in a study designed to improve current methods for training future laparoscopic surgeons using a computer-based simulator. You will be instructed in how to perform several simulated surgical tasks on the computer using simulated surgical tools and a foot pedal and then given time to practice those tasks. In addition, you will be asked to perform another task that requires you to identify different targets in different areas of your display. Afterward, you will also be asked to complete two brief questionnaires that ask you to rate the ease or difficulty of the tasks. The total amount of time for participation is approximately two hours.

EXCLUSIONARY CRITERIA

In order to participate in this study you should not have any problems with your ability to:

- Physically use your right leg and right foot to press a foot pedal periodically
- Physically use both your right and left hands to interact with the simulated surgical instruments

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of slight physical fatigue. Both your arms and hands may become tired from interacting with the simulator instrument device. The researchers have tried to reduce these risks by incorporating frequent breaks and resting periods. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: The main benefit of participating in this study is the opportunity to learn how a surgical simulator is used for developing basic laparoscopic skills. The combined task conditions provide an increase in difficulty that makes the experience more challenging as is often done in most computer games. The difference between the single and combined conditions will help to establish objective measures of proficiency for laparoscopic skills.

COSTS AND PAYMENTS

The researchers are unable to give you any monetary payment for participating in this study. However, you will receive 2 Psychology department research credits, which may be applied to course requirements or extra credit in certain Psychology courses. Equivalent credits may be obtained in other ways, such as conducting library reports and online surveys. You do not have to participate in this study, or any Psychology Department study, in order to obtain this credit.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

The researchers will take reasonable steps to keep private information, such as questionnaires and laboratory performance and findings confidential. The researchers will remove all identifying information from questionnaires and store all data in a locked filing cabinet prior to its processing. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study – at any time. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation. If at any point during the study you wish to stop, simply tell the researcher and you will not be penalized in any way. Any data that has already been collected will be destroyed and will not be included in the final analysis.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact the Faculty research advisor, and responsible principle investigator at 757-683-4217 or Dr. George Maihafer the current IRB chair at 757-683-4520 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Student Researcher:	Rebecca A. Kennedy	rkenn014@odu.edu	518-423-3226
Faculty Advisor:	Mark W. Scerbo, Ph.D.	mscerbo@odu.edu	757-683-4217

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	**Date**

APPENDIX B

PARTICIPANT BACKGROUND INFORMATION FORM

Participant #:______ Group:______ Date:______ Time:______

The purpose of this questionnaire is to obtain background information on the participant that will be used for research purposes only.

1. Age______

2. Gender______

    0 = Female

    1 = Male

3. Do you have normal or corrected-to-normal vision?______

    0 = Yes

    1 = No

4. What is your dominant hand?______

    0 = Right

    1 = Left

    2 = Ambidextrous

5. Do you play video games?_______

    0 = Yes

    1 = No

    If yes: how many hours, on average, do you play each week?______

VITA

Rebecca A. Kennedy
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EDUCATION:

Old Dominion University, Norfolk, VA
Human Factors Doctoral Student May 2014 (Expected)

Old Dominion University, Norfolk, VA
Masters of Science in Experimental Psychology December 2011

State University of New York College at Oneonta, Oneonta, NY
Bachelors of Science (Cum Laude) May 2009

PROFESSIONAL EXPERIENCE:

Graduate Research Assistant August 2009 - present
Supervisor: Dr. Mark W. Scerbo, Ph.D.
Old Dominion University
Psychology Department
Norfolk, VA 23529

Master's Thesis
Kennedy, R.A. (2011). The effect of depth judgments on mental workload in laparoscopy measured by a visual-spatial secondary task. Unpublished master's thesis. Old Dominion University, Norfolk, VA.

PEER-REVIEWED PAPERS PUBLISHED AT PROFESSIONAL MEETINGS:

Kennedy, R.A., Anderson-Montoya, B.L., Scerbo, M.W., Belfore II, L.A., Abuhamad, A.Z., Davis, S.S., & Chauhan, S.P. (April, 2012) *A visual aid as a cue for the detection of critical signals in simulated maternal-fetal heart rate patterns.* Presented at the Virginia Modeling, Analysis, and Simulation Center Student Capstone Conference, Suffolk, VA.

Prytz, E., Scerbo, M.W., & **Kennedy, R.A.** (September, 2011). *Spatial judgments from different vantage points: A different perspective.* Presented at the 55th Annual Meeting of the Human Factors and Ergonomics Society, Las Vegas, NV.

Kennedy, R. A. & Kennedy, K. D. (April, 2011). *An improved virtual operating room training scenario model.* Presented at the Virginia Modeling, Analysis, and Simulation Center Student Capstone Conference, Suffolk, VA.

Kennedy, R. A. & Scerbo, M. W. (April, 2010). *Mental workload in simulated laparoscopy.* Presented at the Virginia Modeling, Analysis, and Simulation Center Student Capstone Conference, Suffolk, VA.

POSTERS PRESENTED AT PROFESSIONAL MEETINGS:

Anderson-Montoya, B.L., **Kennedy, R.A.**, Scerbo, M.W., Belfore II, L.A., Abuhamad, A.Z., Davis, S.S., & Chauhan, S.P. (March, 2012) *A simulator for fetal heart rate monitoring.* Poster and demonstration presented at Symposium on Human Factors and Ergonomics in Health Care, Baltimore, MD.

Prytz, E.G., Montano, M., **Kennedy, R.A.**, & Scerbo, M.W. (March, 2012) *A secondary task for measuring mental workload in simulated laparoscopy.* Poster and demonstration presented at Symposium on Human Factors and Ergonomics in Health Care, Baltimore, MD.

PEER-REVIEWED ABSTRACTS PRESENTED AT PROFESSIONAL MEETINGS:

Kennedy, R.A. & Scerbo, M.W. (2011). Initial laparoscopic performance: Impoverished visual-spatial cues compromise movements in the depth plane. *Simulation in Healthcare, 6,* 798.

Anderson-Montoya, B.L., Scerbo, M.W., **Kennedy, R.A.**, Belfore II, L.A., Abuhamad, A. Z., Davis, S.S., & Chauhan, S. P. (2011). Critical signal detection during multiple patient monitoring of fetal heart rate tracings. *Simulation in Healthcare, 6,* 410.

Scerbo, M. W., **Kennedy, R.A.**, & Anderson, B. L. (2010). Evaluation of a secondary attentional task for laparoscopy. *Simulation in Healthcare, 5,* 445.

PANEL DISCUSSIONS:

Kennedy, R.A. (October, 2011). *Measuring mental workload in simulated laparoscopy.* On panel "Understanding Cognitive Challenges Faced by Healthcare Providers" at ModSim World Conference & Expo, Virginia Beach, VA.

COMPUTER EXPERIENCE:

Microsoft Windows
Microsoft Office
Macintosh Computer
Statistical Package for the Social Sciences (SPSS)
Blackboard
SONA
Adobe Connect
C++ (entry-level)

CERTIFICATIONS:

Modeling and Simulation (M&S) in Human Factors Certificate, sponsored by Old Dominion University

Human Participants Protection Education for Research Teams, sponsored by National Institute of Health (NIH)

Research Ethics Basic Course Certification, sponsored by Collaborative Institutional Training Initiative (CITI)

PROFESSIONAL AFFILIATIONS:

Human Factors and Ergonomics Society (HFES)
HFES Health Care Technical Group
HFES Virtual Environments Technical Group
HFES Product Design Technical Group
ODU Human Factors and Ergonomics Society Student Chapter
Society for Simulation in Healthcare
The National Honor Society in in Psychology (Psi Chi)

ADMINISTRATIVE POSITIONS:

ODU HFES Secretary 2009 - 2012

HONORS AND AWARDS:

Research Abstract 4th Place Winner at 12th Annual International Meeting on Simulation in Healthcare (January, 2012)

Recognition of Outstanding Paper at VMASC Capstone Conference (April, 2011)

Susan Sutton Smith Award for Scholarship and Excellence (May, 2009)

Oneonta Psychology Departmental Honors (May, 2009)

Oneonta's Best and Brightest (Fall 2008)