The Effects of a Multi-View Camera System on Spatial Cognition, Cognitive Workload and Performance in a Minimally Invasive Surgery Task

by

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ABSTRACT

Minimally invasive surgery is a surgical technique that is known for its reduced patient recovery time. It is a surgical procedure done by using long reached tools and an endoscopic camera to operate on the body though small incisions made near the point of operation while viewing the live camera feed on a nearby display screen. Multiple camera views are used in various industries such as surveillance and professional gaming to allow users a spatial awareness advantage as to what is happening in the 3D space that is presented to them on 2D displays. The concept has not effectively broken into the medical industry yet. This thesis tests a multi-view camera system in which three cameras are inserted into a laparoscopic surgical training box along with two surgical instruments, to determine the system impact on spatial cognition, perceived cognitive workload, and the overall time needed to complete the task, compared to one camera viewing the traditional set up. The task is a non-medical task and is one of five typically used to train surgeons' motor skills when initially learning minimally invasive surgical procedures. The task is a peg transfer and will be conducted by 30 people who are randomly assigned to one of two conditions; one display and three displays. The results indicated that when three displays were present the overall time initially using them to complete a task was slower; the task was perceived to be completed more easily and with less strain; and participants had a slightly higher performance rate.

ACKNOWLEDGMENTS

I would like to thank Kevin Ten Brink, a Human Factors Engineer at Intuit Surgical for taking the time to talk with me during my early months of research. His expertise and familiarity with robotic surgery helped me narrow my research scope and put me on the path of minimally invasive surgery.

I would like to thank Todd Tripoli, a Simulation Systems Technician at the Mayo Clinic Hospital in Phoenix for allowing me to meet with him and take a tour of the simulation room. His experience with laparoscopic training and surgical training boxes allowed me to grasp a better understanding of what a training box must have and helped me initially brainstorm how to build my own training box to save on money and allow the manipulations that my experiment called for. Tripoli was also the one who introduced me to the FLS peg transfer task.

I would like to thank Dr. Victor Davila, MD and Dr. David Pearson, MD of the Mayo Clinic Hospital in Phoenix for taking the time out of their day as well to talk to me during the experimental design portion of my research. Their expertise and experience with performing minimally invasive surgery in the operating room helped define my project and find the cognitive research gaps in within current minimally invasive surgery research. During my time with them I was able to distinguish between the assumptions I had made while reading the literature and the true problems and research gaps of the industry. From this conversation my research questions for this study emerged.

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CHAPTER 1

INTRODUCTION

Background

Minimally invasive surgery was developed just under four decades ago as a revolutionary surgical technique intended to better meet the needs of the patient. It was widely accepted based on the proof that it allowed for shorter hospital stays, smaller incisions, decreased the risk of infection, and significantly reduced recovery time (Lanfranco *et al*., 2004). Minimally invasive surgery is performed though using thin long-reached instruments that are fitted with various tools at the end for specific tasks such as cutting, grasping, and sewing. These instruments are inserted into small incisions made in the body. Since the surgical site cannot be seen directly by the human eye a small camera is inserted into the body through another incision. The camera's live feed is displayed on a nearby screen for the surgeon and their team to work from. In general, minimally invasive surgery also known as endoscopy is conducted with three incisions, two of which are occupied by surgical instruments, and the middle incision of the three occupied by an endoscopic camera. The camera is most often placed in the middle incision since it lines up with how humans normally perceive the world; the eyes being located between the hands of the body (Dr. Victor Davila, personal interview). The placement of these incisions is dependent on the type of surgery performed. The technique can be applied to various areas of the body but the most common location and the location being addressed through this study is the abdomen. The term laparoscopy is used to denote minimally invasive surgery that is performed within the abdomen region.

Please note that in this study the terms minimally invasive surgery and laparoscopic surgery were used interchangeably.

Since the early 1980's, advancements such as robotic surgical systems, which stemmed off the process of minimally invasive surgery, have quickly become a common practice and gained the attention of researchers across the globe. Surgical robots have already created a lasting impact and continue to influence current practices witnessed in the operating room and within hospital residency training programs. A surgical robot as defined by expert healthcare organizations is an electromechanical device placed in between a surgeon and a patient that has the capability to assist via computer calculations (Nejat *et al*., 2009). Though surgical robots are proven to have more control and accuracy over surgical instruments, problems surrounding human cognition and visual perception still persist. This is why recent research surrounding surgical robots look at training, haptic feedback, and camera depth perception. Each of these research areas can be traced back to what is lost when direct visual contact is not made between the surgeon and the surgical site where the operation is taking place. Since surgical robots and robotic surgery stemmed from minimally invasive surgical techniques where the idea of a camera was first introduced, everything learned in terms of cognitive workload by those performing simple laparoscopic tasks can be translated to more complex robotic surgical procedures.

Multi-View Systems

Multiple camera views have recently become an option for surveillance companies, sporting events, and video games. The idea behind having multiple camera views is to increase the spatial awareness of the environment of a viewer allowing them to see all aspects of a 3D environment from a 2D representation. Currently in the healthcare industry multiple views have been used in computer-aided design (CAD) imaging of breast abnormalities to discriminate cancerous patients (Velikova *et al*., 2009) and used to capture surgical training videos for classroom use (Rosser *et al*., 2007). Multiple viewpoints have been proven to increase performance of a task significantly. Not only are humans seeing advantages of having more viewpoints, but research shows robots are too. With broader scopes and more 3D information, a computer system can detect more shape relations leading to an increase in performance compared to a single view camera system (Enochsson *et al*., 2004).

Video game research specifically has shown that multiple viewpoints can help a human increase their spatial perception. Research has also been done that directly correlates computer gaming experience with higher endoscopic simulation performance in novice users (Enochsson *et al*., 2004). If this is the case then why are multi-view camera systems not currently being used in the medical field, specifically within minimally invasive surgery? The reason is due to patient safety. Until research has been conducted justifying the need for insertion of another camera there is no reason to do so. Questioning the endoscopic camera within minimally invasive surgery to increase the complexity of surgeries that can be done and lower the learning curve for surgical residents has been the latest research interest. To date prior research has sought to solve the depth perception issue lost when open surgery turns into endoscopic surgery by finding ways to redesign a singular camera. This study takes a different approach. Rather than looking at the camera itself, this study was designed to look further back to identify why losing depth perception is an area of concern. This study raised the questions regarding the spatial cognition of the surgeon performing the surgery and how a multi-view camera system would affect it.

CHAPTER 2

LITERATURE REVIEW

The Problem with Depth Perception

Currently, prior research has been done to look at 3DHD cameras, endoscopic cameras with coarse and local view attachments, and virtual reality simulators. Visual perception and spatial awareness are currently the biggest problem researchers are trying to solve regarding the loss of depth perception. Research based improvements such as the display monitor location being placed front and center in line with the user as being the most effective for human performance have been identified and now represent the standard configuration for minimally invasive surgery. Evidence that monitors placed on a surgeons dominant-hand side decrease the performance overall also has emerged in research but there is little data to support this hypothesis (Hernandez *et al*., 2014). Questions still remain about how screens placed on the non-dominate hand side of the surgeon affect the overall performance. More studies must be conducted that look at screen display placement within the operating room with respect to the location of the surgeon conducting the operation.

Other ways researchers have thought to combat the loss of depth perception is by introducing a new surgical technique that imports video images in image-guided surgery. This idea according to the researchers still does not allow surgeons to operate in an environment with as little side effects and as maximum patient outcome that minimally invasive surgery gives (Bogdanova *et al*., 2016).

Visual Perception

According to research it has also been found that hand motions made during minimally invasive surgical procedures stem from spatial planning and visualization of the user rather than their hand dexterity skill level. This specific article then goes on to confirm based on their results that high-level of visual spatial ability correlates positively with performance and quality of spatially complex surgical procedures (Wanzel *et al*., 2003).

Research on university students and dexterity can continually be found to support the conclusion stated above. Even previous medical experiences and self-assessments of dexterity by participants do not significantly correlate with hand dexterity in medical suturing skills (Hughes *et al*., 2014). In contrast high dexterity does not mean that it is not predictive of initial surgical performance. People with high hand dexterity will perform better in initial surgical tasks when compared to a person with lower dexterity however hand dexterity is independent from previous medical training and or interest in pursuing a medically related field (Lee *et al*., 2012).

Overall as minimally invasive surgical techniques continue to grow in popularity among surgeons and surgical robots begin to be more common in the operating room continuous research efforts regarding surgeon’s behaviors and interactions with visualization technologies must be conducted (Bogdanova *et al*., 2016). The best way to study a surgeon's behavioral responses is to conduct studies on the cognitive workload of their work environment (Bogdanova *et al*., 2016).

This study employed a multiple camera view system in which three cameras are inserted into a laparoscopic training box along with two surgical instrumentations to attempt to confirm the hypothesis that multiple viewpoints will be a way to address the current research gaps regarding depth perception, visual spatial ability, and training programs to reduce the learning curve. The hypothesis was that having three live camera feeds of the surgical site would reduce the overall time needed to perform the surgical task, would reduce the perceived cognitive workload when performing the task itself, and would increase the spatial cognition of the surgeon when performing surgery compared to the traditional single camera feed. If these three things can be achieved or even proved to be beneficial then there is an opportunity for more research to be done to determine if a multiple viewpoints of the surgical site could change the way minimally invasive surgery is conducted and or pave the way for robotic surgery to gain features that go beyond human capabilities, allowing for an increase in patient safety and potentially more complex surgeries to be done.

CHAPTER 3

METHODS

Design

The data identified that is needed to evaluate whether multiple displays used during minimally invasive surgery is a viable option cognitively, for surgeons, fall into the categories of time, errors, perceived workload, and spatial awareness.

The data to address each of these categories was collected through an online mental rotation test, observations, a perceived workload tool (NASA TLX), and a paper survey regarding spatial awareness and dexterity. Each measurement was individually analyzed and compared to the study's hypothesis to come to a final conclusion. The experiment was a between subjects design with two groups of participants that were placed equally and randomly into each respective group. A between subjects design was the best method to use for this experiment because it allowed all participants to complete the exact same task and simplified the overall experimental procedure by allowing for two participant groups instead of the four groups it would have needed for a randomized within subjects design. A between subject design also limited the time participants were in the study along with the number of surveys they needed to take. To cover any individual bias that may have occurred between the two participant groups activity questions were asked in the paper survey along with administering an online mental rotation test, see appendix A and C respectfully.

Measures

The mental rotation test is a 15-question online survey given at the start of the experiment. The survey is a part of the online research bank Psychology Tool Kit. All 15 questions, which include 5 practice trials and 10 testing trials, were the same and given in a different order each time. From this test a percentage of the number of correct testing trials for which the participant was successful out of 10 trials was recorded. This number served as a comparison between the one camera condition and the three camera condition to determine if performance was related to spatial perception abilities.

Observations were collected by the experimenter after the task had begun. The overall task time was collected using a stopwatch and the overall errors were kept track of using the experimental data collection sheet found in Appendix D. Errors consisted of the number of objects dropped and recovered in the task, as well as number of objects dropped and lost. In order for an object to be considered dropped verses lost the participant would have to have been able to recover it by simply being able to grasp it and pick it back up again.

Perceived workload was calculated immediately after the task is completed by the participant through a paper and pen copy of the NASA TLX. This survey is comprised of six Likert scales that assess the user's perception of the following categories; mental demands, physical demands, temporal demands, own performance, effort, and frustration. From these six self-assessed scales a workload index value was calculated. Pairwise comparisons were not given leading to no weighted scales making the data collected raw NASA TLX data. This paper and pen copy served as the first of a two page survey given to the participant to take, it can be viewed in Appendix B.

The second page of the paper survey handed out to participants following the completion of the experimental task listed questions to address both prior research stating that there may be reason to believe only a second screen located opposite of the dominate hand verses 3 screens would be beneficial (Hernandez *et al*., 2014), and to see if the participant could acknowledge and retain information from the task environment that they were not focused upon. Such questions inquired about percentage of time each screen was used, the layout of the pegboard used during the task, and percentage of time they allude for certain activities in their day to day life. All questions can be read in Appendix C.

Participants

The participants for this study were college students; however a large focus was placed on recruiting freshman undergraduate level students attending Arizona State University through the school's SONA system. The SONA system allows students to get research credit for courses they are taking by signing up to be a participant in a research study being put on by a graduate student at the same university. All participants were 18 years or older thus eligible to participate in the study. There was no upper age cut off and students of all socio-economic backgrounds were welcomed. The language for this study was English making it the language the participants needed to have been able to speak and read fluently. It is important to note that this study is being applied to the medical field, but the task, test, and surveys participants were asked to do required no medical knowledge. Medical experience was not needed because the experiment was designed to test the cognitive ability and visual perception of the participant rather than their medical knowledge. Any prior experience with in minimally invasive surgical training would have caused an effect in the data analysis making students with no medical knowledge highly desired. If a participant was to have shown exemplary skills during the peg transfer task and confirmed heavy exposure to the medical field their data would have been excluded from the study. It is important here to note that participants were given a brief overview of minimally invasive surgery through a short PowerPoint presentation and were given a chance to familiarize themselves with the mock medical tools that they would be using to conduct the pegboard transfer task. A random number generator divided thirty participant slots equally into each of the two categories. This randomized condition list was used for the duration of the study. As participants showed up for the study they were automatically slotted into a condition assigned as the next condition to be ran by the system.

Materials

The number of camera views presented to the participant was the independent variable. This number was either 1 or 3 depending on the condition. The single screen acted as a control for the study since it directly stimulates current technology and procedures being used in minimally invasive surgery. The single camera view display was set up in the center of a right and left display, focused directly at the center of the surgical site from above the horizon. The cameras that were manipulated, making up the other two screens in the tri-view condition were the left camera and the right camera. The displays for these camera feeds were placed next to the center camera view display. The three displays were never moved over the course of the data collection; the left and right cameras were simply turned off during the one camera condition as seen in Figure 1 denoted by the black screens. The task the participants performed inside the laparoscopic training box was the peg transfer task that is used by the Fundamentals of Laparoscopic Surgery (FLS) training program. The peg board has a white base with black, metal posts and comes with six silicone triangle pegs that can be placed on and off each of the posts. See figure 2 for a picture of what the peg board looks like.

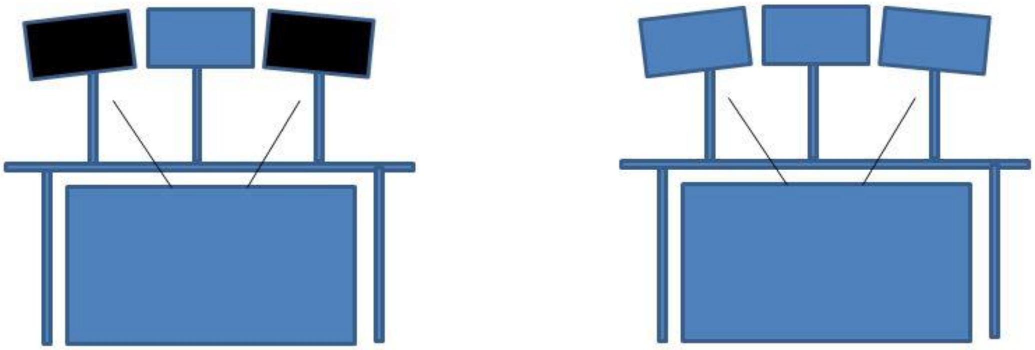


Figure 1. Experiment Setup Configuration

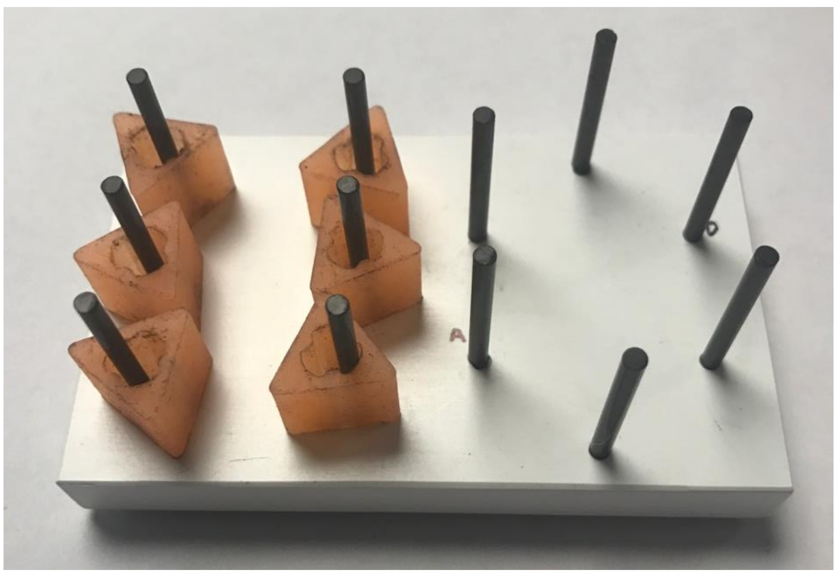


Figure 2. FLS Peg board

Procedure

When participants arrived the day of the study the experimenter checked that they were the correct individual as the reserved timeslot showed before escorting them into the lab. The participants were then handed the consent form and asked to read it in its entirety. Once finished, the experimenter asked if they wished to participate in the research study. If they confirmed yes, they moved into the mental rotation online test that was set up on a computer within the lab. The completion of the online mental rotation test confirmed the participant's participation in the study. At this time during the study data from the online test was recorded on the Experimental Data Collection Sheet. Once the data was recorded and the detailed data output from the mental rotation test had been revealed. The experimenter minimized that application and navigated the participant to a PowerPoint presentation containing the experiment instructions and introduction to minimally invasive surgery at a basic, diagram level. Next the participant was prompted to familiarize themselves with an extra-long-reached grasper that will be used to conduct the task for a few minutes. In the process the participant was allowed ask any clarifying questions about the task. Once the participants felt comfortable with the grabber and had read through the entire PowerPoint presentation they were escorted to the experimental laparoscopic training box set up in the room. Once they were ready to begin, the experimenter turned on the light and camera(s) in the laparoscopic surgical training box and instructed the participant to begin when ready. At this time in the process a stopwatch was started and the experimenter monitored the screens taking note of how many times a triangle shaped object manipulative from the task was dropped and recovered or lost. As the participant placed the last triangle on the peg of the peg transfer task and released their hands from the tools the stop watch was stopped and the time was recorded by the experimenter on a sheet of paper. The peg transfer task was conducted exactly the same way in this experiment as how it is written in the FLS training instruction manual (Fried and Program, 2014). Once the participant finished the peg transfer task and all remaining data has been collected on the Experimental Data Collection Sheet (Appendix D) the experimenter then instructed the participant to take a seat again where they were for the mental rotation online test. Next the participant was given a two page survey containing both the NASA TLX Rating Scales and the survey questions found in appendixes B and C respectfully. The experimenter prompted the participants to complete all questions on the survey being handed to them. Once the participant had completed the survey the experimenter collected it and concluded the study by debriefing what happened during their time. It was reiterated to the participant that they should expect course credit in the following days from the SONA system and who they could contact if they have any further question. If they chose compensation then they were paid by the experimenter for their time. Then the participant was thanked and escorted out of the experimental testing room.

Due to the nature of the set-up conditions were prefixed and reset between each experiment. That means the experimenter needed to reset the peg transfer task if any triangles should have been lost, return the PowerPoint presentation to the beginning slide, turn on or off the left and right camera according to condition which the participant had been randomly assigned to, and prepare a new survey. The experimenter also needed to go back to the minimized mental rotation online test detailed data and copy it over into a Microsoft Excel file and save it next to the Participants ID number before resetting the online test.

Figure 3: Constructed Laparoscopic Training Box

CHAPTER 4

RESULTS

The data analysis consisted of a mixture of comparing averages, medians, and modes for multiple sets of the data for each of the two groups. The design of the study is a between subjects design leaving no way for a trend to emerge throughout the full data collection.

Mean, Median and Mode are defined as follows. Mean is the sum of all the data in a group divided by the quantity of data in the group. The median is the middle most value within a data group and the mode is the data value with the highest frequency in a given set of data. The reason all three types of averages will be addressed throughout the data collections is due to how the outliers of the data collected affect the mean of the data.

This can be seen clearly within the data as mean and median values are compared against statistical p values and independent t-test results.

A series of independent t-test, correlations and chi-square analyses were used to analyze the various mean values obtained in the data collection to compare the one camera and three camera conditions.

Table 1:

Comparison of Average Task Time, Objects Dropped, and Objects Lost

	One Camera Condition	Three Camera Condition
Mean Overall Task Time (seconds)	453.22	612.51
Mean Object Drops	3.97	4.67
Mean Objects Lost	0.80	0.53

Table 2:

Comparison of the Median for Task Time, Objects Dropped, and Objects Lost

	One Camera Condition	Three Camera Condition
Median: Overall Task Time (seconds)	401.4	493.0
Median: Objects Drops	3.00	3.00
Median: Objects Lost	1.00	0.00

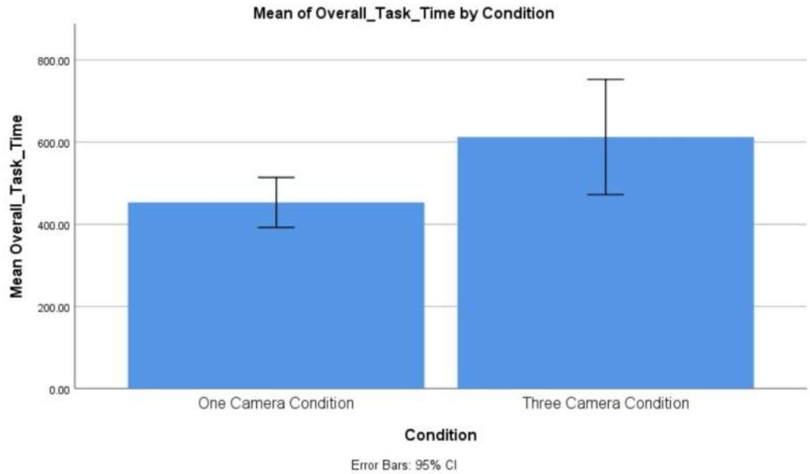


Figure 4: Mean Overall Task Time

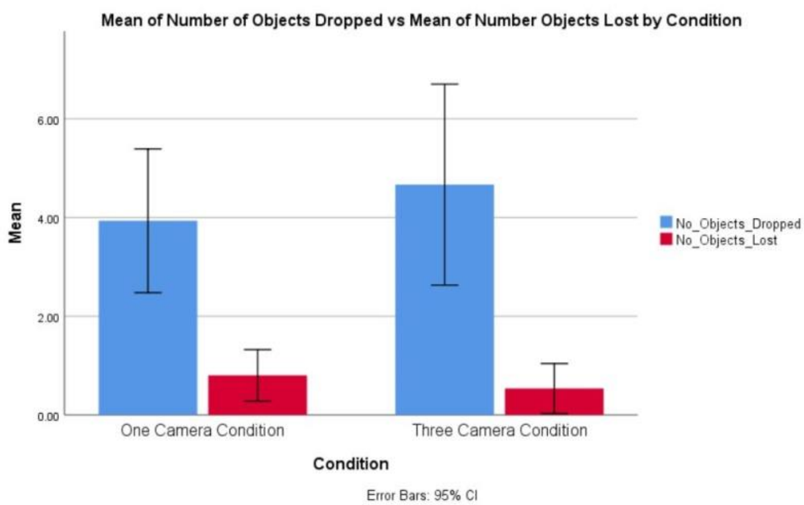


Figure 5: Mean Number of Dropped and Lost Objects

Table 1 above shows the mean overall time taken by the participant to complete the peg transfer task, the average number of object drops within that time, and the average number of objects lost. Table 2 showcases the same dependent variables reporting the median values for each group instead. The tables are broken up into two conditions. The first is a one camera condition which had a single-view camera display, located in the center of the system, while the three camera condition refers to the group that used a tri-view camera system to perform the peg transfer task.

Participants in the tri-view condition (N = 15) took longer to complete the FLS peg transfer task (M = 612.15; SD = 253.23 seconds) than those in the single-view condition (N = 15; M = 453.22; SD = 109.8) An independent samples t-test indicates that this difference is statistically significant t(28) = -2.24, p = 0.02. Cohen's effect size value (*d* = 0.85) suggested a large practical significance.

Participants in the tri-view condition (N = 15) dropped a higher number of objects when performing the peg transfer task (M = 4.67; SD = 3.67 objects) than those in the single-view condition (N = 15; M = 3.93; SD = 2.63). An independent samples t-test indicates that this difference is not statistically significant t(28) = -0.63, p = 0.54, *d* = 0.24.

Participants in the tri-view condition (N = 15) lost a lower number of objects when performing the peg transfer task (M = 0.53; SD = 0.91) than those in the single-view condition (N = 15; M = 0.8; SD = 0.94). An independent samples t-test indicates that this difference is not statistically significant t(28) = 0.79, p = 0.44, *d* = 0.3.

Table 3:

Comparison of Raw NASA TLX Averages

	Overall	One Camera Condition	Three Camera Condition
Effort	75.50	79.67	71.33
Mental Demands	68.67	72.00	65.33
Physical Demands	54.67	57.67	51.67
Temporal Demands	50.00	54.33	45.67
Frustration	47.33	51.00	43.67
Own Performance	38.00	44.33	31.67
Workload Index	55.69	59.83	51.56

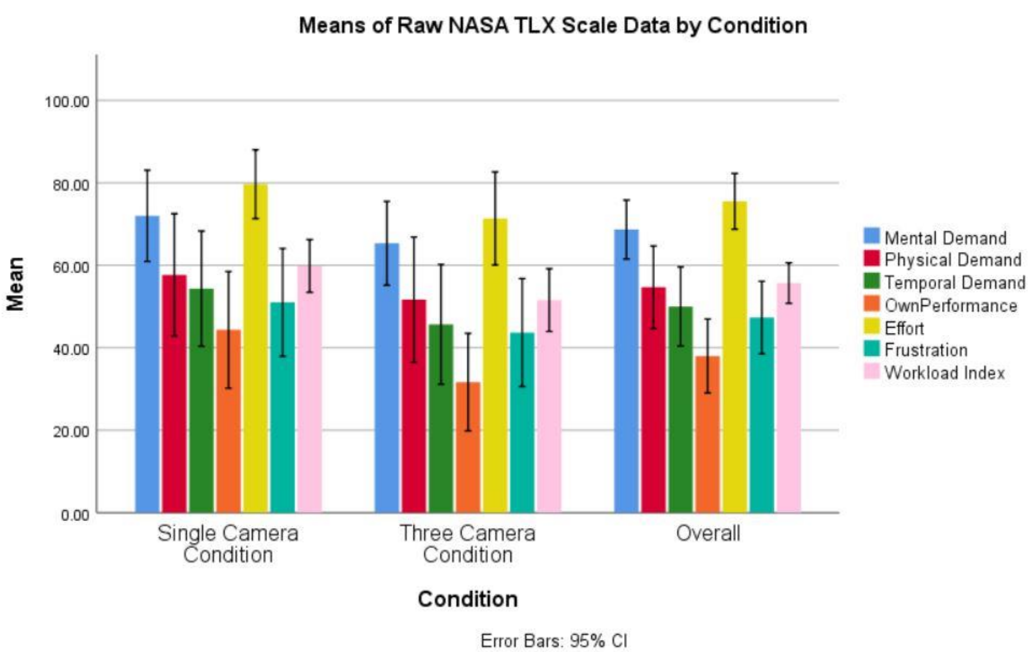


Figure 6: Mean NASA TLX Scale Data

Table 3 shows the data populated by the NASA TLX that participants took immediately following the conclusion of the peg transfer task. For each of the six ranking scales, denoted in the first column, a definition was printed asking a clarifying question to help participants identify how they should rate that category. See Appendix B for a copy of the NASA TLX rating scales used. A raw analysis was conducting meaning that no weighted scores were added to the scales value before calculating the workload index. The mean was calculated for each scale individually for one camera condition, the three camera condition, and the overall data set. The workload index was calculated by first averaging the values for each of a participant's six scale rankings and then taking all the workload index values and averaging them together to get an overall score.

An independent samples t-test was performed on each of the subscales; mental demand, physical demand, temporal demand, personal performance, effort, and frustration. An independent samples t-test was also performed on the overall perceived workload index to test the hypothesis that the three camera condition had a significantly lower perceived cognitive workload than the one camera condition.

Participants in the tri-view condition ($N = 15$) perceived the mental demand of the peg transfer task to be less ($M = 65.33$; $SD = 18.37$) than those in the single-view condition ($N = 15$; $M = 72$; $SD = 19.82$). An independent samples t-test indicates that this difference is not statistically significant $t(28) = 0.95$, $p = 0.35$, $d = 0.36$.

Participants in the tri-view condition ($N = 15$) perceived the physical demand of the peg transfer task to be less ($M = 51.67$; $SD = 27.43$) than those in the single-view condition ($N = 15$; $M = 57.67$; $SD =26.78$). An independent samples t-test indicated that this difference is not statistically significant $t(28) = 0.61$, $p = 0.55$, $d = 0.23$.

Participants in the tri-view condition (N = 15) perceived the temporal demand of the peg transfer task to be less (M = 45.67; SD = 26.25) than those in the single-view condition (N = 15; M = 54.33; SD = 25.204). An independent samples t-test indicated that this difference is not statistically significant $t(28) = 0.92$, $p = 0.36$, $d = 0.35$.

Participants in the tri-view condition (N = 15) perceived their overall performance in the task to be easier (M = 31.67; SD = 21.35) than those in the single-view condition (N = 15; M = 44.33; SD = 25.56). An independent samples t-test indicated that this difference is not statistically significant $t(28) = 1.47$, $p = 0.15$, $d = 0.56$.

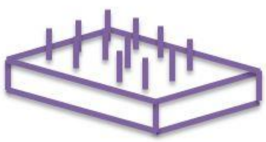
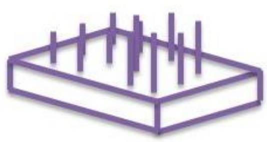
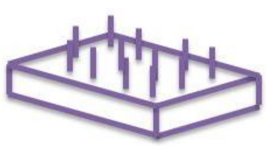
Participants in the tri-view condition (N = 15) perceived to use less effort when performing the peg transfer task (M = 71.33; SD = 20.4) than those in the single-view condition (N = 15; M = 79.67; SD = 15.06). An independent samples t-test indicated that this difference is not statistically significant $t(28) = 1.27$, $p = 0.21$, $d = 0.48$.

Participants in the tri-view condition (N = 15) perceived less frustration associated with performing the peg transfer task (M = 43.67; SD = 23.64) than those in the single-view condition (N = 15; M = 51; SD = 23.62). An independent samples t-test indicates that this difference is not statistically significant $t\ (28) = 0.85$, $p = 0.4$, $d = 0.32$.

Participants in the tri-view condition (N = 15) had a lower workload index score (M = 51.56; SD = 13.74) than those in the single-view condition (N = 15; M = 59.83; SD = 11.53). An independent samples t-test indicates that this difference is not statistically significant $t(28) = 1.79$, $p = 0.09$, $d = 0.68$.

Table 4:

Comparison of Spatial Cognition Survey Question: Which Pegboard Was Used?

	Total Number of Participants That Answered …	One Camera Condition	Three Camera Condition
A (Correct Answer) 	20	9	11
B 	3	3	0
C 	6	3	3
D 	1	0	1

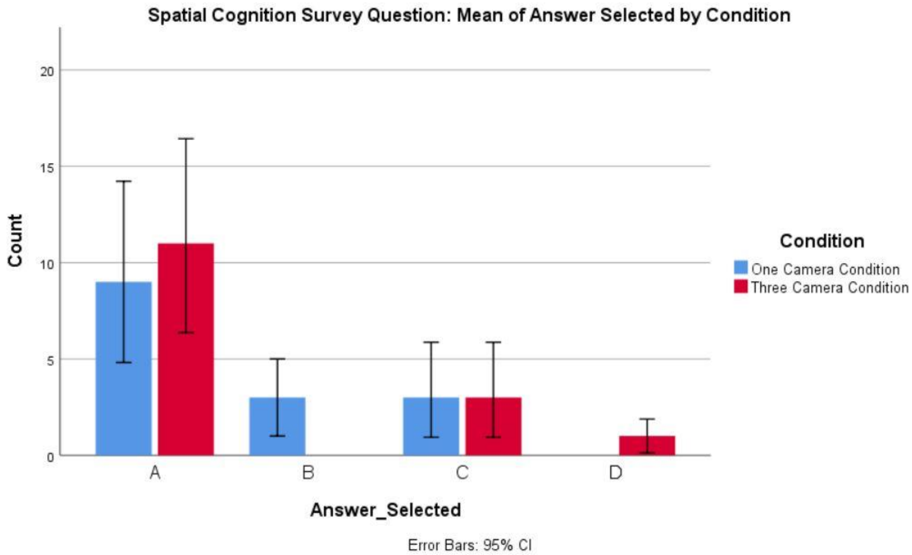


Figure 7: Spatial Cognition Question – Means for Answers Given

Table 4 shows the breakdown of participants' answer to one of the spatial cognition questions placed in the paper survey. In this question participants were asked to choose the pegboard they just used to perform the task of transferring triangles back and forth from the left to the right-hand side of the board. This question was a multiple-choice question. The graphics show how each pegboard differs slightly with rows or a circle formation on the left half of the board and the height of the pegs.

In the first row, first column the number 20 indicates that twenty participants out of thirty answered A, which was the correct answer. This means that overall in both conditions participants were able to recognize the correct orientation of the object at the surgical site as well as was able to pick up on some depth perception cues to choose the one of the boards with all the same height pegs. Out of these twenty participants, nine had access to one camera while eleven had access to three camera views of the surgical site. A small preference towards three cameras being able to use the different angles to gain some depth perception back is shown. In the second row the data shows that only three out of thirty participants chose the correct orientation of the board but failed to distinguish that the posts were all the same size. All three of these participants had access to one camera view. The third row of table three shows that six out of thirty participants choose the wrong orientation of the board but were able to distinguish the height difference. This is the second highest category and the data was split between both experimental groups. Finally, in row four is shown the peg board that has both the wrong orientation and wrong peg heights. Only one participant chose this answer out of thirty and they happened to belong to the tri-view camera condition. A chi-square test was conducted and the results showed that there was no significant difference between the number of correct and incorrect answers given between the two conditions.

A chi-square test of independence was performed to evaluate the relationship between experimental condition and the number of correct verses incorrect answers given. No interaction was found between condition and number of correct answers $x^2(1) = 0.6$, $p > 0.05$. The effect size for this finding, Cramer's V, was small, 0.14. There was no significant difference in the number of correct answers verses incorrect answers given between each condition.

Table 5:

Comparison of Prior Activity Involvement: Percentage of Time

	One Camera Condition	Three Camera Condition
MRT Percentage Correct	84.00	78.00
Video game Involvement	31.67	25.33
Knitting Involvement	13.00	3.67

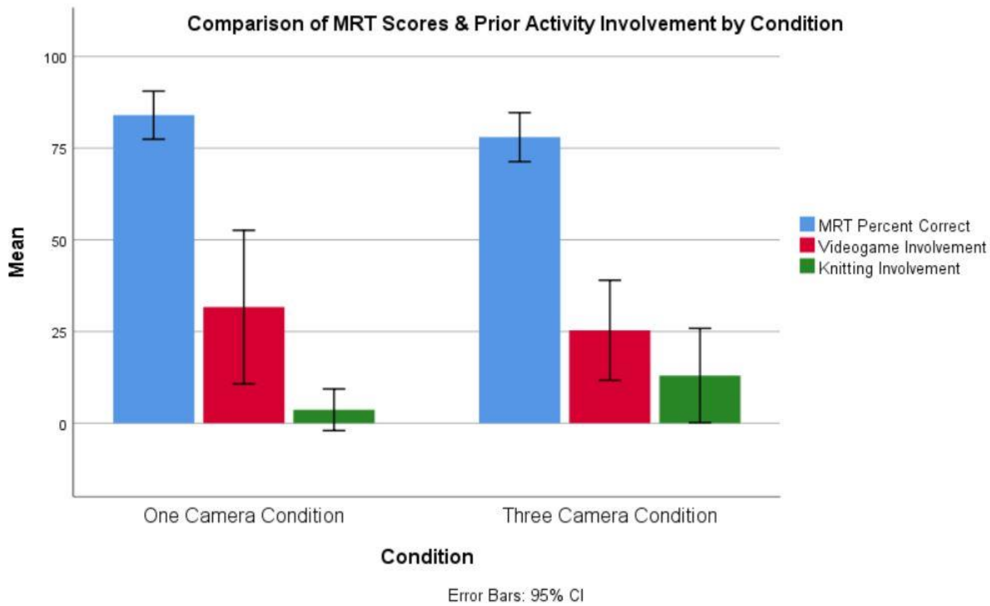


Figure 8: Mean MRT Score and Prior Activity Involvement

Table 5 shows the comparison of the average percentage of participants in the one camera condition compared to the three camera condition in regards to the correct number of items identified in the mental rotation test, time spent playing video games, and time spent knitting.

Participants in the tri-view condition (N = 15) had a lower correct score on the mental rotation test (M = 84.07; SD = 9.06) than those in the single-view condition (N =

15; M = 87.53; 10.31). An independent samples t-test indicates that this difference is not statistically significant $t(28) = 0.98$, $p = 0.34$, $d = 0.37$.

Participants in the tri-view condition (N = 15) reported to spend less of their day playing videogames (M = 25.33; SD = 24.6) than those in the single-view condition (N = 15; M = 31.67; SD = 37.78). An independent samples t-test indicates that this difference is not statistically significant $t(28) = 0.54$, $p = 0.59$, $d = 0.2$.

Participants in the tri-view condition (N = 15) reported to spend more of their day knitting (M = 13; SD = 23.21) than those in the single-view condition (N = 15; M = 3.67; 10.26). An independent samples t-test indicated that this difference is not statistically significant $t(28) = -1.43$, $p = 0.17$, $d = 0.54$.

Table 6:

Correlations: Overall Task Time, Objects Dropped, Objects Lost, & Condition

	Overall Time (Seconds)	Objects Dropped	Objects Lost
MRT Score Percent Correct	r = -0.18 p = 0.35	r = 0.03 p = 0.88	r = -0.28 p = 0.14
Overall Time (Seconds)		r = 0.54 p = 0.002	r = -0.08 p = 0.69
Objects Dropped			r = 0.15 p = 0.42

Table 7:

Correlations: MRT Percent Correct, Videogame Involvement, & Knitting Involvement

	Videogame Involvement	Knitting Involvement
MRT Score Percent Correct	r = 0.09 p = 0.64	r = 0.16 p = 0.39
Videogame Involvement		r = 0.22 p = 0.25
Knitting Involvement		

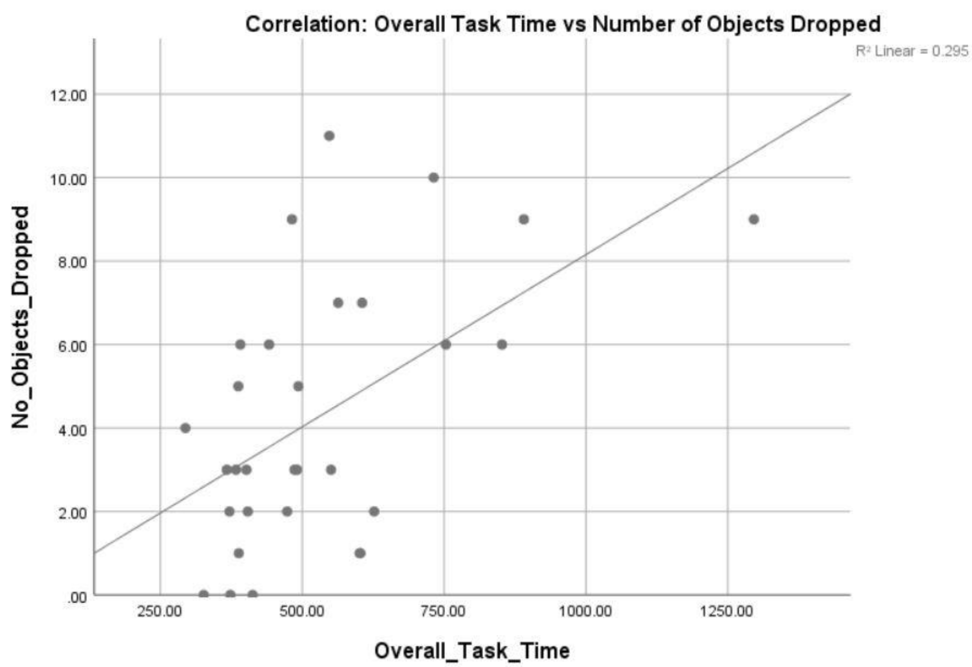


Figure 9: Significant Correlation between Task Time and Dropped Objects

Correlations were run between the mental rotation test scores and peg transfer performance. There was no correlation between the mental rotation test score and the overall time taken to perform the task, $r = -0.18$, $p = 0.35$. There was no correlation between the mental rotation test score and the number of objects dropped during the peg transfer task, $r = 0.03$, $p = 0.88$. There was no correlation between the mental rotation test score and the number of lost objects, $r = -0.28$, $p = 0.14$.

Correlations were also run between the mental rotation test scores and activity involvement; videogames and knitting. No correlation between participant's mental rotation test score and videogame involvements was found, $r = 0.09$, $p = 0.64$. There was also no correlation found between participant's mental rotation test scores and knitting involvement, $r = 0.26$, $p = 0.1$

There was a significant correlation between the overall time and the number of objects dropped during the peg transfer task, $r = 0.54$, $p = 0.002$.

CHAPTER 5

DISCUSSION

The research reported describes the differences between the use of a single-view and a tri-view camera system when conducting a minimally invasive surgical training task in regards to performance, perceived cognitive workload and spatial cognition. The non-medical task was conducted by university students with no prior medical knowledge above the age of 18. This study addresses the loss of depth perception differently than any prior research to date. Rather than looking to redesign a singular camera this study looks at the cognitive effects of adding a second and third camera view of the surgical site. Currently multi-view camera systems have been proven to add significant value to performing a variety of tasks. The videogame industry in particular has had great success with the implementation of multiple view points for the user. However, unless research can first show in a proof of concept study that there is significant reason to believe that multiple viewpoints could transform minimally invasive surgery and enhance the patient's operation significantly and safely, a multiple camera system will never be used in the operating room. This is due to the fact that minimally invasive surgery can be conducted with one camera, though the procedure can always be improved which is where the need for this study and ones like it become apparent.

The hypotheses for this study stated that a tri-view camera system would reduce the overall time needed to perform the surgical task, reduce the perceived cognitive workload when performing the task itself, and increase the spatial cognition of the surgeon compared to those using a single-view camera system. The overall task time for the single-view condition took less time compared to the tri-view condition. This was a surprise because it was hypothesized that the overall time needed to perform a task would decrease when multiple camera views were presented. This phenomenon could be caused by overloading the participant's environment using all three viewpoints. A possible reason for this result is that participants in the tri-view condition took their time assessing an object in all three screens, determining which one gave them the best angle, before continuing the movement. Another study would be required to see if a longer task time was needed simply because there were more visual stimuli to observe, as well as to see if this phenomenon carries though from novice to expert users. Future studies may find that experienced users are able to take advantage of the multiple viewpoints, proving that the effect found in this study came from an overload effect of novice users.

Participants with access to all three cameras were able to recover and find lost objects that they had dropped with a greater success than the group using one camera even though participants in both conditions tended to drop the same number of objects giving the impression that coordination is not a by the result of having more visualization of the surgical site. Just from observations, it was clear to see that almost all the participants went after dropped objects trying to recover them rather than accepting the idea that they lost one and could move on. The more objects participants dropped the longer it took them to complete the task. This showed investment in the task by the participants.

This aligns with prior research stating that multiple viewpoints have been proven to increase task performance (Enochsson *et al.,* 2004). Multiple camera views give participants room to see around obstructions caused by the peg board allowing participants to recover all dropped triangles by picking them up and placing them back on an open peg. The guess work of locating the triangle object was taken out of the equation since there was always one view that showed a glimpse of the object lying off to the side. This reveals that spatial cognition is more prevalent to minimally invasive surgery than prior researchers have thought.

According to (Lee *et al.,* 2012) there was no difference in hand dexterity between those who choose go to medical school and those who did not. There is a difference in performance for those who naturally have higher manual dexterity than those who do not however; beyond this no other predictor of performance in terms of hand dexterity has been found (Hughes *et al.,* 2014). Videogames have been shown to help future surgeons develop stronger hand dexterity and hand eye coordination. It is evident in training styles that the belief for the learning curve regarding minimally invasive surgery can be overcome though repetitive motor skill movements. For experts, practicing hand technique may increase their expertise level along with gaining practice manipulating the surgical tools in surgical environments but for novice users it is visual-spatial ability that is associated with skilled performance (Wanzel *et al.*,2003). Spatial cognition and visual perception should be researched more in regards to minimally invasive surgery as the cause for the large learning curve. Future studies may find and agree that performance is less based on hand dexterity and skill and is influenced more by a spatial awareness of the surgical site when performing a task in a minimally invasive surgical environment.

The second hypothesis of the study stated that using three camera view displays would decrease the perceived cognitive workload as compared to one display. The data supports this hypothesis. For each scale the average value was lower in the three camera condition as compared to the one camera condition and the overall data set. This means that those who conducted the task with three displays perceived effort needed, mental demand, physical demand, temporal demand, and frustration levels to be lower than those that conducted the task with one display. Perceived cognitive workload was measured due to the knowledge that this type of surgical procedure could last up to four hours long. If perceived to have lower workload demands, a multiple camera system could then be tested to see if it would indeed limit the amount of cognitive strain on surgeons when performing the operation. The guesswork of framing out a 3D mental model in this situation would be lowered since the cameras would show more of the surgical site allowing the surgeons to view more and despiser less allowing them to perform at a higher working capacity for a longer duration of time. The data suggests that three displays also allowed the participants to feel more accomplished and successful in the task than those with one screen felt.

The online mental rotation test scores, perceived percentage of video games played, and perceived time knitting on a regular basis. These categories were tested for each condition to understand what prior related skill sets the participant group as a whole might have regarding the kind of hand-eye coordination required of the experiment. The hope was to find both conditions equal in each of these three categories to show that no outside influence or skill dominated in one condition over the other. For almost all categories the percentages come close to each other meaning that the data was not skewed one way or another based upon the prior skills of any of the participants. The one activity that has the most difference would be knitting however both percentages are still low out of 100 creating no lasting significance which was confirmed by an independent samples t-test. An independent sample t-test also found the differences in the mental rotation test scores and in the time spent playing video games not to be statistically significant.

CHAPTER 6

CONCLUSION

The results indicated that when three displays were present the overall time initially using them to complete a task was slower, the task was perceived to be completed more easily and with less strain, and participants had a slightly higher performance rate. The only statistical difference found was in the overall task time it took for the tri-view condition comparted to the single-view condition. The statistical finding rejected the null hypothesis, showing that the tri-view condition took longer to complete the task making the first hypothesis of the paper false. The second hypothesis of the paper stated that the tri-view condition would perceive cognitive workload to be less when performing the task. The data supported this hypothesis but the difference between conditions was ruled not statistically significant making the second hypothesis inconclusive. The third hypothesis of the paper stated that the tri-view condition would have slightly higher performance rates. The data again supports this however the difference was not large enough to be deemed statistically significant making the third hypothesis inconclusive.

More research should be done to look at why these outcomes are occurring. What is known is that initially a tri-view system slows down the user. It is also known that the more object drops that occur the longer it will take the user to finish the task. Other data that was collected that was not presented in the results section concluded that those in the tri-view condition did not use all three screens equally. According to the data collected by the paper survey, fourteen out of fifteen participants used the center screen the most followed by the left hand screen then the right hand screen. Further research should be conducted looking at the need of a second screen versus a third screen as well as the placement of that second screen compared to the dominant hand of the participant. Moving forward there is more research that can be done to test if multiple viewpoints of the surgical site can change the way minimally invasive surgery is conducted and or pave the way for robotic surgery to gain features that go beyond human capabilities, allowing for an increase in patient safety and potentially more complex surgeries to be done.

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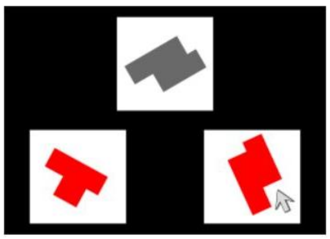
APPENDIX A

MENTAL ROTATION ONLINE TEST INSTRUCTIONS

Online Mental Rotation Test

About this implementation



In the above screen shot, you see three two-dimensional stimuli. For this demo, we use 2D stimuli (in part because they are easier to create).

If you wish, you can get 3D datasets online.

The grey stimulus at the top is the one you need to match with one of the red ones. In order to match the grey stimulus, you need to imagine what it looks like when it is rotated. In this example, the right one matches, and thus needs to be clicked (as indicated by the little grey mouse cursor).

In the following demonstration, you will need to find out which two object match each other. You can only do that if you mentally rotate the objects and see which ones match. In this example, the stimuli are 2 dimensional, or 2D. In psychology, the most common mental rotation experiments have stimuli with depth, that is 3D.

- Note, you can show your response times and copy and paste them to a local file for your own data analysis.

APPENDIX B

NASA TLX RATING SCALES

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX C

SURVEY

Survey

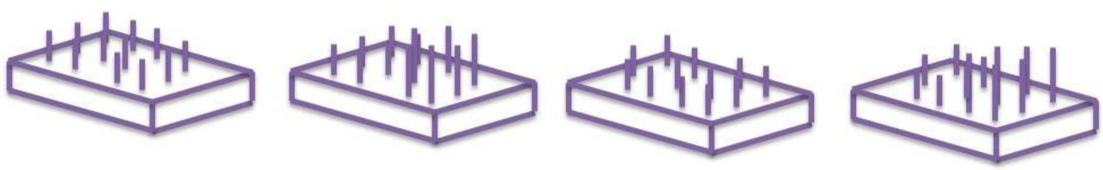
How often did you use the left camera display?

How often did you use the right camera display?

Which camera view did you use the most? (Left, Center, Right)
List in order of most used to least.
1)
2)
3)

Which hand do you write with?

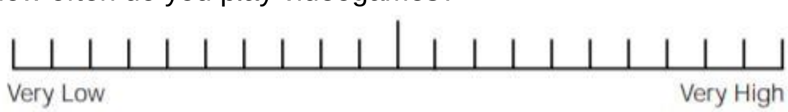
What pegboard did you use in today's task?



A B C D

What word was printed on the base of the pegboard?

How often do you play videogames?



How often do you knit?

APPENDIX D

EXPERIMENT DATA COLLECTION SHEET

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Experiment Data Collection Sheet

Participant ID Number:
Age:
Gender: M / F
Overall Task Time Completion:

MRT Scores: Data Copied?
Average Reaction Time:
_____________ms
% Correct: _______________ /100

Number of dropped triangles during the peg transfer task:

Comments:

Experiment Data Collection Sheet

Participant ID Number:
Age:
Gender: M / F
Overall Task Time Completion:

MRT Scores: Data Copied?
Average Reaction Time:
_____________ms
% Correct: _______________ /100

Number of dropped triangles during the peg transfer task:

Comments: