Fall 2006

The Effect of Camera Placement and Display Configuration on a Remote Manipulation Task

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The Effect of Camera Placement and Display Configuration on a Remote Manipulation Task

by

Debra Clark

B.S., University of Florida, 1997

A Thesis Submitted to the
Department of Human Factors & Systems
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Human Factors & Systems

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on a Remote Manipulation Task

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This thesis was prepared under the direction of the candidate’s thesis committee chair, Shawn Doherty, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. This thesis was submitted to the department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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Abstract

A remote manipulation task was presented to 80 Introduction to Psychology students from Embry-Riddle Aeronautical University. The participants viewed the task via two displays showing two camera views. For the camera views, one camera was always in a top-down position, while the other camera changed positions from normal, right-side, reverse, and left-side positions. For the displays, the camera views were shown in either Configuration 1, with the top-down view on the left display and the other camera view on the right display, or Configuration 2, with the top-down view on the right display and the other camera views on the left display. Performance speed was recorded for the remote manipulation task to find the best combination of camera view and display configuration. The results indicated that the normal camera view was worse than the other camera views, but there was no significant difference between the right, reverse, or left camera views. A significant difference was also found between the two display configurations, but that difference was strongly influenced by the normal camera view conditions. An interaction was found between camera placement and display configuration, but it was also strongly influenced by the normal camera view conditions.
# Table of Contents

Abstract ........................................................................................................... iii
Table of Contents ........................................................................................... iv
List of Figures ............................................................................................... v
List of Tables ................................................................................................... vi
Introduction .................................................................................................... 1
  Direct vs. Indirect Viewing ........................................................................... 3
  Single Camera View ..................................................................................... 4
  Depth Perception ......................................................................................... 5
    Depth Cues ............................................................................................... 6
  Camera Distance to Task Area ................................................................. 8
  Frame of Reference ..................................................................................... 9
    Egocentric vs. Exocentric ....................................................................... 9
  Perturbed Visual Feedback ....................................................................... 11
Multiple Camera Views .................................................................................. 14
  Display View Configuration ..................................................................... 15
Present Study .................................................................................................. 18
Hypotheses ..................................................................................................... 22
Method ........................................................................................................... 26
  Participants ................................................................................................. 26
  Materials .................................................................................................... 26
  Design ......................................................................................................... 27
  Procedure .................................................................................................. 27
Results ............................................................................................................. 29
Discussion ...................................................................................................... 33
  Limitations ................................................................................................. 38
  Future Studies ........................................................................................... 39
Conclusion ..................................................................................................... 39
References ..................................................................................................... 41
Appendix A: Consent Form .......................................................................... 43
Appendix B: Demographics ......................................................................... 44
Appendix C: Spatial Ability Test .................................................................. 45
Appendix D: Debriefing ................................................................................ 50
List of Figures

Figure 1. Example of vertical angular displacement.................................10

Figure 2. Example of horizontal angular displacements and reversal
       displacements...........................................................................11

Figure 3. Example of left-side view and right-side view perturbed visual
       feedback....................................................................................12

Figure 4a. Example of conformal positioning..............................................17

Figure 4b. Example of non-conformal positioning.........................................17

Figure 5a. Top-down camera placement.......................................................19

Figure 5b. Second camera placement...........................................................19

Figure 6. Configuration 1 display views.........................................................20

Figure 7. Configuration 2 display views.........................................................21

Figure 8. Photo of remote manipulator arm.................................................26

Figure 9. Group means for the four camera placements displayed in the two
       configurations.............................................................................30
List of Tables

Table 1. Group means and standard deviations ........................................29

Table 2. ANOVA source table .................................................................31

Table 3. Group mean differences for the camera placement variable... .....31

Table 4. Pairwise comparisons for individual conditions ......................32

Table 5. Accuracy results ..................................................................33
Introduction

Following in the footsteps of great explorers like Christopher Columbus, present day scientists continue the pursuit of searching uncharted territories. Some of these new frontiers, such as deep water exploration, journeys into outer space, processes of endoscopic surgery, and development of nuclear reactor sites, have been unavailable to humans until recently. With the help of remotely operated equipment, these areas can now be explored and improved without requiring humans to enter these harmful or inaccessible environments.

One example of how remotely operated equipment can aid in the new frontiers such as a deep water environment was the rescue of a mini-submarine that had become entangled in an underwater antenna assembly 600 feet under water in August of 2005. The Russian mini-submarine was participating in a combat training exercise when it became caught on underwater antenna assembly cables. The underwater antenna assembly system was being anchored by a 66-ton weight. Cutting the mini-submarine loose from the 1-inch thick cables as soon as possible was critical because the crew were running out of oxygen. The mini-sub was freed after a remotely operated vehicle (ROV) helped cut away the cables (Isachenkov, 2005). In this case, using an ROV was necessary because of the great depth and time sensitivity of the task. In situations like this rescue, ROV operators have to contend with visual disturbances, such as low-light conditions and underwater debris that look like floating snow. An important factor that could influence the efficiency of a cutting task similar to this rescue is the ROV operator's view of the task area. Figuring out the best places to cut, and then completing the actual cutting could be accelerated by viewing the task area from multiple cameras at optimally placed angles.
Another example of using remotely operated equipment in a difficult environment is the Space Station Remote Manipulator System (SSRMS). The SSRMS uses four cameras that provide remote views sent to three video monitors. One camera is fixed at each end of the SSRMS, while the other two are mounted on opposite sides of the SSRMS elbow and are maneuverable. The three video monitors can display the output of three selectable cameras. Despite the fact that the SSRMS has 4 cameras, a study by Lapointe and Boulanger (2001) pointed out that there is insufficient visibility of many work areas. In order to help compensate for the limited number of displays and the limited coverage of the work areas, another astronaut may have to assist the operator by viewing different cameras views at a secondary robotic workstation, or by performing an Extra-Vehicular Activity (EVA) to provide a direct view of the work site. This is precisely what happened during an International Space Station assembly mission in 1998 using the Shuttle Remote Manipulator System (SRMS). The operator of the SRMS received help from two other crew members who performed an EVA to help avoid potential collisions. Lapointe and Boulanger agreed that similar situations could happen with the SSRMS. Since EVAs are always risky, the purpose of these remote manipulators is to avoid the need for taking such risks. However, complete visual coverage of the work sites will continue to be an issue when using video cameras until an optimal arrangement of the cameras and video monitors is discovered.

In both of these examples, the use and placement of multiple cameras and displays during the remote manipulations could affect the efficiency and effectiveness of those tasks. For the mini-sub rescue, by placing the cameras in an optimal arrangement, the ROV operator may have cut the cables faster because he could see the cables from more than one angle. For the SSRMS, learning from the difficulties already experienced by the SRMS
could eliminate the need for additional help from other crewmembers to do a job that is designed for a single operator. In order to improve the remote viewing performance of remote manipulation tasks, we must first understand the factors that influence remote viewing.

Direct vs. Indirect Viewing

Until recently, underwater rescue situations would have only been possible by sending divers underwater to assess the problem visually (direct viewing) and physically cut the cables (direct manipulation). However, due to time constraints and the depth of most submarine rescue operations, performing such a rescue with direct viewing and direct manipulation would have been nearly impossible. Sometimes, the preferred method for deep water excursions is the use of indirect viewing and indirect manipulation, which means using underwater cameras (indirect viewing) and remote controlled equipment (indirect manipulation or remote manipulation). Although indirect viewing may be the preferred, or only, viewing method at times, it has been shown to be inferior to direct viewing. In one study, Mackro (1973) compared direct viewing to three different indirect viewing conditions while performing a remote manipulation task. The direct viewing condition had consistently faster performance speed in all trials and tasks compared to the indirect viewing conditions. In a later study, Plishka (2002) compared direct versus indirect viewing at different distances during a remote manipulation task. He found that the direct view conditions had consistently better performance rates than the indirect conditions. Unfortunately, directly viewing a task is not always the best option, or even possible. When necessary, indirect viewing must be used for remote manipulation tasks.
Single Camera View

Indirect viewing, however, can present a myriad visual problems. Cameras can be positioned to give an optimal view of the task area, but then the picture is sent to a display monitor, which translates the three-dimensional task area into a two-dimensional image. Looking at a two-dimensional image from a single camera view diminishes the ability of the observer to judge distance. Also, the ability to see the complete task area is reduced because of unavoidable blind spots due to obstructions. For example, the next time you sit at your computer, close one eye and point your index finger at the words on the display screen. With your open eye acting as the camera, you not only will have a more difficult time judging the distance between your finger and the screen, but you will also not be able to see any of the letters in front of and below your outstretched finger, hand, and arm. Your outstretched finger, hand, and arm act as obstructions to the complete task area, and you are “blind” to what they are obstructing. If you had both eyes open, the combined views of each eye allow the observer to see some or all of the obstructed view, depending on how far away the obstruction is to your eyes. This can be observed by comparing your single eye views by first closing your right eye, then your left eye.

The difficulties of looking through only one eye can translate to viewing a task area with only one camera. Many studies have looked at camera positioning when using one camera during a remote manipulation. One early study by Mackro (1973) compared four viewing conditions while performing a remote manipulation: one direct view and three indirect views. The three indirect viewing conditions consisted of camera’s placed along the line of site (simulating the operator’s direct view from the first condition), mounted above the task area looking down, or attached to the moving manipulator and looking down on the
task area. Mackro concluded that performance speed is impaired when using a camera instead of direct viewing. He also found that when using cameras, the efficiency of task completion was better when the camera could move with the manipulator. The third indirect viewing condition allowed the task area to be magnified as the camera and remote manipulator moved closer, allowing the operator a more detailed view. However, this indirect viewing condition makes it difficult for the operator to guide the manipulator to reach for distant objects that were outside the view of the camera. The first and second indirect viewing conditions in which the camera was in the line of site or on the manipulator allowed the operator to have a wide view to show the entire task area as well as provide a reference for the positioning of the manipulator. Because the purpose of each task is different, Mackro stated that no single camera position was optimal for all tasks. Adding another camera to view a task area could alleviate some of the single camera problems as well as optimize the view for most tasks. A combination of a camera with a wide view and a camera that moves with a remote manipulator could serve most every remote task. However, we must first discuss a fundamental ingredient of the single and multiple camera views: depth perception.

**Depth Perception**

Depth perception refers to the ability to judge the distance to an object, and can be viewed in two ways. The first way is called absolute distance, which refers to the distance from the observer to an object. For example, a golfer judges exactly how far to hit the ball into the hole while putting at the current position during a game of golf. The second way to view depth perception is called relative distance, which refers to judgment of the distance between two objects, or between different parts of a single object. For example, a car driver
judges the amount of space between two parked cars in order to avoid hitting either one while parking (Sekuler & Blake, 2002). According to Ohtsuka, Ujike, and Saida (2002), information for relative distance can affect the information needed for absolute distance. In other words, they suggested that depth information affects both relative and absolute distance judgments. For example, during a remote manipulation task, a camera with a normal view (positioned at 0° horizontally from the task target) and attached to the remote manipulator arm would allow judging absolute distance by allowing the operator to judge the distance from the camera to the task target. In this case, relative distance can also be judged between the manipulator arm and the task target. In either case, using relative distance or absolute distance, the depth can be perceived because the closer the manipulator arm gets, the bigger the target appears on the display. Alternatively, a camera with a top-down view of the task area would allow judging relative distance in the same way by allowing the operator to judge the distance between the manipulator arm and the task target. In this case, the closer the manipulator arm and target get to each other, the space between them appears to get smaller on the display, and allows the operator to assess the relative difference between the two objects.

**Depth cues.** The ability for absolute and relative judgments of distance to or between objects usually depends on cues to depth perceived by the eyes. There are two categories of cues to depth perception: oculomotor cues and visual cues.

Oculomotor cues involve kinesthetic movements of the muscles of the eyes. One cue involves turning the eyes toward each other in order to fixate on a single object (convergence), and the other cue involves varying the optical power of the eye by temporarily changing the shape of the lens (accommodation). In other words,
accommodation allows normal eyes to focus clearly on either a near or far object, while objects at other distances are out of focus. Oculomotor cues provide the best information about absolute distance, without requiring supplemental help from other cues (Sekular & Blake, 2002).

Visual cues to depth perception are either monocular or binocular. Monocular visual cues include movement cues (called motion parallax) and static cues, such as interposition (when one object obstructs the view of another object), size (closer objects will appear larger; familiarity of an object can help judge size), perspective (apparent changes in objects as they get farther away), and shading (effect of lighting on three dimensional objects). Binocular visual cues are obtained through stereopsis (the ability to see something that can’t be seen with only one eye). Both monocular and binocular visual cues provide good information about relative distance, but they need supplemental information when judging absolute distance (Sekular & Blake, 2002).

Viewing a scene with a single camera changes a three-dimensional (3D) task area into a two-dimensional (2D) image. Since a remote manipulation task is viewed through a two-dimensional image, the observer no longer has the option of using oculomotor cues, so visual cues are the basis of judging distance. However, since visual cues need supplemental information when judging absolute distance, relying solely on visual cues poses a problem to the observer. This dimensional change (3D to 2D) that causes the loss of depth perception forces the operator to infer depth from monocular visual cues within the display. Another option for the operator would be to use more than one camera to simulate binocular visual information. For example, viewing the task area through one camera attached to the remote manipulator arm and a second camera positioned directly above and looking down on the
task area would effectively provide information from all three dimensions. These combined views emulate the previous examples of judging both absolute and relative distance.

**Camera distance to task area.** The distance between a camera and a task area can profoundly affect the ability to judge the distance between a remote manipulator arm and the task target. Mackro (1973) discussed how the positioning of a camera in a remote manipulation task depended on the level of detail of the task. The higher the detail, the closer the camera should be located to the task area. For example, if the Space Station Remote Manipulator System (SSRMS) is being used to move a large payload to a location with lots of spare room, then a wide view of the process is sufficient. However, if the SSRMS is being used to insert a small object, such as a screw, into a form fitting space, positioning the camera closer to the task area would be necessary. The closer view offers more visual detail to perform the task both effectively and efficiently but, like a keyhole, reduces the surrounding visual area (Woods, 1984).

A closer view of the task area affects more than the level of visual detail. A study by Plishka (2002) was performed using one camera to view a remote manipulation at short distances (20cm, 60cm, and 100cm), and found that indirect viewing performance decreased when the distance between the camera and the task target increased. Plishka suggested that this might have been due to lack of binocular cues, or that the clarity (the ability to see fine details) of the object decreased as the viewing distance increased. However, using two cameras may help simulate binocular visual information and help resolve these issues. Also, the cameras can be positioned close enough to see both the detailed task target as well as further away to view the entire task area. Before exploring the benefits of using multiple
cameras, we must discuss another fundamental ingredient of single and multiple camera views: frame of reference.

Frame of Reference

Egocentric vs. Exocentric. When specifying the location of an object, the frame of reference will usually be either an egocentric (inside out) or an exocentric (outside in) perspective. An egocentric frame of reference provides a self-referenced viewing relationship to the world. For example, when facing forward driving a typical car, the door is on your left, the windshield is in front of you and your seat is below and behind you. If you turned your head to the left, the orientation of the reference points would shift so that your door would now be in front of you, your windshield would be to your right, and your seat would be below and to the left. Even though everything in the world remains identical, the reference points for each object shifts to match the new self-centered frame of reference. An exocentric frame of reference provides a world-referenced viewing relationship, regardless of the personal view. For example, if you turned your head left while driving the car the door will still be to the left of the seat in the real world.

Humans are naturally egocentric, viewing the world from our own individual eyes. The only way to see through someone else’s eyes is through pictures or video held up to their eyes and recorded. However, during remote manipulations, an egocentric view may not be optimal because of possible obstructions in the view. If a camera was attached to a remote manipulator arm, or positioned egocentrically behind the remote manipulator arm, the view to the task target can be obscured by the remote manipulator arm. In order to combat this problem, it is necessary to use multiple cameras that are spatially displaced, which means they are positioned to view a task area from different perspectives. Using spatial
displacement would provide multiple, exocentric perspectives that assist in regaining the lost information behind any obstructions.

Spatial displacement consists of four forms: angular displacement (horizontally or vertically displaced reference point), reversal displacement (camera is facing the arm instead of looking from behind it; a 180° displacement), inversion-reversal displacement (camera is upside-down and facing the arm), and inversion (camera is upside-down and looking from behind arm) (Smith & Stuart, 1989). These forms of spatial displacement allow multiple cameras to show all three dimensions – the x-axis (left or right); the y-axis (forward or backward); the z-axis (up or down). Angular displacement consists of any location on the yz or zx axes, such as left or right side, top-down, or bottom-up. Examples of angular and reversal displacements are shown in Figure 1 and Figure 2.

Figure 1. Example of vertical angular displacement (90°).
Figure 2. Example of horizontal angular displacements (90°, 270°) and reversal displacement (180°).

Perturbed Visual Feedback. Using the spatial displacement for the positioning of multiple cameras can introduce a new problem: perturbed visual feedback (Smith & Stuart, 1989). Perturbed visual feedback involves a conflict between what the operator sees on a display and what the operator instructs a remote manipulator to do. Look at Figure 3 on the next page. On the left is a left side view of a task area. If the operator moves the remote manipulator arm forward toward the target, then in the left side view, the arm will appear to move left instead of forward. On the right is a right side view of the same task area. If the operator moves the remote manipulator arm forward toward the target, then in the right side view, the arm will appear to move right instead of forward.
The differing frames of reference can negatively affect performance speed and accuracy by causing conflict between the eyes and the brain. Many studies using single cameras have shown that remote manipulation speed is negatively affected by spatially displaced viewing conditions (Smith & Smith, 1962; Smith, Smith, Stuart, Smith, & Smith, 1989; and Smith & Stuart, 1989), but that performance improves with repeated trials. The study by Smith and Stuart (1989) compared a direct view, a normal single camera view, and three spatially displaced single camera views during a remote manipulation task: normal, reversed, inverted, and inverted/reversed. They found that out of the three spatially displaced views, the inverted/reversed view was better than both the reversed view and inverted view individually. Alternately, a study by Stuart, Manahan, Bierschwale, Sampaio, and Legendre (1991), also compared the same five views as Smith and Stuart. This study found that the reversed view was the best out of the three spatially displaced views. As a result of their study, Stuart, et al. (1991) suggested that using more than one camera view at a time may improve an operator’s performance when dealing with spatially displaced viewing conditions. Another suggestion was to isolate tasks into one or two axes at a time. They also suggested using the movement of the hand controller as a reference point as opposed to the

**Figure 3.** Example of left-side view and right-side view perturbed visual feedback.
movement of the manipulator on the screen. Unfortunately, this suggestion could only work properly if the manipulator was being operated by a joystick-type control because it is simulating the movement of the manipulator arm. If the manipulator is being operated by a push-button control, then the movement of the manipulator on the screen would be the most efficient reference point.

A study by Mackro (1973) also used only one camera for a remote manipulation task. When comparing direct and indirect viewing conditions (normal view, top-down fixed view, and top-down attached to manipulator arm), he found that the optimal indirect viewing condition would depend on the task’s degree of detail. No single camera position was best for all tasks. In order to improve the task view, he suggested using two cameras in the following configuration: one camera should be fixed from a shallow angle (any view horizontal to the task area, such as a normal view), and the other camera should be attached to the moving manipulator arm, facing down on the task area (assuming the manipulator arm is approaching the task area from above instead of horizontally from the side). Mackro suggested that these positions of the two cameras would provide views of all needed viewing angles, and allow for closer viewing for fine manipulation. The fixed camera would provide a complete view of the task area, while the attached camera would provide a closer view of the task target as the remote manipulator arm closes in. This type of two-camera configuration would also allow the operator to isolate tasks into one or two axes at a time as suggested by Stuart, et al. (1991). For example, a camera with a normal view would allow the operator to focus on moving the remote manipulator arm along the x axis or y axis, while the top-down view would assist the operator in moving the remote manipulator arm along the x axis or z axis.
A study by Rastogi (1996) agreed with Mackro that having multiple camera views allows the viewer to see objects that are hidden in one of the views. For example, a remote manipulator arm (approaching the task target from a horizontal position) partially obstructs the view of a camera in the normal position, but adding a second camera with a top-down view will allow the viewer to see the obstructed areas. Rastogi also suggested that having multiple camera views provides higher depth resolution by allowing you to judge depth by combining the information from the multiple axes views. In other words, a more accurate judgment of depth could be made by combining the normal view, providing absolute distance, with the top-down view, providing relative distance. Properly judging distance from one object to another, or from the remote manipulator arm to an object, is a key component in performance task speed.

Multiple Camera Views

Adding a second camera can improve depth perception and reduce blind spots, problems associated with changing from direct to indirect viewing. Depending on the placement of the cameras, each camera’s two-dimensional, monocular image can be combined mentally by the viewer to provide enough information to judge both relative distance and absolute distance. The addition of more cameras simulates binocular visual information needed to supplement the monocular visual cues being used for distance information. For example, attaching one camera to a remote manipulator arm (allowing both absolute and relative distance judgment) and placing the second camera above a task area facing down (allowing relative distance judgment) will supply information from all three dimensions (x, y, and z). The more cameras that are added in different positions, the more detailed the view of the task area becomes. Adding cameras also can counteract Woods’
“keyhole” affect when using at least one camera positioned far enough away to view the entire task area.

Although adding cameras can improve the issue of depth perception loss, having multiple views can negatively affect how an operator interprets what he sees on the displays, or the frames of reference. The use of spatially displaced cameras can produce perturbed visual feedback in each of the camera views. Combining the multiple perturbed views can increase the problem produced by the individual perturbed views by causing the operator to translate multiple, different images seen and properly instruct the remote manipulator to move in the desired direction. For the purpose of this paper, this result of combined multiple, perturbed camera views will be called disturbed frames of reference. Using a push-button control, instead of a joystick control, during a remote manipulation allows for an easier translation of direction of movement while viewing disturbed frames of reference because the movement of the manipulator could be used as a reference point. Even with disturbed frames of reference, it is possible to focus on each camera view in turn and instruct the remote manipulator to move along one axis at a time, assisting with achieving optimal performance speed.

*Display View Configuration*

When indirectly viewing a remote manipulation task, the use of a display is necessary. However, using a display monitor translates the three-dimensional task area into a two-dimensional image which generates difficulties of poor depth perception and blind spots due to obstructions. Another problem with indirect viewing involves maneuvering the remote manipulator arm. If the frame of reference is a close-up view of the task area, it will
be difficult for the operator to guide the manipulator to objects located outside the current view. Adding a second camera can help alleviate these problems.

Since performance speed is a key product in remote manipulation tasks, an alternative method of viewing must be explored. As more cameras are added to view a task area, it will become increasingly difficult to perform a remote manipulation efficiently using only one display. Instead of switching the view on a single display, the operator can view multiple camera views on multiple displays. However, this method has a problem with performance costs in eye scanning that are required by the operator when viewing two displays (Wickens & Carswell, 1995). This cost in scanning refers to the information access cost (IAC) which involves the movement of the operator’s eyes, head, and attention (Wickens, 1992). According to Wickens and Carswell (1995), having the two sources, or displays, close to each other, preferably within a few degrees of visual angle, can decrease the IAC while looking back and forth from one display to the other.

Another way to combat IAC is to use the proximity compatibility principle (PCP). The PCP is a display design principle that states that mentally relevant items should be placed in close physical proximity while items that should not be integrated should stay separated. The PCP thus provides a guideline that helps determine where each display should be located, depending on how the displays are related to each other. Most relevant to this study would be the use of processing proximity, which defines how much the two sources, or displays, are used as part of the same task (Wickens & Carswell, 1995). For example, this study will have two displays that show the same indirect task, using the same remote manipulator arm, viewed from two cameras set at the same distance from the task area. The mental processing that takes place while viewing each display is similar in most
respect (e.g., size of the task area and equipment will be the same in all views), except regarding the direction of the movement of the remote manipulator arm.

Using processing proximity as a guide, the IAC can be decreased by using conformal positioning of the displays, which matches the physical relationships that exist in the task area to what is being presented on the displays (Martin-Emerson & Wickens, 1997). Conformality involves placing the displays so the observer sees views that are consistent with the physical placement of the cameras. An example of conformal positioning would be viewing two displays in the following configuration: a top-down view on the left display and a right-side view on the right display (See Figure 4a).

![Figure 4a. Example of conformal positioning.](image)

Non-conformality involves placing the displays so what the observer sees does not match the physical relationship between the cameras. An example of non-conformal positioning would be transposing the two display views – the top-down view would be on the right, and the right-side view would be on the left (See Figure 4b).

![Figure 4b. Example of non-conformal positioning.](image)
Present Study

The focus of this study was to compare operator performance speed while determining the best two-camera placement. One camera was always in the top-down view, while the second camera changed between a normal view, right-side view, left-side view and reverse view (see Figure 5a and Figure 5b). This study also investigated which display view configuration paired the best with each two-camera placement. Configuration 1 displayed the top-down camera (Camera 1) on the left and Camera 2, 3, 4, or 5 on the right, while Configuration 2 displayed the top-down camera (Camera 1) on the right and Camera 2, 3, 4, or 5 on the left.
**Figure 5a.** Top-down camera placement.

**Figure 5b.** Second camera placement. The second camera can appear in any one of the four positions shown.
Figure 6. Configuration 1 display views.
Figure 7. Configuration 2 display views.
Hypotheses

Performance speed will vary depending on the specific configuration of camera to display placement. The following hypotheses are expected to result from this study:

1. The right-side view (Camera 3) and left-side view (Camera 5) camera combinations will be significantly better than the normal view (Camera 2) and the reverse view (Camera 4) camera combinations because of the lack of obstructions in the views from Camera 3 and Camera 5.
2. The normal view (Camera 2) camera combination will be similar between Configuration 1 and Configuration 2 of the displays.

3. The reverse view (Camera 4) camera combination will be similar between Configuration 1 and Configuration 2 of the displays.

4. The right-side view (Camera 3) camera combination will perform significantly better in Configuration 1 than Configuration 2.
5. The left-side view (Camera 5) camera combination will perform significantly better in Configuration 2 than Configuration 1.

6. The right-side view (Camera 3) camera combination in Configuration 1 will be similar to the left-side view (Camera 5) camera combination in Configuration 2.

7. The right-side view (Camera 3) camera combination in Configuration 2 will be similar to the left-side view (Camera 5) camera combination in Configuration 1.
8. An interaction will be seen between the right-side view (Camera 3) camera combination and the left-side view (Camera 5) camera combination. The performance using Camera 3 will decline from Configuration 1 to Configuration 2, while the performance using Camera 5 will improve from Configuration 1 to Configuration 2.
Method

Participants

Participants for this study were volunteer students from Introduction to Psychology classes at Embry-Riddle Aeronautical University. Each of the 80 participants was screened for normal, or correctable to normal, vision. Each participant was screened for right-handedness. None of the participants were experienced in the operation of a remote manipulator arm with a control similar to the one used in this study.

Materials

The stimuli were presented on two 19-inch Panasonic color monitors model no. CT-20R which showed the views from two Panasonic video cameras (model no. AG188), each with a tripod. A Questech Robot Manipulator Arm (Model TCM) (see Figure 8) that allows for five degrees of movement through a push button interface was used. A dowel (typically used as an upright paper towel holder), and a plastic ring from the center of a roll of cellophane tape were used for the remote manipulation task. Three cubicle style movable walls were used to enclose the remote manipulation task area from viewing. One table was used to hold the monitors. A digital timer was used to record performance speed. A diagram showing the physical placement of the cameras was provided to participants.
**Figure 8.** Photo of remote manipulator arm.

*Design*

This study was performed as a fully-factorial, between subjects study with a 4x2 design. The independent variables were placement of the second camera (Cameras 2, 3, 4, 5) and configuration of the displays (Configuration 1, Configuration 2). The dependent variables for this study were the number of trials placing the ring on the dowel and the performance speed of the successful trials.

*Procedure*

The remote manipulator arm was placed on one side of, and facing the center of, the task area on the floor. The plastic ring was fixed in the grip of the remote manipulator arm. Each camera was placed 50 cm meter away from the center of the task area (centered on the dowel). The movable walls were placed around the cameras. The two display monitors were placed next to each other and side-by-side on the table, on the other side of one of the movable walls.

Each participant was provided a consent form, a demographics sheet, and a mental rotation spatial test (Johns Hopkins University Center for Talented Youth, n.d.) at the beginning of the experiment. After signing the consent form and completing the demographics sheet and spatial test, each participant was shown the remote manipulator arm without the dowel. Then each participant was instructed in the use of the remote manipulator arm controls and given 2 minutes to practice using the push-button controls without any specific task goals. During practice, the participant was able to directly view the remote manipulator arm moving. Upon completion of the practice session, the dowel was placed at the center of the task area, and the remote manipulator arm held the ring at the starting
position which was 15 cm from the dowel. Via the two displays, each participant were then shown the remote manipulator arm holding the ring over the dowel, as well as a diagram showing the physical placement of the two cameras. Each participant was asked to instruct the remote manipulator arm to drop the plastic ring over the dowel while indirectly viewing the task on two displays. Each participant did one combination of secondary camera and display configuration that were measured by the number of times the task was completed within 20 trials, as well as the speeds of the completed trials (measured with the digital timer). The manipulator arm was reset to the same start position for each trial. If a ring was dropped (due to a mechanical problem) or forced off the remote manipulator arm, it was considered an error. After all trials were completed, the participant was given a debriefing form.
Results

The purpose of this study was to examine the relationship between camera placement and display configuration during a remote manipulation task. Performance speed and accuracy with a remotely manipulated task were recorded. Table 1 summarizes simple effects performance data for the experimental groups. Figure 9 illustrates the means for the four camera placements displayed in the two configurations for performance speed.

Table 1

*Group means and standard deviations*

<table>
<thead>
<tr>
<th>Camera Placement</th>
<th>Display Configuration</th>
<th>M</th>
<th>SD</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Configuration 1</td>
<td>14.04</td>
<td>5.56</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Configuration 2</td>
<td>9.81</td>
<td>2.46</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>11.92</td>
<td>4.71</td>
<td>20</td>
</tr>
<tr>
<td>Right</td>
<td>Configuration 1</td>
<td>8.48</td>
<td>2.36</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Configuration 2</td>
<td>7.99</td>
<td>1.32</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8.23</td>
<td>1.88</td>
<td>20</td>
</tr>
<tr>
<td>Reverse</td>
<td>Configuration 1</td>
<td>7.82</td>
<td>1.98</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Configuration 2</td>
<td>8.18</td>
<td>1.19</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8.00</td>
<td>1.60</td>
<td>20</td>
</tr>
<tr>
<td>Left</td>
<td>Configuration 1</td>
<td>8.45</td>
<td>2.53</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Configuration 2</td>
<td>7.57</td>
<td>1.10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8.01</td>
<td>1.95</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>Configuration 1</td>
<td>9.70</td>
<td>4.16</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Configuration 2</td>
<td>8.39</td>
<td>1.77</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>9.04</td>
<td>3.25</td>
<td>80</td>
</tr>
</tbody>
</table>

*Note* Mean values are in seconds
Figure 9. Group means for the four camera placements displayed in the two configurations.

The data were analyzed using a between subjects factorial ANOVA, with camera placement and display configuration as factors. The data from the last 10 trials (out of 20) were used for the statistical analysis to counter the learning effects obtained by the participants who were prescreened for inexperience with a remote manipulator arm. An alpha level of .05 was used for all significance testing. The results of the ANOVA indicated a significant main effect for both camera placement, $F(3, 72) = 10.38, p < .001$, partial $\eta^2 = .302$, and display configuration, $F(1, 72) = 4.82, p = .031$, partial $\eta^2 = .063$ for the reaction time data. A significant interaction between camera placement and display configuration was also indicated, $F(3, 72) = 2.84, p = .044$, partial $\eta^2 = .106$. Because an interaction was found, it is imperative to interpret the results of the main effects only within the parameters of the interaction. In other words, the significant differences found within camera placement were dependent on those found within display configuration, and vice versa. Table 2 shows
additional information regarding the ANOVA results, including estimates of effect size and power.

Table 2

**ANOVA source table**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial η²</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>6542.07</td>
<td>6542.07</td>
<td>914.95</td>
<td>&lt;001</td>
<td>0.927</td>
<td>1.000</td>
</tr>
<tr>
<td>Camera</td>
<td>3</td>
<td>222.58</td>
<td>74.19</td>
<td>10.38</td>
<td>&lt;001</td>
<td>0.302</td>
<td>0.998</td>
</tr>
<tr>
<td>Display</td>
<td>1</td>
<td>34.48</td>
<td>34.48</td>
<td>4.82</td>
<td>0.031</td>
<td>0.063</td>
<td>0.582</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>60.93</td>
<td>20.31</td>
<td>2.84</td>
<td>0.044</td>
<td>0.106</td>
<td>0.658</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>514.82</td>
<td>7.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td>7374.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The mean difference in performance as a function of display configuration (Configuration 1 vs Configuration 2) was 1.31 seconds (p = 0.031). All possible pairwise comparisons for the camera placement groups were made. The results indicate a significant mean difference of 3.69 seconds (p < 0.001) between the normal and right camera placements, 3.93 seconds (p < 0.001) between the normal and reverse camera placements, and 3.92 seconds (p < 0.001) between the normal and left camera placements. None of the other group mean differences were statistically significant. Table 3 shows post-hoc group mean difference data, as well as confidence intervals for the mean difference.

Table 3

**Group mean differences for the camera placement variable**

<table>
<thead>
<tr>
<th>Group I</th>
<th>Group J</th>
<th>Mean Difference (I-J)</th>
<th>SE</th>
<th>p</th>
<th>95% Confidence Interval for the Mean Difference Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Right</td>
<td>3.69</td>
<td>0.85</td>
<td>&lt;001</td>
<td>1.40</td>
<td>5.99</td>
</tr>
<tr>
<td>Normal</td>
<td>Reverse</td>
<td>3.93</td>
<td>0.85</td>
<td>&lt;001</td>
<td>1.63</td>
<td>6.22</td>
</tr>
<tr>
<td>Normal</td>
<td>Left</td>
<td>3.92</td>
<td>0.85</td>
<td>&lt;001</td>
<td>1.62</td>
<td>6.21</td>
</tr>
<tr>
<td>Right</td>
<td>Reverse</td>
<td>0.23</td>
<td>0.85</td>
<td>1.000</td>
<td>-2.06</td>
<td>2.53</td>
</tr>
<tr>
<td>Right</td>
<td>Left</td>
<td>0.23</td>
<td>0.85</td>
<td>1.000</td>
<td>-2.07</td>
<td>2.52</td>
</tr>
<tr>
<td>Left</td>
<td>Reverse</td>
<td>0.01</td>
<td>0.85</td>
<td>1.000</td>
<td>-2.29</td>
<td>2.30</td>
</tr>
</tbody>
</table>
As the only differences in camera placement appear to emerge from the normal camera configuration, all possible pairwise comparisons for configurations within camera placement were made through a simple effects analysis holding camera position constant. The results indicate a significant mean difference of 4.23 seconds ($p = .001$) in the normal camera placement between configurations. None of the other conditions produced a significant difference. Table 4 shows the simple effects analysis data for configurations within camera placement, including confidence intervals for the mean difference.

Table 4

<table>
<thead>
<tr>
<th>Camera Placement</th>
<th>(I) Display Configuration</th>
<th>(J) Display Configuration</th>
<th>Mean Difference (I-J)</th>
<th>SE</th>
<th>p</th>
<th>95% Confidence Interval for the Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Configuration 1</td>
<td>Configuration 2</td>
<td>4.23</td>
<td>1.20</td>
<td>.001</td>
<td>Lower Bound: 1.85, Upper Bound: 6.62</td>
</tr>
<tr>
<td>Right</td>
<td>Configuration 1</td>
<td>Configuration 2</td>
<td>0.50</td>
<td>1.20</td>
<td>.678</td>
<td>Lower Bound: 1.89, Upper Bound: 2.88</td>
</tr>
<tr>
<td>Reverse</td>
<td>Configuration 1</td>
<td>Configuration 2</td>
<td>0.36</td>
<td>1.20</td>
<td>.762</td>
<td>Lower Bound: 2.75, Upper Bound: 2.02</td>
</tr>
<tr>
<td>Left</td>
<td>Configuration 1</td>
<td>Configuration 2</td>
<td>0.88</td>
<td>1.20</td>
<td>.462</td>
<td>Lower Bound: 1.50, Upper Bound: 3.27</td>
</tr>
</tbody>
</table>

Although both performance speed and accuracy data were gathered for this experiment, performance speed was considered the more important factor of consideration. An ANOVA was performed on the summed accuracy totals. After reviewing the accuracy data, no significant differences were found, as shown in Table 5. The lack of significance in accuracy suggests that participants were able to perform accurately on the task, and that there was no speed-accuracy trade-off due to the low number of errors in performance. Performance speed data is subsequently the only data referenced in the discussion section.
Table 5

Accuracy results

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial $\eta^2$</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>7920.20</td>
<td>7920.20</td>
<td>114050.88</td>
<td>&lt;.001</td>
<td>.999</td>
<td>1.000</td>
</tr>
<tr>
<td>Camera</td>
<td>3</td>
<td>.30</td>
<td>.10</td>
<td>1.44</td>
<td>.238</td>
<td>.057</td>
<td>.366</td>
</tr>
<tr>
<td>Display</td>
<td>1</td>
<td>.20</td>
<td>.20</td>
<td>2.88</td>
<td>.094</td>
<td>.038</td>
<td>.388</td>
</tr>
<tr>
<td>Interaction</td>
<td>3</td>
<td>.30</td>
<td>.10</td>
<td>1.44</td>
<td>.238</td>
<td>.057</td>
<td>.366</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>5.00</td>
<td>.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td>7926.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion

The purpose of this study was to evaluate the impact of camera placement and display configuration on a remote manipulation task. Whether exploring outer space, deep water, or another non-human-friendly environment, the ability to perform a task is restricted to remote manipulation and remote viewing. Finding the best placement when using multiple cameras for remote viewing could impact the performance time and accuracy of completing a remote manipulation task. When using multiple cameras, it is also important to determine the best way to translate those camera views. Finding the best display configuration match with the best camera placements could help optimize the performance speed of a remote manipulation task.

In this sample of 80 college students, there was a significant difference in the performance of a remote manipulation across camera placements. In other words, participants completing the manipulation task using the normal camera placement performed worse than those using the right, reverse, or left camera placements. There was also a
significant difference in the performance across display configurations. Participants completing the manipulation task using Configuration 1 performed worse than those using Configuration 2. Configuration 1 showed the top-down view on the left display and the other camera view (normal, right, reverse, or left) on the right display. Configuration 2 showed the top-down view on the right display and the other camera view (normal, right, reverse, or left) on the left display. Also, the normal camera view was noticeably worse in both configurations compared to the right, reverse, and left views in both configurations. The statistically significant main effects of the camera placement variable and the display configuration variable, as well as the significant interaction, could all be attributed to the results of the normal camera view conditions. Without the normal camera view conditions included in this study, there would most likely have been no statistical significance found in any of the conditions. In other words, the interaction shows that which configuration to use would depend on camera placement, and vice versa.

The effect size produced by camera placement expressed by partial Eta squared = .302 indicated that about 30% of the variance in the study was due to camera placement. The effect size of display configuration expressed by partial Eta squared = .063 indicated that only about 6% of the variance in the study was due to the configuration of the displays. The effect size of the interaction between camera placement and display configuration expressed as partial Eta squared = .106 indicated that about 11% of the variance in the study was due to both camera placement and display configuration. In other words, while all factors were found to be significant, only camera placement, with a variance of 30%, probably made any real impact on the results.
The results of this experiment did not reflect the proposed hypotheses. It was hypothesized that the right and left camera views would be better than the normal and the reverse camera views. The results actually showed that only the right and left camera views were significantly better than the normal camera view \((p < .001)\). The normal camera view was also found to be significantly worse than the reverse camera view \((p < .001)\). The reason for the normal view being worse than the other views could be attributed to the way the normal view is presented. In the normal view conditions, the camera was positioned at 0° behind the remote manipulator arm. Since the arm blocked the view of everything in front of it (ring and dowel), the participant was only able to use the top-down view to perform the task. Because the participant was only using one camera view, the normal camera placement condition essentially became a single camera view compared to the right, left, and reverse camera placement conditions in which participants could utilize both camera views. Being only a single camera view, the normal camera placement condition lacked all the benefits of the multiple camera views, including the ability to see the task area from all three dimensions. Unfortunately, since the participants could only see the remote manipulator arm moving along the x axis and y axis, they could only guess at how to move the arm along the z axis, thus adding extra time to their performance rates on average.

It was hypothesized that the normal camera view would be similar between Configuration 1 and Configuration 2 of the displays. The results showed a significant difference \((p = .001)\) between the configurations in the normal camera view. According to Figure 8, it appears that Configuration 1 was quite a bit worse than Configuration 2. A possible reason for this difference is due to the fact that only right-handed participants were tested. Since the participants were only able to use one camera view during the normal
camera placement conditions, they were essentially using either the top-down view on the left side in Configuration 1 or on the right side in Configuration 2. According to Corballis (2003), more than 90% of the human population is right-hand dominant. It is commonly known that the left and right hemispheres of the brain control the right and left sides of the body, respectively, and that right-handed people are typically left-dominant in their hemispheric control (Cardwell, Clark, & Meldrum, 2004). Right-handed people are typically better at motor functions, while left-handed people (right-hemisphere dominant) are typically better with spatial recognition. A study by Porac and Coren (1981) suggested a correlation between right handedness and right eyedness. Their results showed 88.2% and 71.1% of the participants preferred using their right hand and right eye, respectively. In this line of thinking, it is possible that right-handed/right-eyed people also prefer to view things on their right side. Although no studies were found that researched a specific relationship between handedness and viewing side preference, the other studies relating handedness and eyedness could offer a possible explanation as to why participants in this study performed better in Configuration 2 than Configuration 1 during the normal camera placement conditions.

A possible alternative explanation why Configuration 1 was worse than Configuration 2 in the normal view could be attributed to the sequence of conditions run during the experiment. Because of space issues in the lab, and access to minimal equipment (only two cameras), the order of conditions was run with participants completing each condition before moving the 2nd camera and starting the next condition. The order of conditions was as follows: normal, right, reverse, and left, each with Configuration 1 followed by Configuration 2. Although the normal view Configuration 1 was significantly worse than Configuration 2 (while all other conditions had no significance), it is unlikely that the
sequence of conditions affected the results much because a pilot study was performed. Having run through the procedure during the pilot study, no changes to the procedure were evident during the live testing and therefore is a limited explanation to account for the difference between the normal view conditions.

It was hypothesized that the reverse camera view would be similar between Configuration 1 and Configuration 2 of the displays. The results showed no significant difference between configurations in the reverse camera view \( (p = .762) \).

It was hypothesized that the right camera view would perform significantly better in Configuration 1 than Configuration 2. The results showed no significant difference between configurations in the right camera view \( (p = .678) \).

It was hypothesized that the left camera view would perform significantly better in Configuration 2 than Configuration 1. The results showed no significant difference between configurations in the left camera view \( (p = .462) \).

It was hypothesized that the right camera view in Configuration 1 would be similar to the left camera view in Configuration 2. It was hypothesized that the right camera view in Configuration 2 would be similar to the left camera view in Configuration 1. It was hypothesized that an interaction would be seen between the right camera view and the left camera view. The results of this study were unable to show whether there was any statistical difference between any of these conditions because any difference between these comparisons could be attributed from either the camera placement or the display configuration.
Limitations

One of the limitations of this study was the design of the camera and display variables. Since previous studies almost always included normal and reverse camera views, the goal of this study was to compare these to the right and left camera views to see if there were any differences. Also, it originally made sense to separate the display variable into Configuration 1 and Configuration 2, changing only the camera views being shown on the right side and the left side. Instead of focusing on simply switching the camera views from side to side between Configuration 1 and Configuration 2, conformal versus non-conformal display views could have been tried. However, since this study kept the displays horizontally side-by-side, the physical conformality principle on which the hypotheses were being based could only apply to the right and left views. Conformality could only be applied to the normal and reverse camera views if the displays were placed vertically one above the other. Unfortunately, it was later realized that because of this study’s design, it would be impossible to statistically compare individual conditions and address several of the proposed hypotheses.

Another limitation of this study was the horizontal positioning of the four camera views. Although each camera was arranged at either 0°, 90°, 180°, and 270° along the x and y axes from the remote manipulator arm, all four cameras were at 0° horizontal along the z axis. Vertically displacing the cameras along the z-axis could affect the visual field, especially in the normal camera view. Moving the normal camera up high enough could have eliminated the obstruction (remote manipulator arm) and allowed the participant to use the normal camera view in addition to the top-down view.

A third limitation of this study was the lack of contrast of the dowel rod during the reverse camera viewing conditions. In an effort to create more contrast, the dowel rod was
painted black. In the top-down, normal, right, and left camera views, this contrast was helpful to the participants. Unfortunately, a lack of contrast was discovered during the reverse camera viewing conditions when the black dowel rod blended into the dark underbelly of the remote manipulator arm. The display monitor did not reflect the amount of contrast shown through the camera or seen with the naked eye. Several participants commented on the difficulty in seeing the dowel rod while the remote manipulator arm was still holding the plastic wring in a high position. As soon as the arm was lowered to a certain point, the participant was able to use the contrast of the outside of the arm for reference.

**Future Studies**

In order to overcome some of these limitations, there are several directions that future research could take in studies similar to this one. One avenue of research is to explore multiple camera views using multiple display conformality by comparing right and left camera views using multiple, horizontally-placed displays versus normal and reverse camera views using multiple, vertically-placed displays. Another possible research direction would be to use vertical displacement for all camera views to ensure the use of multiple display views. One more possible research direction would be to use a different colored dowel rod in order to keep optimal contrast in all viewing conditions.

**Conclusion**

Present day scientists are continuously searching for new ways to perform tasks in harmful or inaccessible environments, such as deep water and outer space. Working in any difficult environment involves two similar characteristics – the use of cameras for remote viewing and the remote manipulation of equipment. Finding the optimal way to position the cameras could affect the speed and accuracy of a remotely operated task. The purpose of this
study was to find the best way to use multiple camera views during a remote manipulation task.

Overall, the results of this study showed that there appears to be a statistically significant difference between the normal camera view and each of the other camera views, as well as a difference between Configuration 1 and Configuration 2. However, these differences probably would only be significant to real world applications where every second counts, such as bomb deactivation. In most inaccessible environments, performance speed is probably significant when measured in minutes. According to the results of this study, it doesn’t matter whether a right, left, or reverse camera combination is used, or whether those cameras are viewed on the left or right side of the displays. Having an unobstructed view appears to be a key ingredient in optimal performance.
References


Appendix A: The Effect of Camera Placements and Display Configurations on a Remote Manipulation Task

Conducted by Debra Clark
Advisor: Dr. Shawn Doherty
Human Factors & Systems Department
Embry-Riddle Aeronautical University
Daytona Beach, FL

The experiment you are about to participate in is concerned with camera placements and display configurations during a remote manipulation task. The purpose is to investigate the best placements for multiple cameras viewing the remote manipulation task, as well as the best configuration for the displays showing the multiple camera views. The experiment will consist of a remote manipulation task where you will be asked to thread a plastic ring around a dowel by operating a remote manipulator arm. You will view the task via two displays that will show the task area from two camera views. You will be allowed up to 20 trials to complete the task. You will need to complete the task completely and as quickly as possible. You will have 2 minutes to practice using the remote manipulator control before beginning the task. The task will take between 30-45 minutes.

There are no known risks associated with this experiment. You will be compensated for your participation with extra credit in your specified class. That extra credit may only be applied to one course. The data gathered for this study is considered confidential, and your participation will remain anonymous. You may terminate your participation at any time. Your assistance will help us understand better ways to view remote manipulations. You may receive a copy of the completed consent form upon request.

Thank you for your participation. If you have any questions, please ask during the experiment or feel free to email me at daclark@yahoo.com or my advisor at dohertsh@erau.edu

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed as to the general scientific purposes of the experiment, and that I will receive extra credit for my specified class upon completion of the experiment. If I withdraw from the experiment before completion, I will not receive extra credit.

Participant’s Name (please print): ____________________________

Signature of Participant: ____________________________ Date: __________

Experimenter: ____________________________ Date: __________
Appendix B: Demographics

1. Name: __________________________________________

2. Age: ______

3. Gender (check one):  Male _____
                        Female _____

4. Handedness (check one): Right _____
                         Left _____

5. Vision (check one):   Normal 20/20 _____
                        Correctable to 20/20 _____
                        Non-normal or non-correctable _____

6. Do you have any experience operating a remote manipulator arm? (check one):
   No _____
   Yes _____
   If yes, please describe your experience operating the arm: ____________________________
   If yes, which type of control did you use to operate the arm (check one):
       Joystick _____
       Push-button _____

7. Do you play video games often? (check one):
   No _____
   Yes _____
   If yes, how often do you play? _____________________________________
   If yes, what types of controls do you use? _________________________________

8. When do you feel most alert?
   Morning _____
   Afternoon _____
   Evening _____

9. Spatial Test:  1. _____
                 2. _____
                 3. _____
                 4. _____
                 5. _____
Appendix C: Spatial Ability Test

Item 1: Block Rotation
Item 2: Block Rotation

A

B

C

D

E
Item 3: Block Rotation
Item 4: Block Rotation

A

B

C

D

E
Block Rotation Subtest Answers
Item 1=A
Item 2=B
Item 3=A
Item 4=C
Item 5=E
Appendix D: Debriefing

The experiment you have just participated in is attempting to investigate the best combination of multiple camera placement and multiple display configuration while performing a remote manipulation task. Remote manipulation tasks have become widely used in extreme environments, such as outer space, deep water, and nuclear reactor sites. Previous research (e.g. Mackro, 1973; Smith & Stuart, 1989; Plishka, 2002) focused on directly viewing a task or indirectly viewing a task via a single camera. The current study is attempting to investigate if the use of multiple cameras and displays will improve performance accuracy and speed. Several explanations can be offered to explain an improvement:

1. **More viewing angles.** Being able to see all three axes of the task area will allow an operator to use all available visual information to decide where to direct the remote manipulator arm. The operator should be able to save time by viewing only one display at a time, maneuvering the arm into position on one display before looking at the other display.
2. **Fewer viewing obstructions.** The more camera angles shown, the more the operator can see another side of anything blocked from view.
3. **Optimal display positioning (conformality).** When using conformal positioning, the operator should be able to perform a remote manipulation task quicker by spending less time computing the movements of the remote manipulator arm on the displays.

The current study altered the camera placement, which investigated the viewing angles that allowed the most complete views, as well as display configuration, which compared whether a side view display placed to the right or the left of the top-down camera view produced the best performance. Your participation can help us determine the best combination of cameras and displays to use during a remote manipulation task.

If you have any further questions, please ask or contact Debra Clark via email at daclark124@yahoo.com. Thank you once again for participating!

If you’d like more information on this topic, please see these additional reading resources:

