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Perception And Displays For Teleoperated Robots

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PERCEPTION AND DISPLAYS
FOR TELEOPERATED ROBOTS

by

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ABSTRACT

In remote or teleoperational tasks involving humans and robots, various aspects of the remote display system may greatly influence the individual's interactions with the teleoperated entity. This dissertation examined various configurations of display systems on several measures of operator performance, physiological states, and perceptions of the task. Display configurations included altering the camera placement (attached to the robot or placed overhead), screen orientation (horizontal or vertical), and screen size (small or large). Performance was measured in terms of specific task goals, accuracies, strategies, and completion times. Physiological state was assessed through physiological markers of arousal, specifically heart rate and skin conductance. Operator perception of the task was measured with a self-reported perception of workload and frustration. Scale model live simulation was used to create a task driven environment to test the display configurations.

Screen size influenced performance on complex tasks in mixed ways. Participants using a small screen exhibited better problem solving strategies in a complex driving task. However, participants using the large screen exhibited better driving precision when the task required continual attention. These findings have value in design decisions for teleoperated interfaces where the advantages and disadvantages of screen size must be considered carefully.

Orientation of the visual information seems to have much less impact on the operator than the source of the information, though it was an important factor of the display system when taken together with screen size and camera view.

Results show strong influence of camera placement on many of the performance variables. Interestingly, the participants rated a higher frustration in the overhead condition, but not a higher task load, indicating that while they realized that the task was frustrating and perhaps they could have done better, they did not recognize the task as overloading. This was the case even though they took longer to complete the task and experienced more errors related to turning in the overhead camera condition. This finding may indicate a potential danger for systems in which the operator is expected to recognize when he or she is being overloaded. This type of performance decrease due to added frames of reference may be too subtle to register in the operator's self awareness.

For Jeremy.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Introduction

For decades, robots have captured our imagination as science fiction writers have showed us numerous visions of a world where robots live and work among us. In today's applications, robots exist in several forms—from completely autonomous (Breazeal, 2003) to completely controlled. While complete autonomy is currently popular with academic endeavors and entertainment robots (Fong, Nourbakhsh, & Dautenhahn, 2003), most robots in use in industry and public service sectors are semi-autonomous or even completely remote controlled vehicles or machines. These types of robots serve important functions, such as searching and rescuing, working on the space station, or assisting military efforts. Murphy and Stover (2008) summarizes some of the limitations of current teleoperated robots, including challenges to mechanical design based on accurate terrain models and the robustness of the robots. While improvements in the field of teleoperated robots are progressing quickly, the field is still in its infancy. Although much research is focused on improvement, little published research has looked specifically at the effects of viewpoint, including camera placement and screen dynamics.

Viewpoint encompasses the placement of the remote view (camera or sensors) and the dynamics of the display mechanism, including size, angle, distance from the operator, brightness, and other attributes. These factors can influence the overall effectiveness of the display system. From soldiers controlling I.E.D. disarming robots to emergency response teams to command center personnel, the operators, tasks, and environments can vary, but their need for optimal display setup is vital to the use of teleoperated robots.

So the question arises, how can viewpoint for teleoperated robots be improved? We can begin to answer this question by drawing from a diverse range of disciplines. Entertainment, previous works in small-scale simulation, cognitive models of the operator, and individual differences can all contribute to this endeavor. Each of these topics will be covered in the Literature Review.

Literature Review

Robotics

Robots have captured the imagination of popular media. There are many types of robots: tiny to huge, simple to complex, completely controlled puppets to artificial intelligence, intellectual game playing to socially driven, assembly plants to entertainment, military to caretakers, designed and inspired by biology and designed to fit into urban environments. For decades, people have been thinking up ways that robots could be used. We are at a point now in the development of the field of robotics that these uses are beginning to be realized. Current applications are diverse and growing all the time.

Teleoperation.

Teleoperation is a common method of navigation and control for robots. Often, remotely operated robots contain little or no artificial autonomy; they are simply remote control vehicles.

For this reason, for the purpose of this dissertation, the terms *robot* and *vehicle* will be used interchangeably. In general, reliable complete autonomy in navigation is not an economical or technological feasibility for many current types of robots. This limitation was seen in the efforts of the DARPA Grand Challenge and similar robot field demonstrations in which autonomous vehicles performed poorly. In a Director Statement in 2005 for DARPA, Dr. Tony Tether stated, “the progress has not been quick enough on the ability to develop an autonomous vehicle that could navigate a long route, avoid obstacles, and do it with an average speed that is tactically useful to the joint forces,” (Defense Advanced Research Projects Agency Director Statement, 2005). Although autonomy is not yet feasible, remote operation exists as a suitable method to control robots in current real-world applications. Unfortunately, teleoperation has its drawbacks, including signal transmission and latency issues, robots becoming stuck, and operators having an incomplete understanding of the robot’s surroundings. Often the information available to the human operator is gained through visual displays. Navigational or tactical decisions must be made based upon that information. A more complete understanding of the human reaction to the remote video display can help improve the design of the human-robot interface.

Remote operated small-unmanned ground vehicles.

The tasks constructed for this dissertation are modeled after real-world applications of small, unmanned remote-operated robots. The kinds of applications that robots of this type could be and are currently being used for are diverse. Unmanned vehicles have been used in recent military operations, including aerial, ground, and underwater reconnaissance, and they are in development for tasks such as wounded evacuation and secure sentry operations (AUVSI, 2005). Other applications include use by Fire, Police, or EMS units. Robots have been tested for use in search and rescue operations in urban disasters, such as mudslides, earthquakes, hurricanes, and collapsed buildings. (Burke, Murphy, Rogers, Lumelsky, & Scholtz, 2004; Murphy and Stover, 2008). In the near future, people will need to operate robots in highly remote or hostile environments, such as on other planets. (See TAGS: Lewis, Mitchel, & Omilon, 2004 for a more complete review of unmanned ground vehicle applications). Unmanned ground vehicle robots are employed by such agencies as the Military or Department of Defense Joint Robotics Program, (e.g., as part of the Future Combat System Program, the research efforts of the Defense Advanced Research Project Agency, the Army, and Emergency Management) (Carlson, Murphy, & Nelson, 2004).

Previous Research

Previous research suggests that in teleoperations, the viewpoint (size and angle of the display and camera placement) affects performance of the operator and perceived difficulty of the task. While conducting the research on human perception of autonomous robots (Pepe, Ellis, Sims, & Chin, 2008; Ellis et al., 2005), the researchers noted certain difficulties exhibited by participants regarding the point of view during verbal communications with the robots. Specifically, participants seemed to be having trouble adjusting to the frame of reference of the robot. The participants' task in the experiment was to give verbal advice to the robot on which way to go in order to accomplish simple goals, such as exiting the maze. Verbal advice was expected from the operator in the form of directional instructions, "go forward", "turn left", "stop." In this teleoperational task, the participant was in a separate room from the robot and only had a live overhead view of the maze displayed on a conventional monitor with which to work. The difficulty was seen in the verbal mistakes that some participants made while interacting with the robot. Although participants were told to instruct the robot which way to go from the point of view of the robot, some participants still reverted to instructions like, "*go left, good, now go up*." The robot could not go up, since it lacked the ability to jump, climb, or move in a vertical way, nor would going "up" have been of any help in completing the task. These incorrect direction commands may have been the result of the participant concentrating on the visual representation of the robot traveling up the screen, thus using the term "up" to mean a direction relative to the operator's own body. This mistake highlights a difficulty some participants had in directing a robot that has a reference frame different from their own. The participants' cognitive representation of the reference frame of the robot may have been confounded or rendered inaccessible due to the provided display setup. The setup gave navigational data in a static orientation that failed to correlate to the orientation of the robot within the maze.

The interaction between viewpoint and task difficulty was corroborated during the setup of a second robot-maze study (Pepe et al., 2006). In this second study, difficulty with specific display viewpoints occurred for even the experimenters and technicians, who had considerable direct experience controlling the robots. The study involved recording a video of the robot navigating the maze on a highly choreographed path with a controller attached to a nearby desktop computer. The robots moved very slowly and occasionally exhibited unpredictable movements due to lag and uneven surface. As a result, many attempts were needed to record the videos from the camera positioned directly over the maze. The challenge was to produce a flawless video recording run, with no false turns or hesitations for the entire ten-minute drive through the course. During this process, many configurations of the setup were attempted to improve the quality of the robot's run. Full screen mode was introduced, as it was expected that a larger representation would aid performance. Since the robots moved so slowly, increasing the quality and refresh rate of the video display had limited impact. Moving the control mechanism to a position that allowed direct viewing from a 3/4 overhead view (45° angle from above) of the maze area achieved the most improvement. This informal observation led to the question of what specifically causes the difficulties in the teleoperation. The small size of the display monitor inherently compresses the data into a smaller format, which could be contributing to poor performance. Perhaps the camera viewpoint of directly overhead, while providing clear map-like information, is not as helpful as the 3/4 view, which may obscure some areas but provides a more ecologically familiar view. Therefore, this dissertation examines the following variables: screen tilt, screen size, and camera placement. The contributions of the various aspects of viewpoint are examined independently, as well as together, in order to have a clear understanding of the overall role they play in teleoperation.

Research on large displays has shown that people respond to screen size, and certain abilities may be affected. Tan, Gergle, Scupelli, and Pausch (2006) suggest that physically large displays, even at identical visual angles as small displays, increase performance on spatial tasks, such as 3D navigation, as well as mental map formation and memory.

Modeling the Operator State

Teleoperation typically involves directing a robot's motions, navigation, through control mechanism, while relying on continually updating information gained by the robot, usually visual, such as from a camera, presented on a screen at a remote location. There are a few important portions of this task that must be addressed from the psychological aspect of the operator.

Self motion and navigation

When humans and animals travel by walking, several internal systems of the body aid them. Visual cues are augmented by somatosensory, proprioceptive, and vestibular cues. The somatosensory system provides information about touch, and the proprioceptive systems help the person to know how his or her own body has moved. Within the vestibular system, the inner-ear organs are stimulated by physical acceleration. The vestibular system is important for estimating distance traveled, even if the physical means of travel are not one's own body, as was shown in (Berthoz, Israel, Georges-Francois, Grasso, & Tsuzuku, 1995). The experiment involved individuals riding passively on a robot, which moved forward in runs of various velocities and distances. Then, while blindfolded, the individual would reproduce the movement by again riding the robot, but controlling it with a joystick. Individuals were able to reproduce whole body displacement movements by reproducing the velocity profiles. In order to accurately reproduce the distance traveled, participants would try to drive at the same speeds that they had experienced in the run. This suggests that spatial (and temporal) patterns of motion can be stored and then retrieved, even while blindfolded, using vestibular and somesthetic cues.

These internal mechanisms of the body are important to the design of teleoperation in two ways. First, while they normally help individuals understand and navigate their surroundings, they can be counterproductive during a teleoperation task, as the operator is not moving. Imprecise estimates, overreactions to visual stimulus, and even simulator sickness may result from the incongruity of moving visual stimulus and the stationary body. Second, individual operators must rely much more heavily on the visual stimulus provided through the display.

Visual information

During a teleoperation task, only visual information is available to the operator, non-visual cues of vestibular, somatosensory, and proprioceptive cues normally provide complimentary information about self movement are absent. In the absence of physical movement of one's own body, an individual can use visual cues to build an understanding of an environment and their movement within it. The visual information can provide cues for the operator to use to understand the relationship of objects, as well as perceived motion, through several means. This requires an interpretation of both static and dynamic spatial information. Static information provides some relationship information, but dynamic information is also important.

Changes in the retinal image cause the perception of motion. These changes can be called optic flow or streaming perspective (Gibson, 1979; Coren, Ward, & Enns, 1999). For instance, in forward motion, the visual array seems to radially expand outward from the center of the visual field. Imagine driving down a straight road looking ahead: trees in the distance at first are close together, then widen or move away from each other outward until they pass by either side of the car. In lateral motion, however, the visual array seems to slide in a lateral direction, with closer objects sliding faster than further objects. This phenomenon is known as parallax, and it can be seen when a shift in perspective causes an apparent motion of an object against a more distant object or background. Again, imagine riding down a straight road looking out the side window:

closer objects, such as telephone poles, slide quickly by, while farther objects slide more slowly, such as mountains. The relative speed and direction of objects within the visual field resulting in phenomena, such as optic flow and parallax, can provide valuable cues about self-movement, as well as the relative placement of those objects to each other. These phenomena are mostly present in visual presentations of first-person motion, such as teleoperation with the camera mounted on the robot, but absent with a stationary camera.

Virtual environments offer a unique way to study optic flow and distance estimation. Redlick, Jenkin, and Harris (2001) found that navigation of self displacement using visual cue alone is possible. However, low accelerations (below the vestibular threshold) can produce overestimation of distance traveled; that is, participants think they have traveled further than they actually had. Other studies involving visual simulations on large projection screens and fully immersive computer animated virtual environments also indicate that participants can estimate distances using only visual information of optic flow (Frenz, Lappe, Kolesnik, & Bührmann, 2007; Frenz & Lappe, 2005). These studies used a setup where participants first viewed self-motion videos and then indicated their estimate of distance traveled in a static image or virtual environment. It was found that although individuals can estimate distances intervals that correlate with traveled distances, they consistently underestimate the travel distance.

Teleoperation and viewpoint

Similar to virtual environments, the teleoperation task may provide only visual information without actual motion of the operator’s own body. We may expect to see similarities in behavior of operators, such as poor estimates of distance traveled. Additionally, the placement of the camera may play an important role in this context, as the optic flow and parallax cues would be skewed (in the case of a camera off to the side or not facing directly ahead) or even absent (in the case of a stationary camera).

During a remote control or teleoperation setup, the operator must attend to multiple tasks. In the case of solely visually directed navigation, the operator has a visual stimulus conveying the location and direction of the remote vehicle, and a control mechanism by which he or she must direct it. In essence, the operator must maintain multiple frames of reference and viewpoints simultaneously: the reference frame of his or her own body, the viewpoints of the visual display mechanism (both the camera and the display screen), and the reference frame of the robot. Each of these concepts may have difficulties or challenges associated with maintaining it. If the challenges are significant, multiple frames of reference and viewpoints may end up competing for the limited capacity of cognitive resources.

Working Memory Models

Cognitive resources are the mechanisms people use to store, process, and recall information. Understanding how the operators' working memory is functioning will help us design a display system that can take advantage of the structure of the brain instead of working against the way the operator thinks. Working memory can be defined as a limited capacity system responsible for the active maintenance and manipulation of relevant information to current task goals (Bayliss, Jarrold, Baddeley, & Gunn, 2005). Conceptual models of working memory can help us predict and understand what is happening inside the mind of the teleoperator.

Baddeley's model

To begin looking at models of working memory, we must first consider the seminal model presented by Baddeley and Hitch (1974). In short, this model can be described as three mechanisms working together to make up working memory. The central executive system helps direct attention, among other things, and is aided by two subsystems (Miyake & Shah, 1999). The phonological loop holds verbal or auditory information, and the visuo-spatial sketchpad holds visual or spatial information. This early model provided a valuable means of understanding the mechanisms of working memory, and it served as a catalyst for a whole body of research that helped to refine these subsystems. This research examined the phenomenon of information interfering with one or the other of the subsystems. As a consequence, the model of these areas was refined and made more elaborate, adding a passive store with rapid decay of information —a few seconds—and an active process used for rehearsal (Kauer & Stegmaier, 1997). Since these elements working memory have only so much room, researchers could determine the capacity of the processing loop by overloading these areas. Most importantly, early work indicated that verbal information interferes with other verbal information, and visual interferes with other visual information. This early work reinforced the model of two distinct reservoirs with separate capacities.

Revised models of working memory by Baddeley (2001) divided the phonological loop into two parts, a short-term acoustic or echoic store, which passively holds information for immediate use but has a rapid decay of only a few seconds, and the articulatory rehearsal system, which actively rehearses information to retain it in working memory. Studies that test memory recall of similar sounds show evidence for this structure (Baddeley, 2001). Less work has been performed on the revision of the visuo-spatial sketchpad. Some studies point to separate sections that are responsible for storing immediate visual information, such as color and shape, and another section responsible for spatial encoding (Baddeley, 2001). This immediate visual memory can be seen when using a type of test called the pattern span, which requires participants to reproduce a pattern of black and white squares immediately after being presented. The immediate visual information holding area is similar to the acoustic store, and has a rapid decay. When people think about visual or spatial information for a length of time or manipulate that information, they are using the other part of the visuo-spatial subsystem, i.e., spatial memory. This portion of the subsystem has been often examined using the Corsi Block-Tapping Task developed by Kessels, van Zandvoort, Postma, Kappelle, and de Haan (2000). In this task the participants must repeat a pattern of movement involving a set of blocks in the correct order. Unlike the pattern span test, the order of the blocks is important and must be maintained in spatial memory in order to reproduce the pattern properly, somewhat like the verbal rehearsing that happens in the articulatory rehearsal system.

Some studies have used the Corsi Block-Tapping Task to demonstrate how the central executive may play an active role in visuo-spatial memory by helping to design a route from one block to the next within the Corsi pattern. For instance, performance on the task has been linked to memory for verbal descriptions of a route (Pazzaglia and Cornoldi, 1999). This suggests that the way people plan routes and think about the spatial relationships of items utilizes the visuo-spatial sketchpad, as well as the central executive. The central executive, again, is responsible for directing attentional resources within working memory, among other things. Edward, Jonides, and Reuter-Lorenz (1998) performed a study that showed that when participants were hindered from attending to memorized locations, their spatial working memory was impaired. It was argued that the results implicate selective spatial attention as a rehearsal mechanism for spatial working memory. This study and others, such as Smyth and Scholey (1994) and Klaur and Stegmaier (1997), explore the connection between spatial attention and spatial working memory in more depth. These studies demonstrate that although spatial attention and spatial working memory are distinct, they may share a resource pool and interfere with each other within the subsystem of the visuo-spatial sketchpad. If this is the case, adding information to the spatial working memory may also hinder spatial attention, and vice versa. The studies of Rudkin, Pearson, and Logie (2007), which utilize the dual task paradigm, indicate that the visuo-spatial tasks may be interfering with each other by involving the central executive. This interference effect in the central executive seems to be supported by studies of brain activity. Singhal (2006) and Robitaille, Jolicoeur, Dell'Acqua, and Sessa (2007) suggest that spatial and object-based working memory utilize common processing resources. Given that people have this limited capacity as described above, the potential for overloading the cognitive resources is present in teleoperational tasks. Therefore, performance and perceived workload may be affected by an overload of the cognitive resources.

Rehearsal

The temporal nature of working memory requires that information be rehearsed in order to maintain it in working memory (c.f. Hanley and Thomas, 1984). This rehearsal can be interrupted by significant distractions, or overloads of the working memory. If the information rehearsal is interrupted, then it would need to be reloaded into working memory, for instance drawn from long-term storage, or entered in through senses again. Additionally, studies have shown that only a limited amount of information can be rehearsed at a time. Miller (1956) implied that seven, plus/minus 2, simple elements, such as numbers or words, can be held within working memory with continuous rehearsal. Although the newer studies suggest that a much larger amount of informational chunks can be maintained in working memory when those chunks are multimodal in nature (e.g., verbal, visual, tactile and other modes) (Stanney et al., 2004), an individual's working memory is still of limited capacity.

An external frame of reference is a unit of information that requires continual rehearsal in order to be maintained in working memory. When a task, such as teleoperation, requires simultaneous rehearsal and updates to multiple separate frames of reference, each of these units of information occupy space in the rehearsal area and may interfere with each other in working memory. Given this overload, one would expect to see a reduction in performance with the addition of each separate frame of reference, or conversely, an increase in performance with a reduction of frame of reference conflicts.

Spatial Ability

The ability to navigate and function in the three-dimensional world around us is possessed by everyone, but people have different aptitudes in this area. Spatial ability aptitude can be measured. Some examples of spatial ability have to do with: mentally rotating and manipulating three-dimensional objects (spatial visualization), comprehending elements of a three-dimensional space (spatial orientation), or comprehending a set of elements in relation to themselves independent or in relation to one's own body (McGee 1979). Others have defined more precise divisions between types of spatial ability, and have constructed means to measure these within individuals. More recently, Carroll (1993) defined spatial ability domains in a broader set of distinctions, including five primary measures, which are then subdivided further. Although much research has been done on testing abilities within these domains in order to have more complete distinctions, these distinctions are concentrating on manipulating or comprehending objects or visual patterns that are external.

Other research has examined spatial ability as it relates to a person's own body. When asked to perform transformations and rotations of their own body, people exhibit different reaction times that depend on the amount of rotation (Parsons, 1987). The further the rotation was removed from the person's own body orientation, the longer his or her reaction time became on the response. This has bearing on teleoperational tasks in that the controller mechanism and the screen interface may be adding the need to make mental translations from the orientation of the operator's body.

Lorenz and Neisser (1986) studied spatial ability more in the context of real world navigation, and the ability to orient in a real world space, thus including concepts of landmark memory, route knowledge, and awareness of geographic direction in the distinction of spatial ability domains. This study looked at the ability to have imagery or imagined movement within a space without movement, and conversely the ability to move oneself within a space while comprehending the spatial relationships of it. Thus, a person may imagine a space and mentally navigate within that imagined space without actually moving his or her body through that space, but, it is not possible to effectively navigate within a space without having a spatial representation or mental understanding of that space. This has implications for understanding virtual or remote spaces. As people move around in space, they form mental maps or representations in their mind of that space. Through studies that utilized a dual task methodology (map drawing and spatial tapping task) to interfere with either the learning or the recalling of map information, Coluccia, Bosco, & Brandimonte (2007) showed that visuo-spatial working memory was essential to learning or recalling this mental understanding of the space.

Diaz and Sims (2003) studied the effect of individual spatial ability on the spatial knowledge gained from virtual environments. Participants were given views in a virtual environment from overhead, first person, or a combination of the two while they learned the position of seven targets. Spatial knowledge was tested by the ability to locate these targets in the physical building. Results indicate that success in navigation is a function of individual spatial ability, display viewpoint, and the individual task. For this reason, analysis of individual spatial ability is expected to show varying interactions with viewpoint and type of performance variables.

Measuring spatial ability

Individual differences in spatial ability can be measured using a number of different tests. Spatial ability and related abilities are commonly included in batteries of tests used for a variety of reasons, from general assessment, to suitability for particular jobs, to training purposes. For example, cut-to-length timber harvesting requires operators to have a wide variety of skills, such as memory functions, comprehensive perception and spatial perception, as they operate the modern harvesting equipment (Ovaskainena & Heikkiläb, 2007). Air traffic controllers also undergo spatial ability tests (D'Oliveira, 2003). Individual differences exist in spatial ability, including between age (Voyer, Voyer, & Bryden, 1995), and sex (McGee, 1979), see also Linn and Peterson (1985).

Spatial navigation

Literature on orienteering, map-reading, and spatial navigation may provide clues for designing tasks that are cognitively challenging. Because the competitive orienteer must use a compass and map simultaneously moving himself or herself through the terrain, there are several frames of reference that are in play: the map, the compass, the planned route, and the person's own body direction. Interestingly, most maps orient North as upwards, but anecdotal observations of orienteering experts show that the fastest and most efficient orienteers do not consistently hold their map with north facing up but rather with their current route direction facing their direction of travel so that they are the same. This reduces the conflict between the two frames of reference. Laboratory studies confirm that viewer centric maps are preferred to exocentric maps (c.f. Hegarty and Ferguson, 1995).

Mental rotation

Some tasks, such as reading a map, may require a mental re-orientation of a person's viewpoint or a mental rotation of an object in order to evaluate that object. This type of mental rotation has been shown to require a measurable amount of cognitive processing, relative to how much mental manipulation is required. For example, when comparing two perspective drawings of either the same or different three-dimensional objects, reaction time was found to increase linearly with angular difference in portrayed orientation (Shepard and Metzlers, 1971). In some instances, rotating the map is an easy way to improve navigation task performance. These observations help put into perspective the impact that viewpoint will have on a teleoperation task, since orientation of the viewpoint will most certainly be affected by the camera placement and the screen orientation. It is expected that both of these orientation components of viewpoint will play a major role in the usefulness of the navigational data. Thus, the current study includes tasks with turning components and fine orienting manipulations as performance measures.

Telepresence Literature

The interpretation of viewpoint can also be linked to the operator's sense of involvement with a represented place. Various terms are used in literature to describe a person's sense of involvement with a place that is represented by a display. These include presence, telepresence, and immersion. Witmer and Singer (1998) use the term presences to describe an individual's subjective feeling of being in a place, even if not physically there. Some research distinguishes between a sense of being in a remote virtual and a remote real environment. Hendrix and Barfield (1996) use telepresence for remote real and virtual presence for remote virtual or computer generated environment. Draper, Kaber, and Usher (1998) describe varying degrees and types of telepresence, which they define as a sense of being in a remote site, either real or virtual. These degrees include 1) simple telepresence, which is when the person remotely controls a machine such as would occur in a robot teleoperation task, 2) cybernetic telepresence, which is the feeling that one's behaviors and physiological responses are passed through to a remote avatar, and 3) experiential telepresence, which is a sense of feeling present in a virtual or computer world. In this research, we use the term telepresence as we examine teleoperation. Specifically, teleoperated machines are operating in a remote real environment that is being presented through a display mechanism, which may result in a sense of telepresence.

Previous research on telepresence can help us examine aspects of viewpoint in terms of where the operator places his or her sense of self while performing a teleoperation task. One useful distinction that Hendrix and Barfield (1996) put forth is between ego presence, where one feels projected into another environment, and object presence, where an object from another environment seems to be projected into the physical world. This distinction may become very important in a task in which an operator is controlling a remote object. With a strong sense of ego presence, the operator feels more projected into a remote environment, and may act entirely differently than if the operator feels a strong sense of object presence, where aspects of the remote location, such as obstacles or targets, are projected into the operator's personal space.

Measures

Spatial Ability Measures

The Mental Rotation Task (MRT) is a measure of the ability to mentally manipulate three-dimensional objects in a rotational manner (Vandenberg & Kuse, 1978). The test involves a set of questions in which the viewer is presented with a rendering of an object made up of several blocks, and then the viewer compares a series of renderings that show similar or different objects in various rotational presentations. The viewer must correctly identify which renderings show rotations of the same object and which show mirror images of similar objects. See APPENDIX F: MENTAL ROTATION TASK for the complete MRT test. People exhibit individual differences in spatial ability, or the ability to hold and manipulate data regarding spatial relationships of objects within working memory. Spatial ability may have a significant impact on performance for tasks in this study that involve manipulating objects (vehicle and barrels). Also, spatial ability may interact with specific viewpoint setups, such as a mismatched camera placement and screen orientation.

The Guilford-Zimmerman Aptitude Survey, GZAS, (Guilford & Zimmerman, 1948) is a set of ability measures. Parts 5 and 6 have to do with spatial ability. Part 5, Spatial Orientation, is a test of the ability to see changes in direction and position. See APPENDIX E: SPATIAL ABILITY APTITUDE SURVEY for the complete Part 5 test. It involves a set of questions that each show two renderings of the view off the front of a motor boat. The first rendering shows where the boat is headed, the second rendering shows the boat headed in a different way, and the viewer is asked to identify how the heading has changed by selecting from the possible answers. The answer choices are given as icons of the aiming point and slant of the boat. Part 6, Spatial Visualization, evaluates how well the viewer is able to visualize spatial position. It involves viewing a rendering of an alarm clock and a picture with arrows indicating a set of rotations to be applied to the alarm clock. The viewer must choose the correct answer from a set of answer choices showing possible outcomes after the rotations have been applied. MRT captures similar aptitude as GZAS Part 6; therefore, only Part 5 was used in this study. Spatial Orientation may have a significant impact on performance for tasks in this study that involve changes in direction and position.

Workload and the NASA TLX

The NASA Task Load Index (NASA TLX) is a multidimensional evaluation method that looks at a combined workload measure. This combined measure is determined through a weighted average of six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The definitions of each of these subscales can be found in APPENDIX D: NASA TLX . The first three dimensions relate to the demands imposed on the participant, and the last three relate to the interaction of a participant with the task. The weights of the subscales are determined by the subjective importance of each factor towards the workload according to each participant. This is gathered through a pair-wise comparison of the six factors, presented to the participant. Higher weights are given to factors that contribute more towards the participant's perceived workload. The NASA TLX was given as a computer-based rating procedure with two parts. First, a rating scale was presented for each factor that contributed to workload. The scale was from 0 (low) to 100 (high) in multiples of 5. Second, the 15 pairs of factors were presented, and the participant chose which one contributed more to the total workload (Hart & Staveland, 1988). This measure was included to gather subjective workload ratings, because it was expected that workload would be influenced by viewpoint.

Physiological Measures

Various physiological responses are heightened by stress, happiness, or other emotional states. These responses arouse the sympathetic nervous system (Kalat, 1998). Physiological markers of arousal (pulse/heart rate and galvanic skin conductance) were taken as an objective measure of the internal operator state. The BIOPAC System was used to gather these three measures

(BIOPAC System, Inc. http://www.biopac.com). The inclusion of physiological measures in the study was for exploratory purposes, but the results were expected to parallel the performance variables.

Current Research

In summary, the display portion of the human-machine interface for teleoperation tasks contains multiple aspects that may contribute, independently or collectively, to the success of the operator. This research utilizes an experimental design that tests these multiple aspects. Using a small-scale live simulation, the study involves having the operator guide a teleoperated robot through a series of tasks designed to be challenging in a variety of ways. This research investigates various independent variables of the display, including camera viewpoint, screen size, and screen orientation with a between-subjects design. The effects of these variables are measured by variance in task performance, internal operator state, and perceptions of the task.

Studying the human-machine interface involves understanding the human, understanding the machine, and also understanding how the interface affects both parts. The domain of robot teleoperation is an ideal example of where this type of research excels because information about the robot is conveyed to the operator who then uses that information to direct the robot's movements. This cyclical flow of information continuously change the state of the machine and sends new information to the operator; Figure 1 Robot teleoperation illustrates this concept. The visual display and handheld controller make up the control interface. The visual display channels information from the robot to the operator, whereas the controller channels information from operator to the robot. This dissertation looks at the mechanics of the display, which is just one part of the system, and how the operator perceives it.

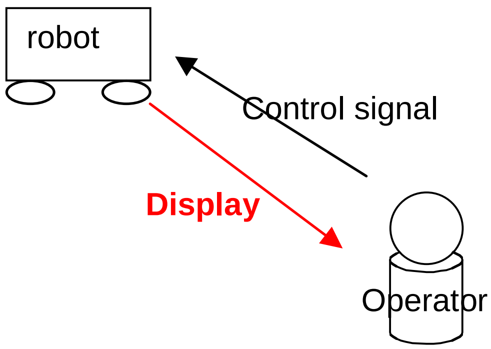


Figure 1 Robot teleoperation, this research looks at the Display portion of the communication cycle between robot and operator.

The design of the control interface can be a helpful or hindering asset to the teleoperator during his or her task. The visual display portion of the interface is especially important, as it is the mechanism that conveys to the operator an understanding of the state of the robot. This dissertation examines the effect of the setup of the display on a variety of dependent variables. A number of hypotheses were constructed relating to these variables. These hypotheses drove the design of several tasks that could test them. The Methods and Materials section contains the individual detailed hypotheses, along with the descriptions of the tasks. In general, it was expected that those conditions in which the camera view matched the display orientation would produce less favorable performance by the operator than those conditions that had mismatched viewpoints. Specifically, the conditions with mismatched viewpoints are the overhead camera position paired with the upright vertical display, and the attached camera position paired with the flat horizontal display. In these conditions, the multiple frames of reference were in conflict, which was likely to increase the cognitive load on the operator, thus leading to lower performance.

CHAPTER 2: METHOD AND MATERIALS

This section contains first a description of the experimental design, then a description of participants. The Apparatus and Materials sections, next, contain specifics about the equipment and surveys/software used. The Tasks Used in the Study section details of each of the four tasks used. Of particular interest is the location of hypotheses within this section. Because there were so many dependent variables, the number of specific hypotheses were rather large. The tasks were created specifically to test these hypotheses, so the corresponding hypotheses for each task are explained in that task's section. A summary of the hypotheses can be found on page 92, Table 5 Summary of Hypotheses. The next section, Measures, contains a description of each of the measures, excluding the performance measures. The Procedure section, last, includes descriptions of the precise order of the experimental procedure.

Experimental Design

This dissertation covers an overall treatment of the effects of size and orientation of the display mechanism in a teleoperational robot-control task. The experimental setup examined viewpoint in terms of camera position, display orientation, and display size. The tasks consisted of teleoperating a robotic vehicle. The participant remote-controlled a physical robot through an obstacle course with specific sub-tasks, such as following paths and collecting environmental objects. Live video was used in the display mechanism to indicate the robot's location within the course, giving the participant visual access to the robot's progression throughout the task.

The study concentrated on establishing the effects of various aspects of the display mechanism and viewpoint on the dependent measures. The experiment was set up as a 2 (small or large size display screen) by 2 (directly overhead or attached to the vehicle camera viewpoint) by 2 (vertical or horizontal display screen) design. The variables were manipulated between participants.

The display mechanism was either a small or large size, where the small condition was approximately 7 inches diagonal, and the large was approximately 30 inches. The orientation was likewise either similar to a standard computer workstation, i.e. vertical, or flat on a table surface, i.e. horizontal.

The camera views were achieved by using one of two differently placed cameras. In one case, the camera was set in a static position directly over the maze. In the second case, the camera was attached in such a way as to seem to be following behind the robot, showing the very front of the robot and the immediate surrounding area in front of the robot. See Figure 2 for a view of the robot from the front. Note how the camera is aimed down to see the area in front of the robot.

The experiment contains a large number of measures, which can be divided into four categories: performance, physiological, perceptions, and individual differences measures. Detailed descriptions of the performance variables can be found in the Tasks Used in the Study Section, page 38. Descriptions of the other measures can be found in their respective subsections of the Measures Section, staring on page 55.

Dependent measures include the following:

- Overall performance was measured in terms of completion of task goals, efficiency, accuracy, and completion times.
- Physiological state was assessed through physiological markers of arousal, specifically, a collection of selected low level physiological measures including heart rate (through electrocardiogram, ECG), pulse, and galvanic skin conductance (through galvanic skin conductance, GSR).
- Perceptions of the task by the operator were also measured through the use of the NASA task load index, as well as questions about frustration and fun.

Individual differences were assessed using a set of spatial ability measures:

- Gilford-Zimmerman Aptitude Survey Part 5 Spatial Orientation
- Mental Rotation Task Parts 1 and 2
- Set of questions on the post questionnaire regarding comfort with the task and controller.

Participants

Participants for the study were drawn from the University of Central Florida undergraduate student population. In total, 123 participants were recruited for the study, but some of them were dropped from some analyses as described in the results due to difficulties with the setup or incomplete data. Participant numbers included in each analysis will be noted throughout. Participants were obtained through the university-approved system of recruitment, Experimentrak, which the Department of Psychology set up for the purpose of facilitating psychological research at the University of Central Florida. Students signed up for the study voluntarily online and received compensation in the form of credit through the system. There were 48 females and 75 males with an average age of 20.5 (SD 3.2) years. The participants were evenly distributed by sex into conditions.

Apparatus

Robot

The robot was assembled from a Lynxmotion 4WD1 Robot kit with two deck add-ons using the Bot Board and Basic Atom electronic components and a Play Station 2 style game controller. Figure 2 shows the robot configurations used in the study. The robot was programmed to move very slowly since the space was small. Slow movement was also better for novice operators. In addition to forward and backward, the robot could turn right and left at any time, regardless of forward or backward movement, allowing it to turn in place. These movements were necessary to navigate the tight corridors of one of the tasks. The game controller was not wireless, as the wireless option introduced additional delay into the system (beyond that of the video display). The robot was programmed to respond to controller signals from just one hat stick (small joystick, or thumb-stick, on the controller), which could be switched to the right or left side depending on the handedness of the participant. The control was as follows: up or away from the participant's body on the joystick caused the robot to travel forward, down or in toward the participant's body caused the robot to travel backwards, any right movement caused the robot to turn toward the right, and left for left. This means that if the joystick was pointed away and to the right, the robot would go forward, but also turn slightly to the right, resulting in an arc. If the joystick were held directly to the right, the robot would turn in place in a clockwise direction.

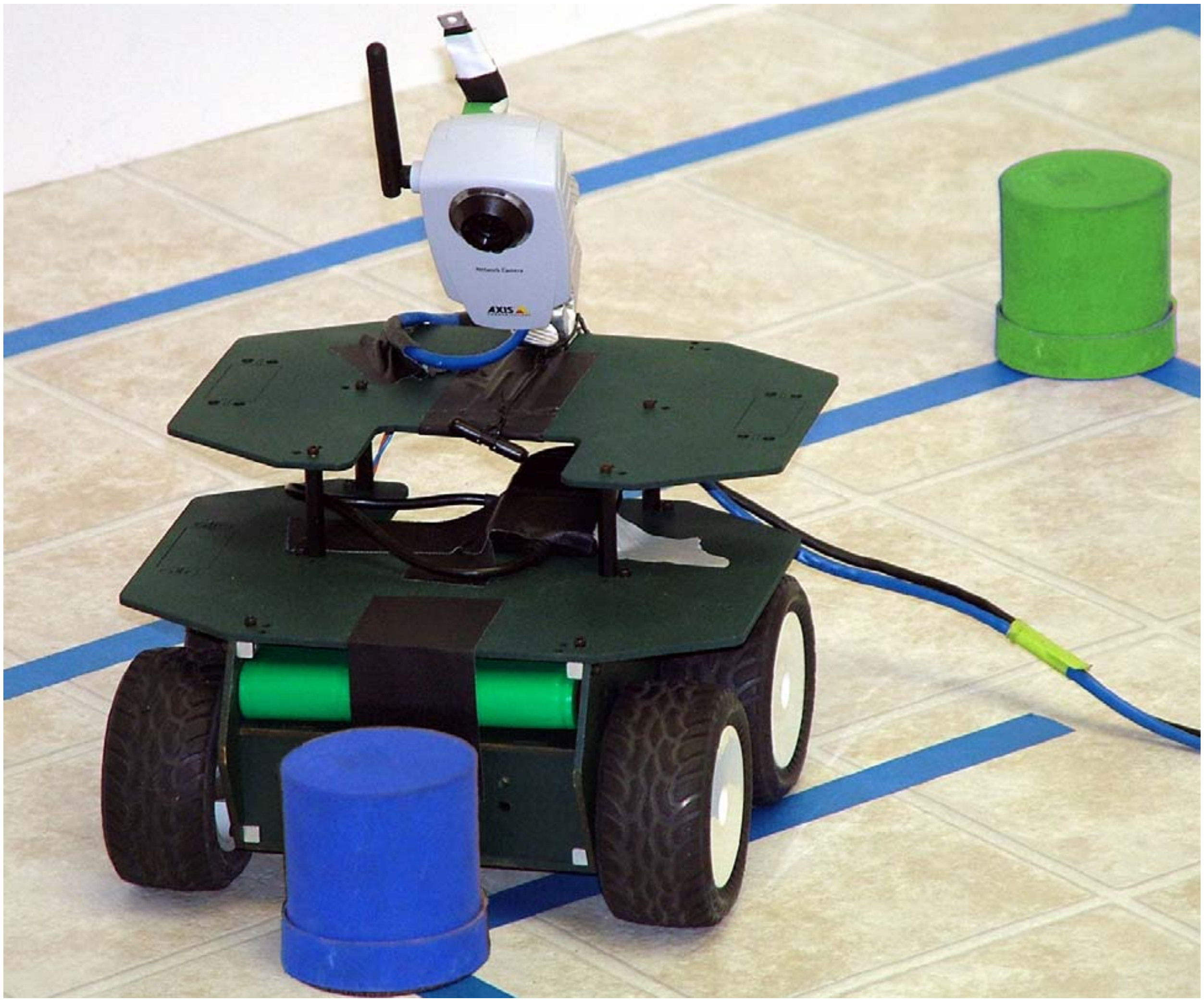


Figure 2 Robot seen from the front, camera attached on the back.

Cameras

Two identical cameras were used in the experimental setup. Then brand was Axis 207W Wireless Network Camera Model # 0241-004. They were both running in Ethernet mode, since the wireless mode introduced delays into the setup and interfered with other wireless devices in the room, such as the controllers. One camera was attached to the robot and one was attached to the ceiling above the task course area. Both cameras were running at 30 frames per second in color streaming JPG through the built-in web server over the dedicated networking equipment. The network was a Linksys WRG54G Wireless Broadband Router, although all devices were connected via Ethernet cable.

Computers

The experimental setup involved two computer workstations, Dell Optiplex 745 Mintower with Intel Core 2 Duo Processor (2.13GHz, 2M, 1066Mhz FSB), running Microsoft Windows XP Pro Service Pack 2. In addition to these two computers, a LACIE 500 GB D2 Extreme external drive was used to store the video and physiological data as it was being recorded. The computer with the external drive was the experimenter computer, and ran the BIOPAC recording software as well as the Techsmith Morae software. It also ran Microsoft Internet Explorer 6.0 in order to view the streaming video from the overhead camera. This computer was attached to a standard desktop display screen. The other computer was used to display the camera viewpoint to the participant. It only ran Microsoft Internet Explorer 6 to display the appropriate streaming camera view during the task portion of the experiment.

Screens

The display mechanism was either a small or large size, where the small condition was approximately 7 inches diagonal, and the large was approximately 30 inches. The display screen is varied by size and orientation to the extreme. Various intermediary steps were considered, such as 45 degree angles or 15 inch laptop size. However, extremes were chosen for this study in order to highlight any possible effects and increase power in the conditions due to limited resources in terms of time and number of participants.

The two monitors used for the large and small conditions were both connected to the participant's computer, though only one monitor was turned on at a time. This computer had an additional graphics card that supported two monitors — one Dual Link DVI and one standard VGA connection. The large screen and small screen were both attached to this computer, and were simply turned off and on depending on the participant's condition. After the tasks, this computer also ran the NASA TLX program for the participant with a standard Microsoft mouse. The large monitor was a 30 inch UltraSharp 3007WFP Wide-Screen Black Flat Panel LCD Monitor and the small monitor was a Lilliput 7 inch Touch Screen LCD 2005 Version. The small screen had a default contrast ratio of 200:1 and the large screen 700:1, so the contrast on the large screen was reduced with the menu to attempt to equalize the two screens. Both screens had a brightness of 400 cd/m2, screen dimension ratio of 16:9 (wide screen), and were using TFT active matrix technology. The small screen had a response time of 30Ms, while the large screen was 11Ms. Both monitors were using VGA input, running 1024x768, and 24 bit color depth.

The two screens were mounted in such a way as to provide similar field of view for all conditions. The large screen was mounted to a specially designed table that was adjustable in height and had a top that could fold flat to be horizontal or flip up to be vertical. The participant's view of the large monitor was adjusted to be a set distance away, so this height adjustment was important to maintain this distance. The small screen was mounted to a smaller wall mount that allowed for height and angle adjustment. The height adjustment was accomplished by raising or lowering the wall placement of the mount arm, and the tilt was adjusted using the built in angle adjustment mechanism of the screen's mounting hardware.

The participant's eye-height was measured by having him or her stand next to a series of markers in the doorway that had been set up for this purpose. This method provided a quick and easy way to start the adjustments to the screen setup for the experimenter at the beginning of each experiment. Final checks to the adjustments were made using a hand held tape measure to verify that the field of view was correct for each participant.

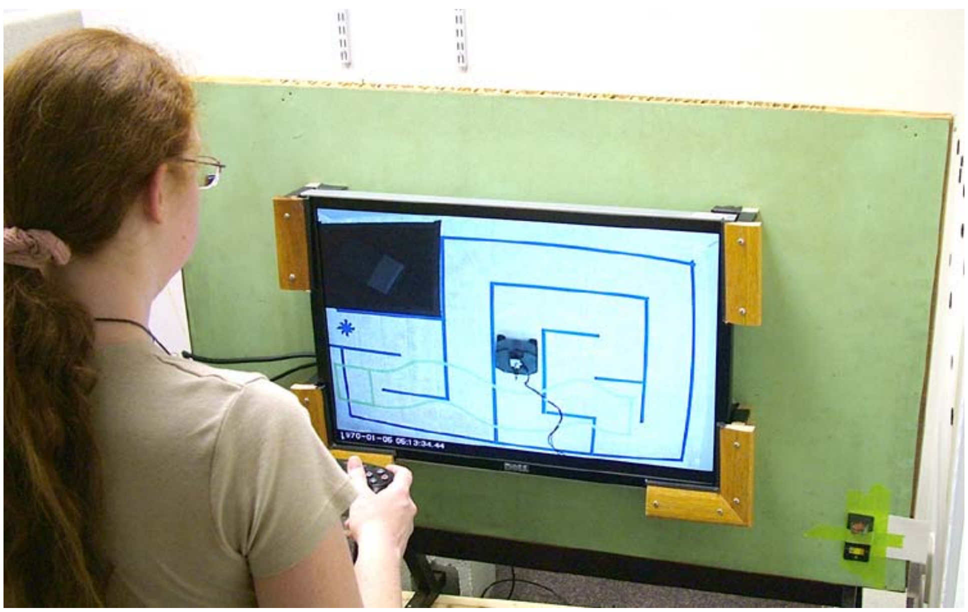


Figure 3 Large screen setup for the upright condition, showing the overhead camera view on the screen.

Figure 4 Large screen setup for the flat condition

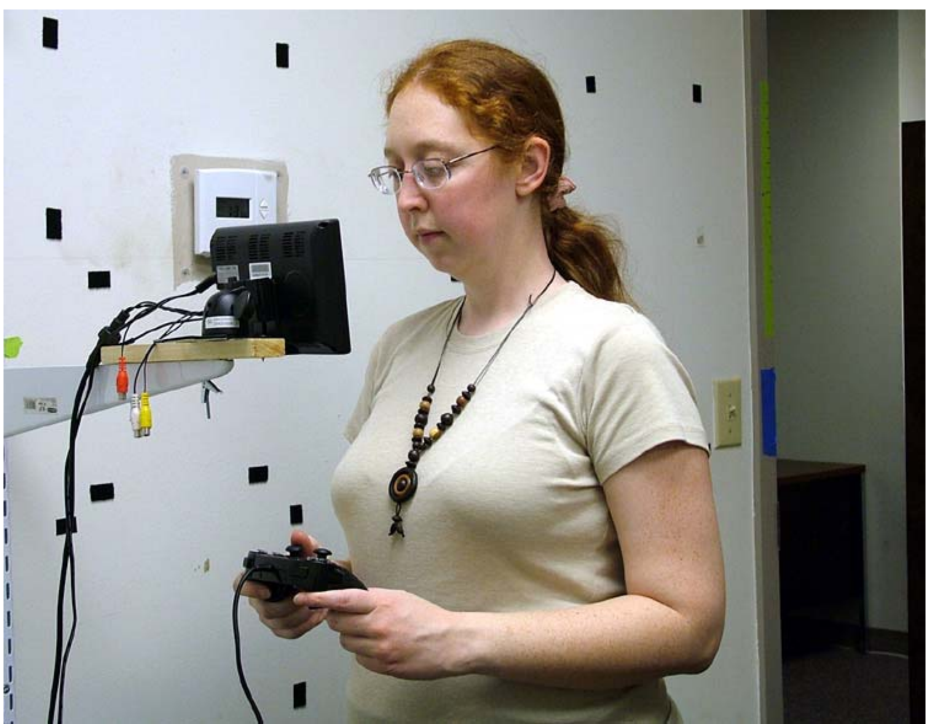


Figure 5 Small screen setup for the upright condition

Figure 6 Small screen setup for the flat condition.

Figure 7 Measuring the eye distance

BIOPAC

The physiological measures were taken using a BIOPAC MP35 System, which was connected to the experimenter's computer via USB. The BIOPAC EDA Finger Transducer, BSL SS3LA, was used to take the galvanic skin conductance measures. This transducer has two plastic housings with Ag-AgCl electrodes imbedded in a 1.6mm cavity that forms a 6mm contact area when electrode gel is used. These housings attach to the fingers by a Velcro strap. The BIOPAC pulse plethysmogram, BSL SS4LA, was used to measure blood pressure. This transducer consists of matched infrared emitter and photo diode, which transmit changes in blood density caused by varying pressure in the finger. It also was attached with a Velcro strip to the finger of the participant to record a pulse pressure waveform. The ECG measures were taken using disposable general-purpose electrodes from BIOPAC, EL503, connected to the LEAD110 series electrode leads. These electrodes have a circular contact area of 1 cm diameter and come pre-gelled and ready to be applied to the participant for one use.

Materials

NASA Task Load Index

The NASA Task Load Index was administered to the participant immediately after his or her completion of the task and the Biopac electrodes were removed. The computerized version of the TLX was used, so the participant utilized the large display screen and a supplied mouse to answer each question as it was presented by the computer program. The instructions and definitions of each measure were also given to the participant in paper form, so that they could be referenced as the participant needed. These definitions can be seen in APPENDIX D: NASA TLX .

MRT and GZAS

The Mental Rotation Test, MRT, was administered to the participant in paper form. The MRT version used in this study was first adapted from the Shepard & Metzler (1971) task by S. G. Vandenburg at the University of Colorado into paper and pencil version (Vandenburg & Kuse, 1978). Then the instructions were revised by H. Crawford at the University of Wyoming in 1979 and finally digitally re-mastered by S. Rehfeld and S. Scielzo at the University of Central Florida in 2005. This test has two parts, each part with 20 questions to be completed in 3 minutes. It is included in APPENDIX F: MENTAL ROTATION TASK.

The Gilford-Zimmerman Aptitude Survey, GSAZ, was also administered to the participant in paper form. Only Part 5 was used, which has a time limit of 10 minutes. An unaltered photocopy version was used of Part 5, which was originally copyrighted by Consulting Psychologists Press, 1976. See APPENDIX E: SPATIAL ABILITY APTITUDE SURVEY for the complete Part 5 test.

For each of these two tests, participants were given unlimited time to work through the directions and any questions were answered, then they had only the allotted time to complete as much as they could of the test. A digital stopwatch, which the participant could see, was used to keep track of time. These measures were gathered for the purpose of evaluating the impact of individual differences in spatial ability on the dependent variables.

Post-Questionnaire

The participants filled out a post-questionnaire after completing the task. This questionnaire was custom designed for this study; see APPENDIX C: POST QUESTIONNAIRE for the complete set of questions. The post questionnaire consisted of several types of questions on one form. First, it contained boxes for participants to fill in their age, sex, and how many times they made a mistake on each task. This served the purpose of reminding them about each task, since they had to think about each one to answer these questions. Then there was a series of Likert item questions that were scored as ratings from 1 (strongly disagree) to 7 (strongly agree). The first two questions, "I found the task fun" and "I found the task frustrating" were self report measures, and are discussed more in the section on scoring the self report measures.

The remaining questions included: "I was comfortable with the remote control mechanism," "I was comfortable with the remote format of the task," "I was comfortable with the complexity of the task," and "I have a great deal of experience with video games." These measures were gathered for the purpose of evaluating the impact of individual differences on the dependent measures. The last question, an open response question, "What do you think was the purpose of this task?" was designed to screen out any participants who may have believed that they were expected to not try their best on the task, which no one reported as the case.

Color Plate

The participants were shown a set of color plates to determine color deficiencies. The plates used were selected from the PseudoIsochromatic Ishihara Plates 5 and 7. These color plates were used in addition to asking the participant if they were colorblind. Also, the participant was later shown the colored barrels used in the experiment and asked to identify them. Their data were used if they could accomplish this identification task.

Software

Several software packages were utilized in the experimental setup. Both computers were running Microsoft Windows XP service pack 2. Techsmith Morae version 1.3 (2005) was used to capture the video from the cameras for post processing. Internet Explorer 6.0 was used to display the streaming video from the cameras to the participant's computer. The video was streamed using the software that was installed on the cameras. This software provided connectivity options such that the cameras could connect to the Linksys router and serve a webpage with the option to run the video in full screen mode. The BIOPAC BSL Pro software, which was packaged with the BIOPAC System was used to collect and later analyze the physiological recordings.

Tasks Used in the Study

There were four different tasks in the study. Each participant was required to perform each task within the obstacle course area, as shown in Figure 8. These tasks were chosen to require different types of skills and activities, to best highlight the differences in operator performance, physiological state, and perception of the interaction between conditions. The specifics of the tasks, including the purpose, how the performance was measured, and the corresponding hypotheses that drove the design are included in the respective section for each task.

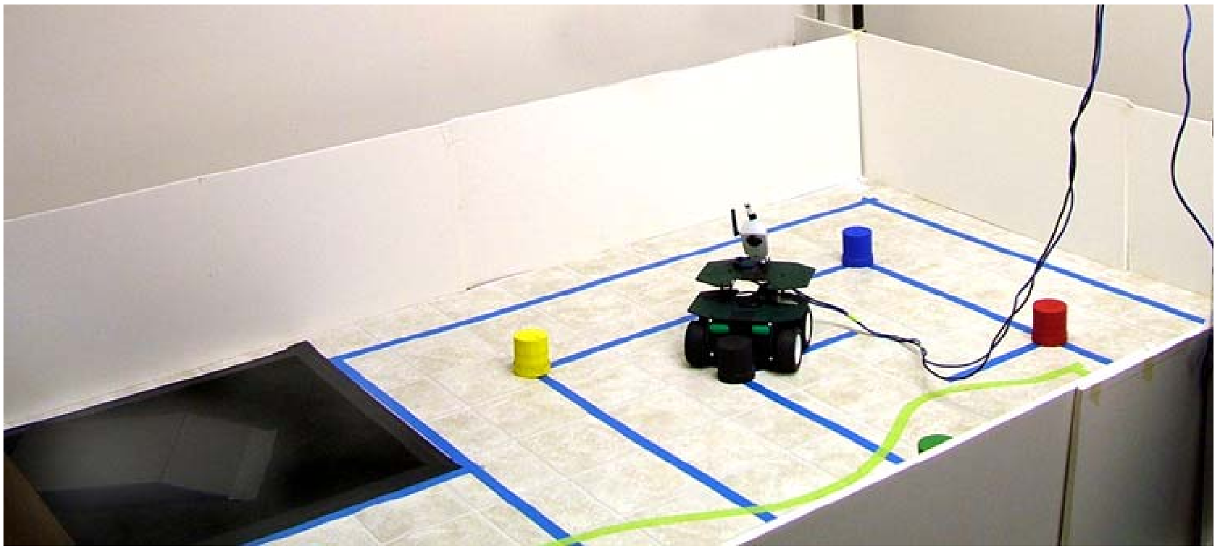


Figure 8 Obstacle Course Area: This figure shows the robot pushing the black barrel back toward the corral; the other colored barrels can be seen in their starting positions.

Task 1 Parking

Purpose of Parking task

Task 1 was designed to investigate differences in performance and driving ability that may be influenced by condition. The task has two parts that are designed to simulate different types of typical maneuvers.

Distance estimation is a complex task when done with teleoperation, since the remote nature interferes with the operator's situational awareness and spatial awareness. Since the operator is not physically with the robot, visual and visceral cues, which would normally assist with the estimates of distance traveled, are absent or obfuscated. In order to examine the effects of the screen viewpoint on these types of tasks, the first part of the parking task required traveling an estimated distance before orienting the robot to the parking space.

Often teleoperated robots are expected to perform maneuvers that are within a space only slightly larger than the robot itself. This precision type of movement can pose difficulties that may be made worse by conditions of screen size, orientation, or camera position. The second part of the parking task was designed with that in mind. The precision nature of the second part of this timed task was expected to highlight the differences in performance of the participants with different screen viewpoints.

Description of Parking task

During the task, the participant was required to park the robot on a small raised platform. The platform was approximately one inch high and had a ramp up one side. The platform was low enough that the vehicle could not be harmed or flipped should it fall off, yet high enough that it was obvious when the vehicle was not on the platform completely. Also, the platform was only just big enough for the vehicle to fit on, so that the participant was required to perform very precise corrections to complete the task successfully.

Before the task began, the participant was shown the platform and ramp and the robot was placed in a starting location that did not line up with the ramp. This positioning did not allow for direct navigation to the ramp, the participant needed to travel forward and then turn over 90 degrees to the left in order to align the robot to go up the ramp. This maneuver required an accurate estimation of distance traveled in order to optimize the path to the ramp. If the participant misjudged the proper amount of distance to travel out, either they turned too far and the extra distance cost them more time or they turned too close and then had to turn back and travel further, also costing more time.

Finally, the area of the obstacle course was covered in black and the ramp and platform also were black. The coloring was intentional in order to make the ramp and platform difficult to discern in order to cause the participant to proceed carefully during the actual parking portion of the task.

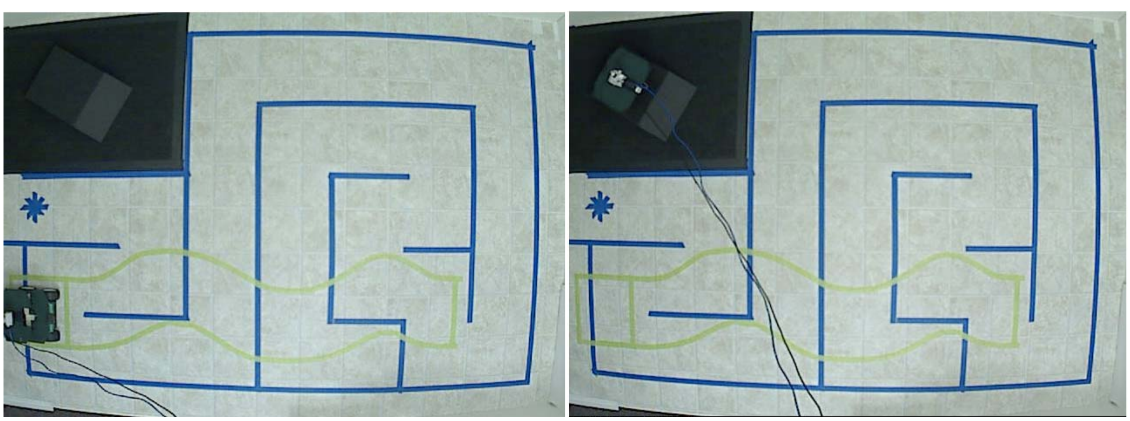


Figure 9 Task 1 starting position shown on left and ending position shown on right.

Performance measures on Parking task

Measures of performance for this task were total time to complete the task, time to get to the ramp (seconds), percent of total time spent getting to the ramp, extra distance traveled to get to the ramp (measured in 6 inch increments away from the ramp base), and parking success (scored from 1 to 4 as: complete success if vehicle was parked correctly, vehicle fell off the platform, vehicle made it partially up the ramp, and vehicle never even entered the ramp).

Hypotheses for Parking task

It was hypothesized that during Task 1, a performance effect would be seen across conditions (camera position, screen size, and screen orientation). Note that for simplicity, hypotheses will be labeled H 1, H 2, and so on. A table of hypotheses (Table 5) is available at the beginning of the discussion section for reference.

H 1: [General]: Parking task performance is influenced by condition

In addition to this general hypothesis, three specific hypotheses were generated in regard to the camera position condition and Task 1. It was hypothesized that this task would show more overall successes in the condition where the participant has an attached camera view than the overhead. This hypothesis was predicted because the attached camera should allow for a closer and cleaner angle to view the parking platform. Additionally, it was hypothesized that the participants in the overhead camera position would have shorter completion times and smaller extra distance measures, as they would be faster at getting to the ramp and travel less extra distance while doing so. This hypothesis was predicted because the participant began this task facing away from the ramp, thus with the ramp in a blind spot for the attached condition, it should be easier for the participants in the overhead condition to accurately judge the vehicle's traveled distance and to align the robot with the base of the ramp. Previous research in virtual reality experiments have shown that participants underestimate their own distance traveled when they are viewing the scene in first-person. (Frenz, Lappe, Kolesnik, & Bührmann, 2007). The attached camera position presents a similar first person view, so we should see similar difficulty in judging distance traveled, represented in distance traveled to the ramp.

H 2: Camera position influences parking success: lower success score (i.e. more successful) with attached camera

H 3: Camera position influences extra distance: higher (more) extra distance with attached camera

Regarding the physiological measures, it was hypothesized that the precision parking task would produce different arousal changes in the participants based on their condition. Since the task had two parts, the physiological markers of arousal were measured in two parts as well. It was expected that the markers of arousal would indicate an increased arousal for those individuals in the conditions of onboard camera during the first part of the task, due to the difficulty of estimating the distance traveled before orienting towards the parking ramp in that condition. In the second portion of the task, it was expected that the participants in the small screen condition would exhibit an increase in arousal due to the difficulty of performing precision tasks on a screen that feels small.

Task 2 Road Course

Purpose of Road Course

Task 2 was a simple road task that allowed for testing basic navigation ability. Navigating the robot through a series of turns while under time pressure required the operator to be precise with turning control maneuvers. Errors in these maneuvers may reveal any difficulties the operator is having with simultaneously holding multiple frames of reference in his or her working memory.

The setup of the course was specifically designed to balance the types of navigation turns needed to complete the task. There are an equal number of left and right turns, to balance any bias in the turning direction. Additionally, the course is balanced for turns when the course is viewed from overhead. Specifically, if the course is viewed from overhead, as in Figure 10, and a coordinate system is assigned, such as thinking of the direction toward the top of the view screen as 'up', then some traveling directions in the view match the control mechanisms, and some do not. For instance, the robot starting position, as shown in the figure, starts out traveling 'left', then turns right and travels 'up' the view. This means that as the robot approaches the second turn, the direction of travel is matching the controller knob position, and a right turn on the controller is the correct mechanic to guide the robot through the turn. On the other hand, on the approach to the fourth turn, the robot is traveling 'down' the view, and although the direction of travel changes from 'down' to 'left', the turn is actually a 'right' for the robot requiring the participant to move the controller knob to the right. This fourth turn illustrates a type of navigation procedure that is particularly difficult for those participants who are working within a condition that promotes strong exocentric perception of robot control. The turns within the course demonstrate four different levels of navigation difficulty: easy (where the control orientation matches the direction of travel), medium (where they are off by 90 degrees either one direction or the other), and difficult (where they are different by 180 degrees). There are two of each of these turns, one to the robot's right and one to the robot's left.

Figure 10 Road Course: Robot is shown starting position, ready to travel between the darker straight lines toward the star pattern.

Description of Road Course

In this task, the participant must travel from beginning to end of a road course while staying within the defined edges of the lanes. As can be seen in Figure 10, the course is outlined in dark blue tape on the obstacle course floor, thus viewable in either camera placement condition.

The participant was told to complete the task by driving within the lines all the way to the end, which was marked with a star. The participant was also told that each time they went over the lines, points would be deducted from their score, and that the total time it takes to get to the end would also affect their score, so they should "try to be as quick and accurate as possible to get to the end of the course." These directions were worded to create an equal focus on time and accuracy, while implying a points-based score, which was expected to motivate the participant to perform well in both dimensions.

Performance measures for Road Course

The performance measures for this task were total time to complete the task and a selection of error scores. The types of errors that participants made on the road course were straying outside the path and turning the wrong way. Because some participants strayed outside the path many times for brief periods, and others strayed few times but took more time to self correct and come back into the path, these measures were computed separately. They are scored as the number of times outside of the path, time spent outside the path in seconds, and percent of total time spent outside the path. In terms of turning errors, each turn 1-16 was scored individually, to see which turns if any the participants turned the wrong way. The total number of turns was computed for each participant.

Hypotheses for Road Course

It was hypothesized that during Task 2, performance effects would be seen across conditions (camera position, screen size, and screen orientation) for all the performance scores.

<u>H 4 [General]: Road course performance is influenced by condition</u>

Specifically, it was hypothesized that the total time to complete the task would be influenced by the camera position. This hypothesis is based on expectation of higher turning errors in the overhead camera position because that condition may promote strong exocentric perceptions that may compete with correct turn behavior. These turning errors would reflect difficulties in the participant's ability to hold multiple frames of reference in working memory simultaneously. Attached camera should be more straightforward for the participant, as any turning errors would be due to accident or unfamiliarity with the controls. The overhead camera condition has the potential to add error to the turning maneuver through addition of frames of reference. This additional turning error is expected to be higher in the upright screen orientation than the flat or horizontal orientation, due to a tendency to think in terms of 'up' and 'down' when the screen view is vertical. For similar reasons, there is expected to be an interaction effect of screen orientation and the camera viewpoint for all participants on the performance variables that relate to turning.

<u>H 5: Camera position influences completion time in road course: more time with overhead camera</u>

<u>H 6: Screen orientation influences turning errors: higher number of turning errors with upright screen</u>

H 7: Mismatched frames of reference (camera position by screen tilt) influence performance variables: more turning errors and time to complete

It is expected that the majority of the effect seen in this case would be due to individuals who have low spatial ability, since these individuals would be more sensitive to conflicting frames of reference. This individual difference in spatial ability can be partially measured with the spatial ability questionnaires and the self-report questions on experience. It is hypothesized that accounting for individual differences should show a stronger effect on performance variables related to turning errors.

H 8: Individual differences influence performance variables related to turning

Task 3 Barrel Round Up

Purpose of Barrel Round Up

The third task was designed to be complex and somewhat free form. This design was used so that we could evaluate the participant’s ability to form, act on, and revise goals and hold rules in mind while completing the navigation task necessary to perform the actions those goals require. The timed task consisted of gathering barrels into a pen in an order dictated by several rules that were told to the participants before the task started.

Description of Barrel Round Up

The third task requires the participant to gather colored barrels into a specified area, somewhat like rounding up sheep into a pen. Figure 11 shows the layout of the course at the start of the task, the 6 colored barrels and robot are placed at specific starting points. Figure 12 shows the ending goal layout for this task, each of the six colored barrels is gathered into the green box on the lower left side of the course area.

During the instructions, the participants were told that the task would be timed and that the goal of the task was to gather colored barrels into the designated area by pushing them with the vehicle. They were informed that their vehicle would start in the designated area, which was called the pen, and that they could gather the barrels in any order they wished with these restrictions: The green barrel must be put in before the red, and the blue one before the yellow one, the black and white have no restrictions. These restrictions were imposed in order to have a measurable performance variable for success, and to create some challenge to completing the task. The vehicle could push two or possibly three barrels at a time, and the participant was told this during the instructions. Since the barrels were always placed in the same starting locations, the restrictions helped to create an optimum order for gathering the barrels with the least amount of traveling time. The participant was reminded of the restrictions twice and also warned about the possibility of pushing the barrels out of bounds or into areas where they could become stuck. Those participants who lost barrels due to these reasons were unable to complete the task fully.

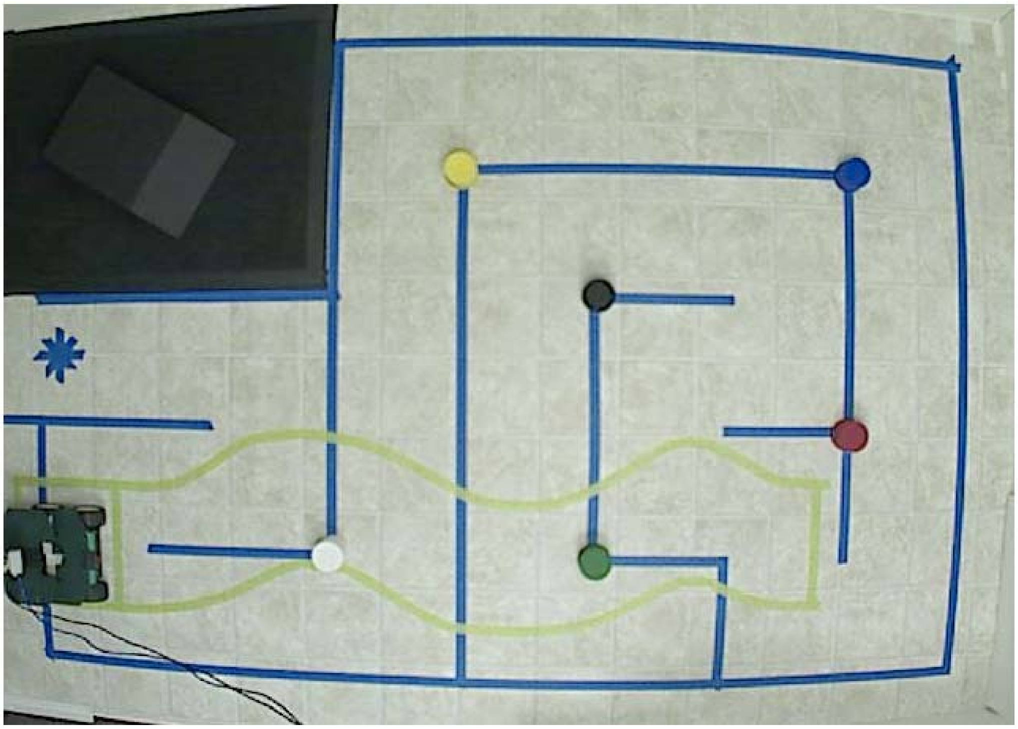


Figure 11 Barrel placement at the beginning of Task 3

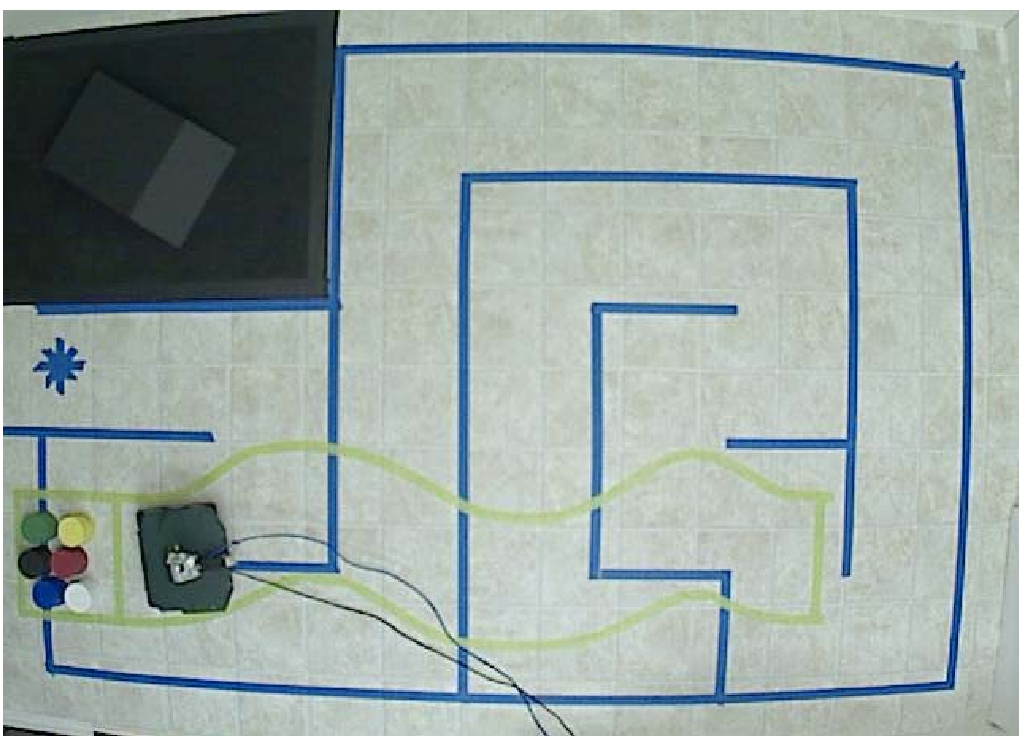


Figure 12 Gathered barrels at the ending state for Task 3

Performance measures for Barrel Round Up

Scoring the barrel task consisted of completion time and a set of performance variables. The two restrictions concerning color order must have been met in order to complete the task successfully. Additionally, the strategy used to complete the task was also evaluated. Optimal strategy was to gather three barrels at once into the pen, green, blue and either black or white, and then to gather the remaining three into the pen at once, thus taking only two trips and satisfying the restrictions. This strategy was difficult, since pushing three barrels at once was likely to result in failure with a barrel sliding off to one side as the robot turns. Second to this strategy, would have been to gather the barrels in pairs while satisfying the restrictions, such as green and blue, then red and yellow, then black and white. Least efficient would have been to gather each barrel on its own into the pen, since the travel time to do this is greatest. An efficiency score from 1 to 4 was assigned to each of these strategies in order of least to most efficient: 1 for gathering each barrel on its own, 2 for gathering one pair and the rest individually, 3 for gathering two pair and the rest individually or one set of three, and 4 for gathering three pairs or two sets of three barrels.

Hypotheses for Barrel Round Up

It was hypothesized that during Task 3, a performance effect would be seen across conditions (camera position, screen size, and screen orientation).

H 9 [General]: Barrel task performance is influenced by condition

Those participants in the overhead condition were able to see where all the barrels were placed immediately upon starting the task, whereas those in the attached camera condition only saw about half the barrels immediately, and would need to drive forward and turn to see the placement of all the barrels. This difference was expected to impact he participant's ability to plan his or her route, causing those in the attached condition to require more time and possibly even have less optimal strategies in completing the task than those in the overhead condition.

H 10: Camera placement influences barrel task completion time: more time with attached camera

H 11: Camera placement influences barrel task strategy: less optimal strategy with attached camera

Mismatched frames of reference in the overhead and upright condition and the attached and flat condition were expected to negatively influence completion time and success rates, but there were no specific hypotheses about screen size and tilt for this task in regard to goal setting as measured by strategy coding.

H 12: Mismatched frames of reference negatively influence completion time in barrel task

H 13: Mismatched frames of reference negatively influence success in barrel task

Task 4 Hazard Lights

Purpose of Hazard Lights

Task 4 was designed to load the participant's attention while challenging his or her reflexes. It was a simulated hazard-warning task. The task was timed and it required driving skill. The task simulated a situation where the vehicle must remain stationary during hazardous times, but travel as quickly as possible within a defined path during safe times. This required that the participant watch the signal while driving in order to stop as soon as the hazardous signal was shown, and then start again as soon as the signal ends. The signal was placed beyond the end of the path, so the participant needed to watch his or her current location as well as near the end of the path simultaneously, splitting his or her attention.

Description of Hazard Lights

The fourth task required the participant to guide the robot through a curved path while observing the hazard warning lights that appeared when the condition was unsafe to travel forward. The hazard lights came on and turned off at predetermined random intervals that were the same for all participants. An average time for these lights was about 2 seconds on and 3 seconds off. The participants were told that they should travel down the path, within the lines, as quickly as possible, but they should only proceed when it is safe to do so, i.e., when the hazard lights were not on.

Performance measures for Hazard Lights

Completion time was calculated for each participant, but several measures of accuracy were needed in order to evaluate success at the task. As far as the path that was taken, there were several measures of accuracy: the deviation from the optimal path was recorded for each participant for each half second of his or her travel, and the average of these was calculated. Also, the number of times they went outside the path and the number of seconds spent outside of the path, as well as the percent of time spent outside the path, were noted. There were several types of error scores attributed to movement. The primary error was if the hazard lights were on and the participant was moving, and the secondary error was if the lights were off and the participant was not yet moving. These two error scores were calculated for each frame of the video (one half second increments).

Hypotheses for Hazard Lights

It was hypothesized that during Task 4, a performance effect would be seen across conditions (camera position, screen size, and screen orientation).

<u>H 14 [General]: Hazard lights task performance is influenced by condition</u>

In all conditions, the operators were required to divide their attention between staying within the path and monitoring the warning lights. The increased complexity of this task was expected to impact all participants’ ability to cope with additional attention and working memory requirements such as working with multiple frames of reference simultaneously. For this reason, it was expected that participants in the conditions with mixed viewpoints, overhead and upright, and attached and flat, would exhibit decreased performance and increased arousal during this task.

H 15: Screen tilt and camera placement influence performance on hazard lights task: longer completion time for mismatched frames of reference

Measures

Physiological Measures

Scoring the Physiological measures

The participants were connected to a BIOPAC System throughout the entire portion of the experiment in which they were controlling the robot. They were connected to the system at least 5 minutes before the first task, and one continuous recording was made. Markers were set in the recording during the task with the BIOPAC recording software to denote the beginning and end of each task.

Post-analysis was performed on each participant's physiological measures using the BIOPAC Student Lab Analysis software (BSL). For the ECG signal, the template correlation function in BSL Software was used to clean the signal. First, a filter was applied to clean the signal. Within the BSL menu, a Transform – Digital filters – FIR – Band Pass was chosen with the settings: Low Freq to .5000, High Freq to 35.00, and Coefficient to 1600. Then, in each participant's file, a single heartbeat was selected and set as a template heartbeat. Then, the BSL Transform –

Correlation Function was used to transform the ECG channel and create a relatively clean continuous heart beat signal. The BSL Find Rate menu option from the transform menu was then used (with the default values, 5% of Peak) to generate a continuous heart rate channel. The same procedure was used for the pulse channel to create a pulse measure. The skin conductance measure channel just had the Band Pass filter applied with the same settings. Once these clean channels were created, the BSL Find Mean option was used to get means for 5-second intervals. These intervals included: Task1: before start, before ramp, after ramp, before end, after end, Task2: before start, before end, after end, Task3: before start, before end, after end, Task4: before start, before end, after end.

Hypotheses for Physiological measures

It was hypothesized that certain portions of the tasks would cause an increase in arousal due to their difficulty and the participant's increased workload. This increased arousal would be indicated by a positive change in heart rate, measured by both beats per minute and electrocardiogram measures, and an increase in galvanic skin conductance, GSR. It was expected that although these measures of the participant often correlate with increased arousal, they are not always a true measure of increased workload or difficulty. Still, these measures may be sensitive enough to show any large differences in physiological state. It was expected that GSR would be a more sensitive measure than heart rate or ECG since it is not subject to as much noise such as breathing, coughing, or talking.

The tasks that were especially expected to increase arousal were the parking task and the hazard lights task. The first because it is a difficult task and the instructions stressed that there would only be one attempt allowed, the second because the entire task requires intense concentration.

H 16 [General]: Arousal is influenced by condition in parking task

H 17 [General]: Arousal is influenced by condition in hazard lights task

Perception Measures

Scoring the Perception measures

The NASA Task Load Index was administered electronically. The program handled both parts of the questionnaire, with the participants completing the questions at their own pace. The resulting scores were computed by the program and saved to the computer. The combined workload measures were calculated through weighted average of six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The weights of the subscales, determined by the participant's rating on the pair wise comparisons, were factored by the program to generate 7 scores: total workload, and one score for the contribution of each subscale. These scores were from 0 (low) to 100 (high).

In addition to the TLX, the Post Questionnaire contained two questions concerning the participant's evaluation of the tasks in general. The first was a rating of frustration and the second was a rating of fun. These were Likert item questions in the form of statements "I found the task frustrating" or "I found the task fun" both scored from 1 (strongly disagree) to 7 (strongly agree).

Hypotheses for Perception measures

It was hypothesized that screen size would predict fun; participants in the large screen would agree with the statement, score higher, than those in the small screen condition. This is because the large screen could be considered novel to most participants as a means to control a vehicle. Anecdotal evidence supported this as the experimental setup was being constructed, as some students had comments of, "Wow, that really big screen is so cool" and "I wish I had that screen in my home to play video games with."

H 18: Fun reports are influenced by screen size, more fun in larger screen

It was hypothesized that camera placement would predict frustration, as those participants in the overhead camera condition would agree with finding the task frustrating, rate higher, than those in the attached. This is because the participants in the attached camera would have a tendency to adopt an egocentric perspective of the interaction and so be less likely to have a negative perception of the interaction.

H 19: Frustration reports are influenced by camera placement, more frustrating in overhead camera

It was hypothesized that workload would be most affected by camera placement and screen tilt. The overhead camera placement was expected to add additional workload as the participant needs to hold the additional frame of reference in working memory. Further, the conditions with mismatched frames of reference, i.e. overhead camera and upright screen and attached camera and flat screen, were expected to report higher workload. It was expected that these results would be evident in the total workload measure as well as the individual contributions to workload as a result of mental demand and effort.

H 20: Workload reports are influenced by camera placement, higher workload in overhead camera

H 21: Workload reports are influenced by screen tilt and camera placement, higher workload in mismatched frames of reference

H 22: Workload contributions from mental demand and effort mirror total workload expectations, higher for overhead camera and mismatched frames of reference

Individual Differences Measures

Scoring Individual Differences measures

The MRT was administered on paper and scored by hand. The test had two parts that were each 20 questions. These parts were scored individually and then added together to form a combined score. The GZAS Part 5 was also administered on paper and scored by hand as the number correct adjusted by the number attempted. The questions about individual differences on the post questionnaire that were Likert items were scored from 1 to 7.

Hypotheses for Individual Differences measures

It was hypothesized that spatial ability would impact those participants who were in the overhead camera condition the most. Those participants who scored low on spatial ability would be more likely to experience decreases in performance and ratings of fun, increases in reported workload and frustration, and increased arousal as the tasks continued due to heightened anxiety and difficulty caused by handling multiple frames of reference. Low spatial ability individuals may also be likely to experience these same results when they are in the conditions with mismatched viewpoints, i.e. overhead camera with upright screen, and attached camera with flat screen. The responses to questions on comfort with the controller, format of the task, and complexity of the task were expected to correlate with operator performance; those operators reporting more comfort would perform better.

Procedure

The entire procedure required about an hour and participants were run one at a time. Participants were first greeted and thanked for their participation, then given the opportunity to read over and sign an informed consent document, as shown in APPENDIX B: INFORMED CONSENT FORM. Participants were then given a brief orientation about what would happen during the experiment. This orientation included an outline of the procedure and a chance to see the robot in person. They were especially directed to note the robot's size in relation to obstacles in the course, such as the parking task ramp and the width of the driving lanes.

Setup Placement

After being assigned to his or her condition, the participant's eye height was measured and the setup adjusted to the proper condition and height. Once the setup was adjusted to the participant's height, the physiological sensors were attached to the participant. The participant assisted in the placement of three electrode sensors, one on each wrist, and one on the ankle, with the guidance of the experimenter. Then the leads were attached and the two finder sensors were fitted on the participant's non-dominant hand. Once the sensors were attached, the participant was asked to step into the marked placement in the setup, and the setup was further adjusted to the participant's height. Proper eye placement was achieved with the aid of markers on the floor and measuring tape. In Figure 7 Measuring the eye distance, you can see how a participant would be placed in the setup for the large, flat screen condition. Participant's color vision was then tested using a color plate and the identification of the colored barrels. Once the setup was in place, the participant was introduced to the controller and the robot's movements with a verbal explanation. Please refer to APPENDIX H: SCRIPT for precise phrasing of these explanations used during the setup.

Practice

Participants were given a practice time of two minutes, during which they were instructed that they could drive around the course in whatever manner they wished, except in the ramp area or outside the edges. During this time, the physiological sensors were able to equalize and that was verified on the experimenter's computer.

Tasks

The participant then performed four tasks in the obstacle course. All participants performed the tasks in the same order. A short amount of time occurred between each task while the directions for the next task was read and questions about the directions were answered. The sensors were continuously recording during this time in order to minimize procedure time and provide need for only one calibration at the beginning.

After the Tasks

After completing the tasks, participants were disconnected from the sensors, and then answered the NASA TLX electronic questionnaire. They then filled out the post-questionnaire and took the MRT and GZ tests as described in the section on Individual Differences. Lastly, they were debriefed, see APPENDIX G: DEBRIEFING, their questions about the experiment were answered, and they were thanked for their time. Credit was given through the online system through which they signed up for the experiment.

CHAPTER 3: RESULTS

Table 1 is a summary of the analyses in the following section and is included here as a reference.

Table 1 Results Summary

Measure	Main Effect	Direction	Interaction Effect
T1: Parking Success	Tilt	Upright: better	.
T1: Time Complete	.		.
T1: Extra Distance	Camera	Attached: extra distance	Size x Camera[1]
T2: Time Complete	Camera	Overhead: Longer Time	.
T2: # times outside	.		.
T2: Time outside	.		.
T2: % Outside	Camera	Attached: more % time outside	Size x Tilt[2], Size x Tilt x Camera[3]
T2: Turns	Camera	Overhead: more turning errors	.
T3: Success	.		.
T3: Time	Camera	Overhead: Longer Time	.
T3: Strategy	Size	Small: Higher Efficiency	.
T4: Time Complete	Camera	Overhead: Longer Time	.
T4: Time outside	Size	Small: more time outside	.
T1: ECG	.		.
T1: PPG	.		.
T1: EDA	Size	Small: Larger Positive Change	.
T2: ECG	Camera	Overhead: Larger Positive Change	.
T2: PPG	.		.
T2: EDA	Camera	Overhead: Larger Negative Change	.
T3: ECG	.		.
T3: PPG	.		.
T3: EDA	Size, Camera	Overhead: Larger negative,	Size x Tilt[4]
T4: ECG	.		.
T4: PPG	.		.
T4: EDA	Size, Camera	Overhead pos, attached neg, reverse for Large	Size x Camera[5]
Total Workload	Size	Small: Larger Workload	.
Mental Demand	Size	Small: Higher contribution	.
Physical Demand	Size	Small: Higher contribution	.
Temporal Demand	.		.
Performance	.		Size x Camera[6]
Effort	Size	Small: Higher contribution	.
Frustration	.		.
Frustration Self	Camera	Overhead: Higher frustration	.
Fun	.		.

1: Large overhead had short extra but attached had far extra; no significant difference in Small
2: Small flat high %, upright low %; Large flat low %, upright high %
3: Attached Camera: small flat high %, upright low %; Large flat low %, upright high %
4: Small and large upright: similar negative change; small flat: slight negative, large upright: very negative
5: Small overhead: positive, attached: negative; large overhead: small negative, attached: small positive
6: Small overhead: low, attached: high; large overhead: high, attached: low

There were 123 participants, spread over the eight conditions, as can be seen in Table 2. Some participants were dropped from some analysis due to incomplete data or other reasons as described in each analysis. Analyses were performed with SPSS 13, and *p* levels were set at .05.

Table 2 Number of Participants in Each Condition

Screen Size	Screen Tilt	Camera Position	N
Small	Flat	Overhead	15
		Attached	16
	Upright	Overhead	15
		Attached	15
Large	Flat	Overhead	16
		Attached	15
	Upright	Overhead	15
		Attached	16

Performance Measures

Each task had specific performance measures associated with it. To examine the hypotheses associated with performance variables, a series of 2(Size of screen: large or small) by 2(Orientation of screen: upright or flat) by 2(Camera viewpoint: attached or overhead) ANOVA analyses were performed for each task as described below.

Performance Measures in Task 1

To examine H 1: [General]: Parking task performance is influenced by condition, several different measures of performance were calculated, including parking success, total task completion time, and the amount of extra distance traveled getting to the ramp.

T1: Parking success

In the precision parking task, most participants (103) completed the task completely successfully, 15 fell off the platform, 4 did not make it up the ramp to the platform, and 1 person was unable to even reach the ramp. Parking success was scored as a number from 1 to 4 (1-vehicle was parked correctly, 2-vehicle fell off the platform, 3-vehicle made it partially up the ramp, and 4-vehicle never even entered the ramp). To examine the influence of condition on parking success score, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA was performed on all 123 participants. The analysis of parking success yielded significant main effects only for Screen Tilt, $F(1,115)=3.98$, $p=.048$. In this case, participants in the Flat Screen condition were less successful (Mean=1.31, SD=0.64, N=62) than those in the Upright Screen (Mean=1.11, SD=0.37, N=61). This main effect for screen tilt supports H 1 in regard to parking success, but there was no support for H 2: Camera position influences parking success: lower success score (i.e. more successful) with attached camera.

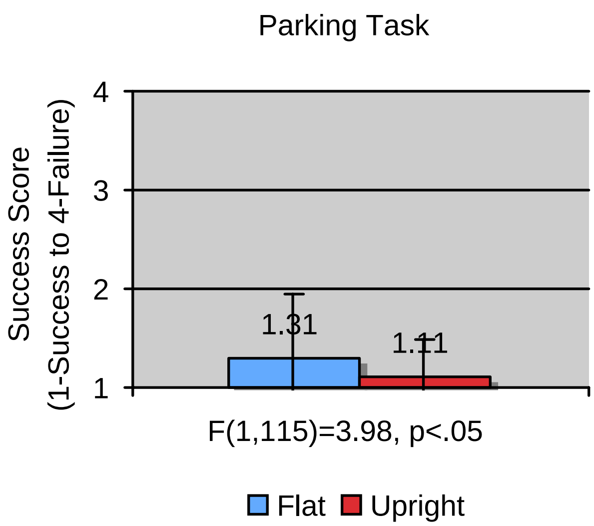


Figure 13 Parking task success score

T1: Time to complete

Including all participants, the average time to complete the task was 27.11 seconds (SD=21.92), but among those who completed the task successfully, the mean completion time was 26.83 seconds (SD=23.24). Upon examining the distribution of completion times, it was noted that 3 participants had times that were more than 4 standard deviations away from the average. Excluding these as outliers, the remaining participants had a mean of 24.52, SD=12.43. To examine the hypothesis that condition influences the performance variable of completion time, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed on 120 participants, excluding the outliers as described above. The analysis of total completion times for Task 1 yielded a main effect for screen tilt, $F(1,112)=6.83$, $p=.010$. In this case, participants in the flat screen condition took longer to complete the task (Mean=27.38, SD=13.80) than those in the upright screen condition (Mean=21.57, SD=10.25). No interaction effects were found. This finding does provide support for H 1 in regard to total completion time.

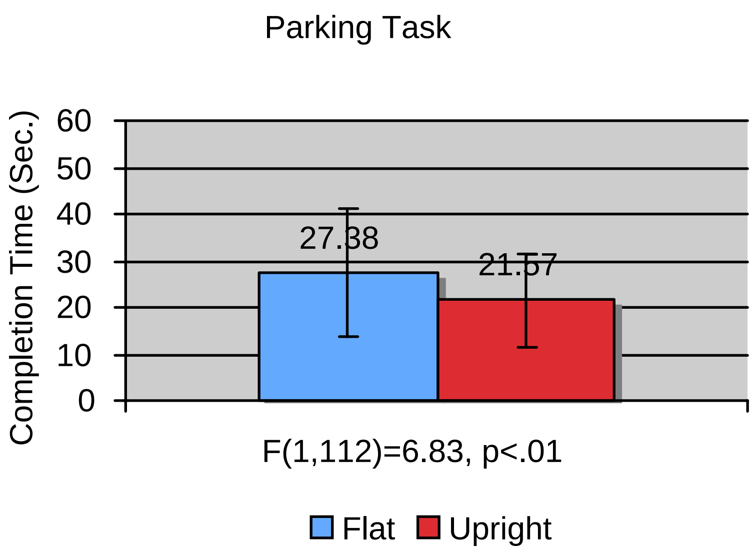


Figure 14 Parking task completion times.

T1: Extra distance

Although the majority of participants completed the task, only two did so in an optimal way without traveling out beyond the ramp, with the average participant driving more than a vehicle's length farther out of the way before turning to drive up the ramp. To examine the performance variable of extra distance traveled, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed for all 123 participants. The analysis of extra distance traveled yielded a main effect for camera position, $F(1,115)=4.74$, $p=.031$. In this case, participants in the overhead camera condition took a more direct route and traveled less extra distance to get to the ramp (Mean=2.53, SD=1.57, N=61) than those in the attached camera condition (Mean=3.05 SD=1.42, N=62). This result directly supports H 3: Camera position influences extra distance: higher (more) extra distance with attached camera.

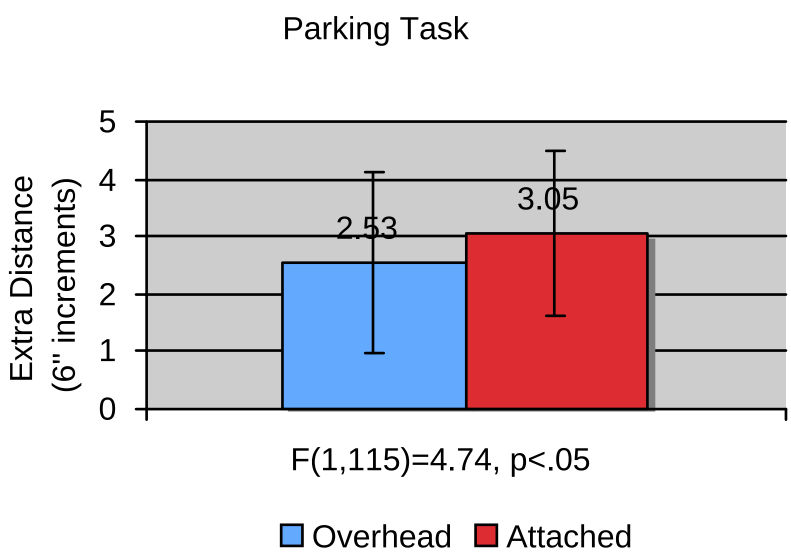


Figure 15 Parking task extra distance travelled by camera position.

There was also a significant interaction effect of screen size by camera placement, F(1,115)=5.53, p=.020. Post Hoc analysis revealed that this interaction effect was driven by the large screen condition. In the case of the small screen, the overhead and attached camera conditions yielded similar means (M=2.78, SD=1.29, N=30 and M=2.74, SD=1.28, N=31 respectively), which were not significantly different in pair wise comparisons. In the case of the large screen, the overhead camera yielded a mean of 2.20 (SD=1.01, N=31), and the attached camera yielded a significantly (p=.002) larger mean of 3.35 (SD=1.50, N=31).

Table 3 Extra distance traveled in Parking Task

Extra Distance beyond ramp in Parking Task		
	Overhead Camera	Attached Camera
Small Screen	2.78 (1.29)	2.74 (1.28)
Large Screen*	2.20 (1.01)	3.35 (1.50)

* Significant (p=.002) difference in camera condition M(SD)

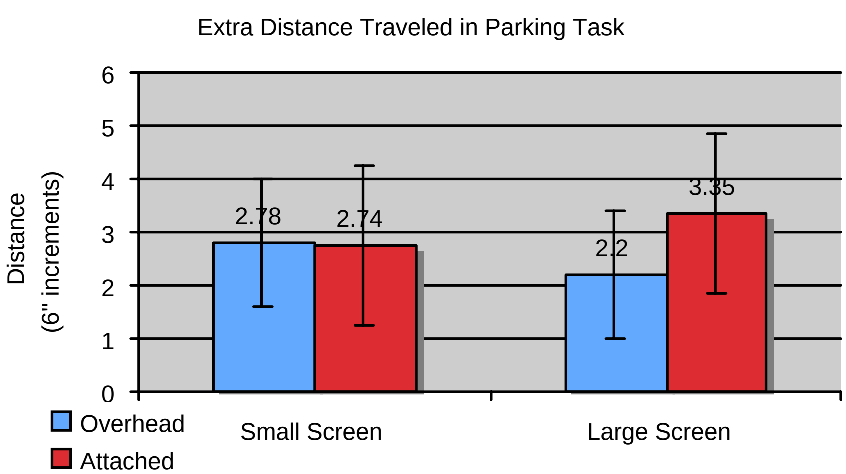


Figure 16 Parking task extra distance traveled, by screen size and camera placement.

Performance Measures in Task 2

To examine *H 4 [General]: Road course performance is influenced by condition*, several different measures of performance were calculated. A set of similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead)

ANOVA analyses was computed. The measures of performance analyzed included total task completion time, number of times traveled out of the path, number of seconds spent outside the path, and the percent of total time spent outside the path, and number of turning errors. All 123 participants were included in the analysis of completion time, but only 113 were included in the other performance variable analysis due to incomplete or corrupted video recordings.

T2: Completion time

All 123 participants were able to complete the road course task with a mean completion time of 105.88 seconds, SD=51.65. To examine the hypothesis that condition influences the performance variable of completion time, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed on all 123 participants. This analysis yielded a main effect for camera placement, $F(1,115)=42.34$, $p<.001$. In this case, the Overhead Camera yielded a higher mean of 132.46 (SD=54.65, N=61) than the attached camera (Mean=79.72, SD=31.54, N=62). This supports both the main *H 4 [General]: Road course performance is influenced by condition* and further supports H 5: Camera position influences completion time in road course: more time with overhead camera.

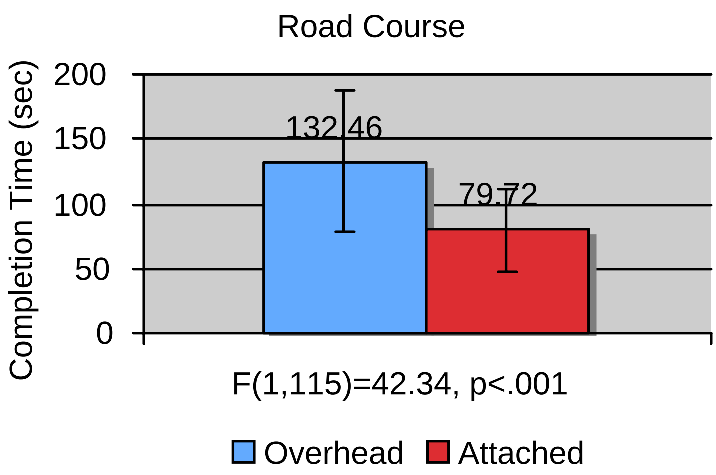


Figure 17 Road course task completion time.

T2: Number of times outside lines

To examine the effects of condition on the number of times that the participant strayed outside the path, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed using the participants that had video data available, which was 113. This analysis yielded no main effects or interactions of conditions.

T2: Time outside lines

To examine the effects of condition on the number of seconds spent outside the path, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed using the participants that had video data available, which was 113. This analysis yielded no main effects, nor interactions of conditions.

T2: % Total time spent outside lines

To examine the effects of condition on the percent of total time spent outside the path, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed using the participants that had video data available, which was 113. This analysis yielded a main effect for camera placement F(1,105)=16.09, p<.001. In this case, participants in the overhead camera condition spent less percent of their time outside the path, mean=18.72, (SD=11.52, N=58) than those in the attached camera condition, mean=30.69, (SD=21.53, N=55). So those in the overhead camera condition self-corrected their errors more quickly.

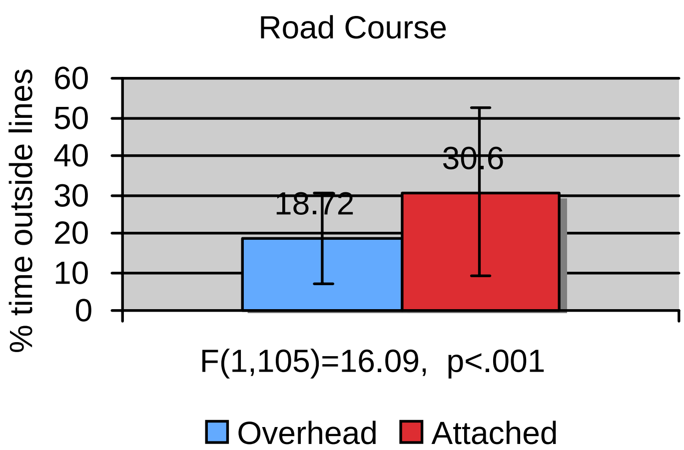


Figure 18 Road course task percent of time spent outside the lines by camera position.

There was also a significant interaction effect of screen size by screen tilt, F(1,115)=12.35, p=.001, and a three way interaction of screen size, by screen tilt, by camera position, F(1,115)=5.78, p=.018. Pairwise comparisons showed that this two way interaction was significant, LSD, for both small screen by tilt p=.010, and large screen by tilt p=.020. For the small screen, flat screen was much higher at mean=29.38, (SD=27.89, N=28), than the upright, mean=19.80, (SD=8.31, N=27). The opposite was the case for the large screen, where the flat screen was lower, mean=19.02, (SD=12.03, N=29), and the upright screen higher, mean=29.83, (SD=15.60, N=29). Additionally, pairwise comparisons revealed that the three way interaction of the conditions was being driven by screen tilt in both the small screen attached condition, p=.003, and the large screen attached condition, p=.007. In the case of the small screen attached camera condition, flat screen condition had a mean=42.32, (SD=35.65, N=13), and the upright mean=22.70, (SD=8.78, N=13). In the case of the large screen attached camera condition, flat had a mean=21.07, (SD=12.11, N=15) while upright mean=37.62, (SD=12.83, N=14). *H 4 [General]: Road course performance is influenced by condition* is supported by these results.

Table 4 Percent of time outside the lanes in Attached Camera condition on Road Course

% time outside – Attached Camera		
	Flat Orientation	Upright Orientation
Small Screen	42.32 (35.65)	22.7 (8.78)
Large Screen	21.07 (12.11)	37.62 (12.82)

Mean(SD)

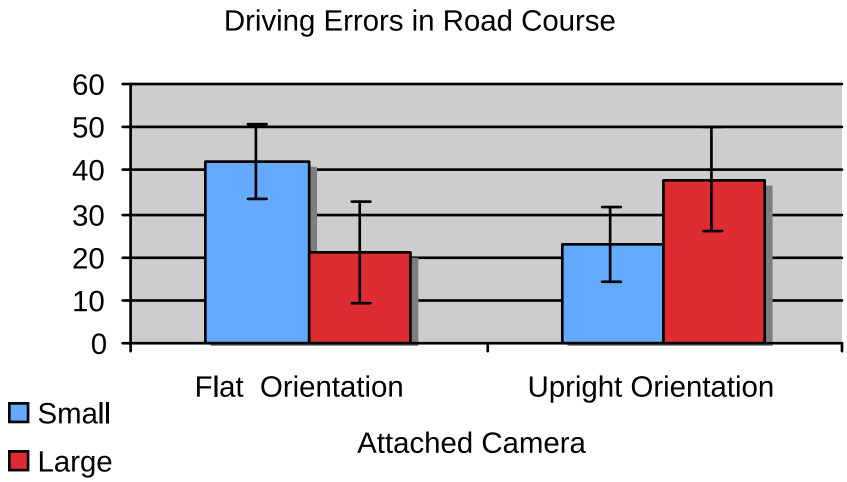


Figure 19 Road course percent of time spent outside lines by screen orientation in attached camera position.

T2: Turning errors

To examine the hypothesis that mismatched viewpoints would affect turning errors, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed using the participants that had video data available, which was 122. There was a significant main effect for camera placement, $F(1,114)=20.16$, $p<.001$. In this case, participants in the overhead camera view made more turning errors (Mean=1.44, SD=2.51, N=61) than those in the attached camera view (Mean=.02, SD=.13, N=61). Of the 26 participants that made turning errors, 25 of them were in the overhead camera condition. No interaction of camera by screen tilt was found, which failed to support H 6: Screen orientation influences turning errors: higher number of turning errors with upright screen, or H 7: Mismatched frames of reference (camera position by screen tilt) influence performance variables: more turning errors and time to complete.

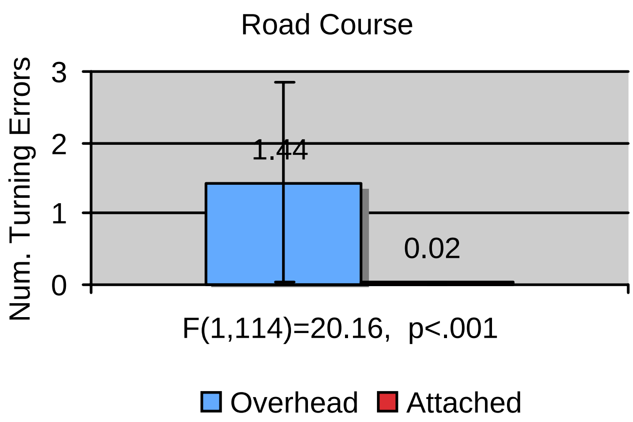


Figure 20 Road course number of turning errors by camera position.

Performance Measures in Task 3

To examine the hypothesis that performance on gathering barrels would be affected by condition, two measures of performance were used, completion time and an efficiency score. A set of similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses was computed for each.

T3: Success

Of the 123 participants, 11 were unsuccessful at the task of placing all the barrels in the pen in the proper order, and one was colorblind and could not identify the barrel colors. To examine the effect of condition on success on the barrel task, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA was performed on all 123 participants. No significant effects were found, which failed to support H 3: Camera position influences extra distance: higher (more) extra distance with attached camera.

T3: Completion time

To test the hypothesis that completion time on the barrel task would be affected by condition, a similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses of the completion was performed on the 111 participants that successfully completed the task. A main effect was found, $F(1,103)=15.686$, $p<.001$, for camera placement. In this case, the participants in the overhead camera condition took longer on average to performed the task (Mean=219.39 seconds, SD=151.23, N=54) than those in the attached camera condition (Mean=134.73, SD=62.35, N=57). This not only failed to support, but is contrary to H 10: Camera placement influences barrel task completion time: more time with attached camera. Although the result was unexpected in direction, it does partially support the H 9 [General]: Barrel task performance is influenced by condition. No significant interaction effects were found, which failed to support H 12: Mismatched frames of reference negatively influence completion time in barrel task.

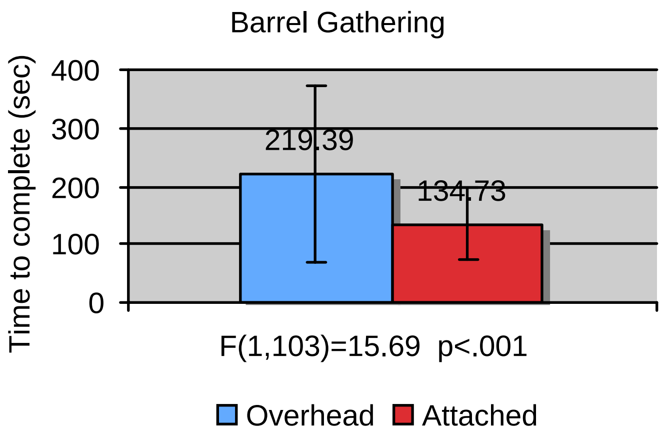


Figure 21 Barrel gathering task time to complete by camera position.

T3: Strategy

To evaluate the hypothesis that efficiency of strategy would be affected by condition, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses of the efficiency of the successful 111 participants was performed. A main effect was found for screen size $F(1,103)=2.44$ $p=.040$. In this case, the participants in the small screen condition had a higher efficiency rating, were more efficient in their strategy (Mean=2.70, SD=1.13, N=54), than those in the large screen condition (Mean=2.26, SD=1.17, N=57). An efficiency score from 1 to 4 was assigned to each of these strategies in order of least to most efficient: 1 for gathering each barrel on its own, 2 for gathering one pair and the rest individually, 3 for gathering two pair and the rest individually or one set of three, and 4 for gathering three pairs or two sets of three barrels.

No significant effect was found for camera placement, nor were there significant interaction effects, which failed to support H 11: Camera placement influences barrel task strategy: less optimal strategy with attached camera. Since there was an effect due to screen size, there was support for H 9 [General]: Barrel task performance is influenced by condition.

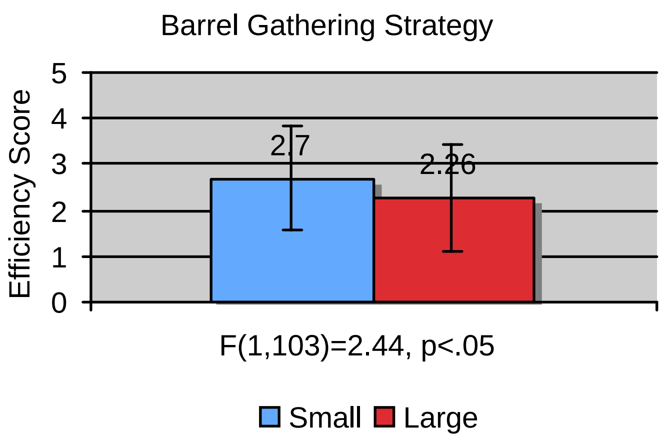


Figure 22 Barrel gathering task efficiency score by screen size.

Performance Measures in Task 4

To examine the hypothesis that performance of Task 4 would be affected by condition, a set of performance variables was examined, completion time and time spent outside the path. All of the 123 participants were able to complete this task. Unfortunately, some difficulties were encountered in the attempt to score the video data for this task, so only a portion of the scores was available for the error score analysis.

T4: Completion time

To examine completion time effects, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses of the completion time was performed on all 123 participants. A main effect was found for camera placement F(1,115)=26.55, p<.001. In this case, the participants in the overhead camera condition took significantly more time to complete the task (Mean=46.68 seconds, SD=26.93, N=61) than the participants in the attached camera condition, (Mean=28.41 seconds, SD=18.12, N=62). This supported H 14 [General]: Hazard lights task performance is influenced by condition. There were no significant interaction effects, which failed to support H 15: Screen tilt and camera placement influence performance on hazard lights task: longer completion time for mismatched frames of reference.

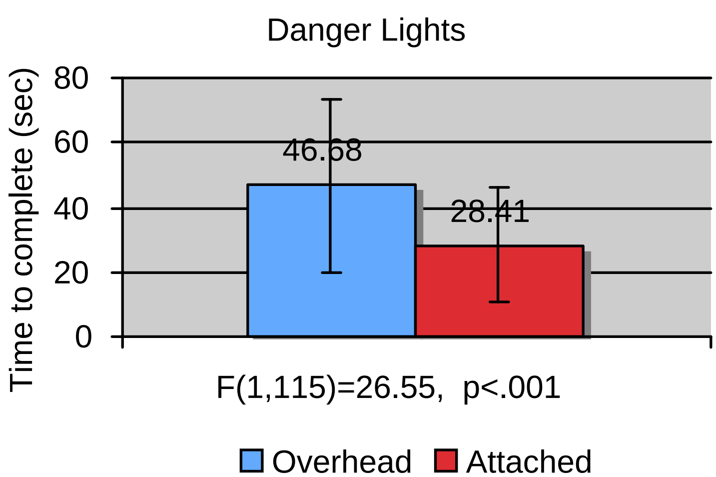


Figure 23 Danger lights task time to complete by camera position.

T4: Time spent outside lines

To examine the effect of condition on the amount of time spent outside the path, a 2(Size of Screen: large or small) x 2(Orientation of Screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses of the available video data was performed. The video scoring for this task proved to have some technical difficulties, so only 67 participants were able to be included in the analysis. A main effect was found for screen size, $F(1,59)=4.21$, $p=.045$. In this case, the participants in the small screen condition spent more time outside the path (Mean=17.37, SD=23.72, N=35), than those in the large screen (Mean=8.88, SD=7.53, N=32). This supported H 14 [General]: Hazard lights task performance is influenced by condition.

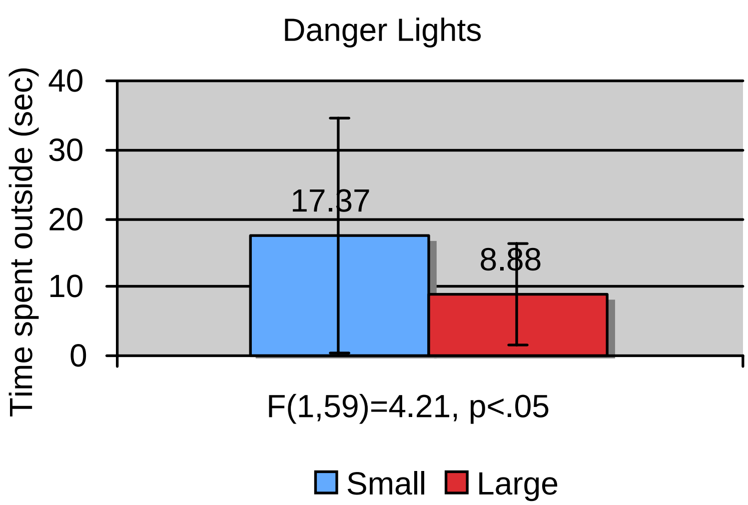


Figure 24 Danger lights task time spent outside the lines by screen size.

Physiological Measures

The three markers of physiological state include the change in ECG, PPG, and EDA measures of the participant between the beginning and the end of the task. Each Task is analyzed separately.

Physiological Measures in Task 1, Parking

To examine the hypothesis that condition influenced the physiological state of the participant during Task 1, a set of three similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses were computed, one for each physiological marker of arousal. The number of participants included in each the analysis was 96 of the 123 due to incomplete or unreadable data.

For Task 1, the analysis for change in ECG yielded no significant effects. The analysis for change in PPG also yielded a no significant effects. The analysis for change in EDA yielded a main effect for screen size $F(1, 88)=17.99$, $p<.001$. In this case, the small screen yielded a larger positive change in EDA (Mean=.92, SD=1.05, N=49) than the large screen (Mean=.08, SD=1.06, N=47). This partially supported H 16 [General]: Arousal is influenced by condition in parking task.

Physiological Measures in Task 2, Road Course

Although there was no specific hypothesis regarding arousal for task 2, examination of the physiological measures was analyzed similar to the parking task. A set of three similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses were computed, one for each physiological marker of arousal. The number of participants included in each the analysis was 97 of the 123 due to incomplete or unreadable data.

For Task 2, the analysis for change in ECG yielded a main effect for camera placement, F(1,89)=12.45, p=.001. In this case, the overhead camera condition yielded a larger positive change in ECG (Mean=12.03, SD=19.49, N=51) between the start and end of Task 2 than the attached camera condition (Mean=.33, SD=12.61, N=46).

The analysis for change in PPG yielded a no significant effects.

The analysis for change in EDA yielded a main effect for Camera Placement, F(1,89)=5.17, p=.025. In this case, the overhead camera condition yielded a larger negative change in ECG (Mean=-1.10, SD=1.24, N=51) between the start and end of Task 2 than the attached camera condition (Mean=-.57, SD=1.09, N=46).

Physiological Measures in Task 3, Barrel

Although there was no specific hypothesis regarding arousal for task 3, examination of the physiological measures was analyzed similar to the parking task. A set of three similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses were computed, one for each physiological marker of arousal. The number of participants included in each the analysis was 96 of the 123 due to incomplete or unreadable data. All conditions yielded mean negative changes in each of the three physiological markers of arousal, but some were significantly more negative as described below.

For Task 3, the analysis for change in ECG yielded no significant effects. The analysis for change in PPG also yielded a no significant effects. The analysis for change in EDA yielded a main effect for screen size, F(1, 88)=6.65, p<.020, and camera placement, F(1,88)=4.76, p=.032. In the case of the screen size, the small screen yielded a smaller negative change in EDA (Mean=-.58, SD=1.22, N=49) than the large screen (Mean=-1.22, SD=1.71, N=47). In the case of camera placement, the overhead camera yielded a larger negative change in EDA (Mean=-1.18, SD=1.69, N=50) than the attached camera (Mean=-.57, SD=1.22, N=46). The analysis for change in EDA also yielded a significant interaction between screen size and screen tilt, F(1,88)=6.07, p=.016. While both small and large upright screen conditions yielded negative change, mean=-0.83, SD=1.16, N=26, and Mean=-0.81, SD=1.02, N=25 respectively, flat screen conditions yielded larger differences. The condition of small and flat screen yielded a small negative change (Mean=-0.30, SD=1.25, N=23) and large flat screen yielded a larger negative change (Mean=-1.69, SD=2.19, N=22).

Physiological Measures in Task 4, Hazard Lights

To examine the hypothesis that condition influenced the physiological state of the participant during Task 4, a set of three similar 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA analyses were computed, one for each physiological marker of arousal. The number of participants included in each the analysis was 91 of the 123 due to incomplete or unreadable data. There was support for H 17 [General]: Arousal is influenced by condition in hazard lights task. All conditions yielded mean negative changes in each of the three physiological markers of arousal, but some were significantly more negative as described below.

For Task 4, the analysis for change in ECG yielded no significant effects. The analysis for change in PPG also yielded a no significant effects. The analysis for change in EDA yielded a interaction effect for screen size by camera placement, $F(1, 83)=4.51$, $p<.037$. In this case the small screen and overhead camera yielded a positive change in EDA (Mean=0.84, SD=0.84, N=24) and the small screen and Attached Camera yielded a negative change (Mean=-1.49, SD=0.61, N=22), while the large screen and Overhead Camera yielded a smaller negative change (Mean=-0.63, SD=1.34, N=23) and the large screen and Attached Camera yielded a small positive change (Mean=0.03, SD=0.90, N=22).

Self Report Measures

The self report measures are divided onto two parts. The NASA TLX measures, which were taken on a computer directly after the completion of the tasks and are scored as values between 0 and 100, and two of the questions that were included on the Demographics form. The two Likert item questions, "I found the task fun," and "I found the task frustrating," were scored as ratings from 1 (strongly disagree) to 7 (strongly agree).

Perceived Workload

Total Workload

To examine the hypothesis that condition influenced Perceived Total Workload, a 2(Size of screen: large or small) x 2(Orientation of screen: upright or flat) x 2(Camera viewpoint: attached or overhead) ANOVA was computed. 121 participants were included of the 123, since

2 had incomplete data for workload measures. This analysis yielded a main effect for screen size, F(1, 113) = 4.39, p<.05. In this case, the small screen (Mean=54.79, SD=15.33, N=60) yielded higher reported workload results than the large screen (Mean=48.57, SD=17.50, N=61). There were no significant interaction effects. These results failed to directly support H 20: Workload reports are influenced by camera placement, higher workload in overhead camera and H 21: Workload reports are influenced by screen tilt and camera placement, higher workload in mismatched frames of reference, since these hypotheses relate to camera placement and screen tilt. There was no specific hypothesis for the influence of screen size on workload.

Additionally, a similar ANOVA analysis was performed for each subscale factor of the NASA TLX to examine if condition influenced the perceived contributions of each factor towards the total perceived workload. Each of these factors was reported by the participants as contributing to the overall workload in various degrees. The factors include Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The same 121 participants were included in each analysis.

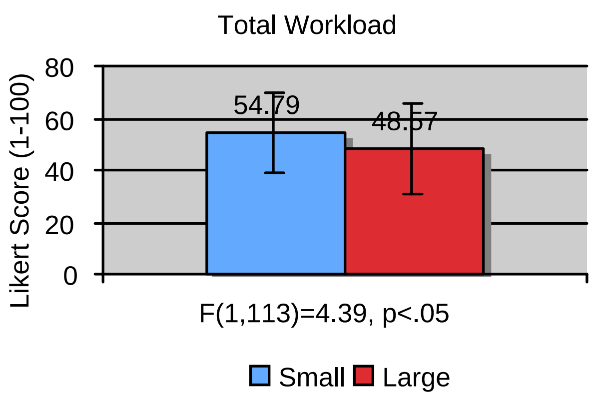


Figure 25 Total perceived workload scores by screen size.

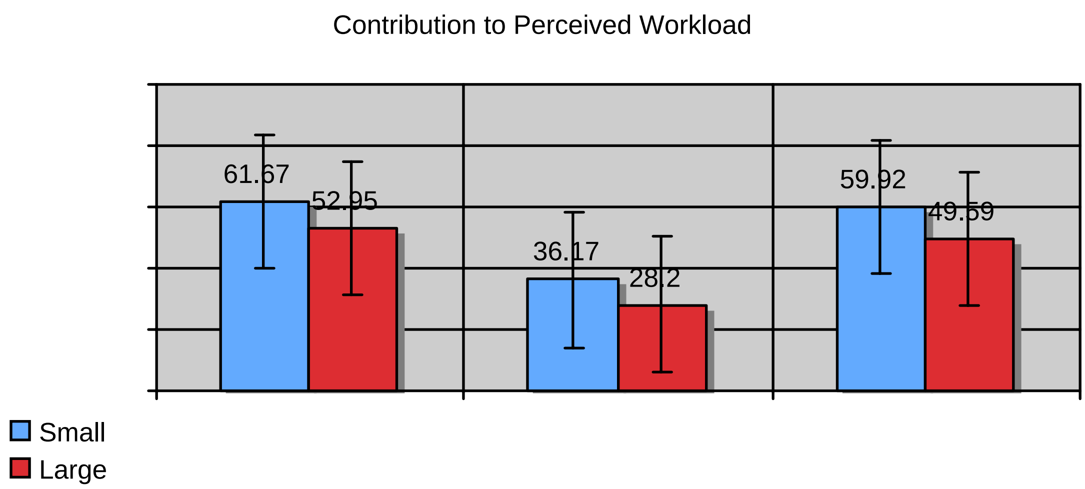


Figure 26 Contribution to perceived workload by screen size.

Mental Demand

For mental demand, the analysis yielded a main effect F(1, 113)=4.30, p=.040 for screen size. In this case, the small screen (Mean= 61.67, SD=20.56, N=60) yielded higher reported mental demand as a contribution to workload than the large screen (Mean=52.95, SD=25.256, N=61). There were no significant interaction effects. H 22: Workload contributions from mental demand and effort mirror total workload expectations, higher for overhead camera and mismatched frames of reference addressed this result. Although the influence of mental demand on workload did mirror the total workload reports, as hypothesized, the influence was due to screen size, not camera placement or mismatched frames of reference.

Physical Demand

For physical demand, the analysis yielded a main effect F(1, 113)=3.13, p=.079 for screen size. In this case, the small screen (Mean=36.17, SD=26.25, N=60) yielded higher reported physical demand as a contribution to workload than the large screen (Mean=28.20, SD=23.08, N=61). There were no significant interaction effects.

Temporal Demand

For temporal demand as a contribution to workload, the analysis yielded no main effect, nor significant interactions.

Performance

For performance, the analysis yielded only an interaction of screen size by camera placement F(1, 113)=7.31, p=.008. Small screen and overhead camera yielded a low (Mean= 34.67, SD=18.29, N=30), while attached camera was high (Mean=43.83, SD=26.51, N=30). While large screen and overhead camera yielded a high (Mean=43.87, SD=20.85, N=31), while attached camera yielded low (Mean=31.83, SD=20.53, N=30).

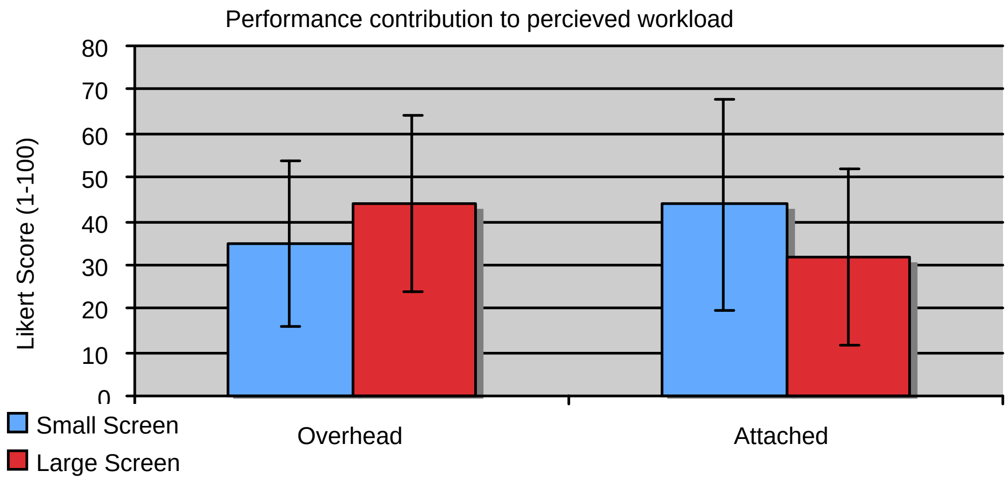


Figure 27 Contribution of performance to perceived workload.

Effort

For effort, the analysis yielded a main effect F(1, 113)=6.40, p=.013. In this case, the small screen (Mean=59.92, SD=20.26, N=60) yielded higher reported effort as a contribution to workload than the large screen (Mean=49.59, SD=24.60, N=61). There were no significant interaction effects. H 22: Workload contributions from mental demand and effort mirror total workload expectations, higher for overhead camera and mismatched frames of reference addressed this result. Although the influence of effort on workload did mirror the total workload reports, as hypothesized, the influence was due to screen size, not camera placement or mismatched frames of reference.

Frustration

For Frustration as a contribution to workload, the analysis yielded no main effect, nor significant interactions.

Other Self Reported Measures

Fun

To examine the hypothesis that participants would have higher self reported measure of fun with the task for some conditions (large screen, attached camera, and flat screen) a 2(Size of screen: large or small) x 2(Orientation of screen: vertical or horizontal) x 2(Camera viewpoint: attached or overhead) ANOVA was computed. This analysis yielded no significant effects for reported

Fun with the task, failing to support H 18: Fun reports are influenced by screen size, more fun in larger screen.

Frustration

To examine the hypothesis that participants would have higher self reported measure of frustration for the some conditions, especially the overhead camera condition, a 2(Size of screen: large or small) x 2(Orientation of screen: vertical or horizontal) x 2(Camera viewpoint: attached or overhead) ANOVA was computed. This analysis yielded a main effect of Frustration, $F(1, 115) = 7.961$, $p=.006$ for camera placement. In this case, the overhead camera (Mean=3.41, SD=1.87, N=61) yielded higher reported frustration with the task than the attached camera (Mean=2.55, SD=1.52, N=62). There were no significant interaction effects. This result supports H 19: Frustration reports are influenced by camera placement, more frustrating in overhead camera.

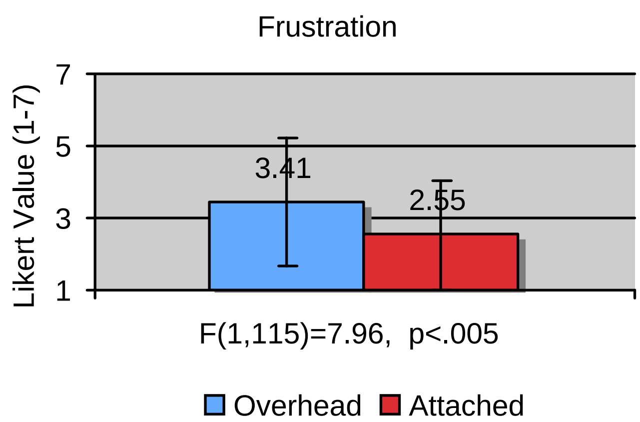


Figure 28 Reported frustration score by camera position.

Influence of Individual difference

The demographics form first contained boxes for participants to fill in their age, sex, and how many times they made a mistake on each task. Then there was a series of Likert item questions that were scored as ratings from 1 (strongly disagree) to 7 (strongly agree). The questions were: “I was comfortable with the remote control mechanism,” “I was comfortable with the remote format of the task,” “I was comfortable with the complexity of the task,” and “I have a great deal of experience with video games.” The participants also all took two spatial ability measures, GZAS and MRT, as discussed in the intro. Future research plans include analysis of these individual difference measures on the performance and physiological as well as self report variables through correlation analysis techniques.

CHAPTER 4: DISCUSSION

To examine the way in which display setup affected participants' interaction with a teleoperated setup, participants were assigned to different display setups to complete a set of tasks. During the tasks, their physiological state was assessed. Afterwards they answered questions about their perceptions of the task, and individual differences in spatial ability were measured. The results of this experiment indicate that the display does influence the way participants perform on the tasks, report their interaction, and how their physiological state changes during the tasks, but this influence is complex.

Results Summary

There were a number of hypotheses proposed in this dissertation, and the results of each are summarized in Table 5. This table lists each of the hypotheses, whether each is supported by the data, and where in the results section the analysis can be found. The general hypotheses are in italics, and the more specific ones are in regular text.

Although many of the hypotheses were not supported, or only partially supported, there are a number of important findings revealed by the analyses. Rather than restating these findings in the order that they were analyzed, the results will be discussed in relation to the underlying cognitive mechanism that drives them.

Table 5 Summary of Hypotheses

Hypothesis	Result	In Section
H 1: [General]: Parking task performance is influenced by condition	Partially Supported	Performance Measures in Task 1, p65
H 2: Camera position influences parking success: lower success score (i.e. more successful) with attached camera	Not Supported	T1: Parking success, p65
H 3: Camera position influences extra distance: higher (more) extra distance with attached camera	Supported	T1: Extra distance, p67
H 4 [General]: Road course performance is influenced by condition	Partially Supported	Performance Measures in Task 2, p69
H 5: Camera position influences completion time in road course: more time with overhead camera	Supported	T2: Completion time, p70
H 6: Screen orientation influences turning errors: higher number of turning errors with upright screen	Not Supported	T2: Turning errors, p74
H 7: Mismatched frames of reference (camera position by screen tilt) influence performance variables: more turning errors and time to complete	Not Supported	T2: Turning errors, p74
H 8: Individual differences influence performance variables related to turning		Influence of Individual difference, p90
H 9 [General]: Barrel task performance is influenced by condition	Partially Supported	Performance Measures in Task 3, p75
H 10: Camera placement influences barrel task completion time: more time with attached camera	Not Supported	T3: Completion time, p76
H 11: Camera placement influences barrel task strategy: less optimal strategy with attached camera	Not Supported	T3: Strategy, p77
H 12: Mismatched frames of reference negatively influence completion time in barrel task	Not Supported	T3: Completion time, p76
H 13: Mismatched frames of reference negatively influence success in barrel task	Not Supported	T3: Success, p75
H 14 [General]: Hazard lights task performance is influenced by condition	Supported	Performance Measures in Task 4, p78
H 15: Screen tilt and camera placement influence performance on hazard lights task: longer completion time for mismatched frames of reference	Not Supported	T4: Completion time, p78
H 16 [General]: Arousal is influenced by condition in parking task	Partially Supported	Physiological Measures in Task 1, p81
H 17 [General]: Arousal is influenced by condition in hazard lights task	Partially Supported	Physiological Measures in Task 4, p83
H 18: Fun reports are influenced by screen size, more fun in larger screen	Not Supported	Fun, p88
H 19: Frustration reports are influenced by camera placement, more frustrating in overhead camera	Supported	Frustration, p89
H 20: Workload reports are influenced by camera placement, higher workload in overhead camera	Not Supported	Perceived Workload, p84
H 21: Workload reports are influenced by screen tilt and camera placement, higher workload in mismatched frames of reference	Not Supported	Perceived Workload, p84
H 22: Workload contributions from mental demand and effort mirror total workload expectations, higher for overhead camera and mismatched frames of reference	Partially Supported	Mental Demand, p86

Viewpoints

Turning through multiple frames of reference

In the road course, which was designed to test basic navigation ability, the participants drove the robot through a series of turns while under time pressure. Errors in these maneuvers may reveal any difficulties the operator has due to simultaneously holding multiple frames of reference in working memory. It was expected that participants in upright screen and mismatched frames of reference conditions would perform more turning errors. Of the 123 participants, 26 made at least one error in regard to turning (i.e., they turned the wrong way). Of these 26 participants, all but one was in the overhead camera condition. Contrary to the H 6: Screen orientation influences turning errors: higher number of turning errors with upright screen, screen orientation failed to be a contributing factor to the turning errors. Camera placement was far more influential, with the participants in the overhead camera condition overwhelmingly more likely to make turning errors, regardless of screen orientation.

It was expected that the orientation of the presentation of the visual information would have a significant effect on the participant's ability to perform certain tasks that required holding sets of reference frames in memory simultaneously, since the orientation might add an additional frame of reference. In the danger light course, participants needed to monitor not only the area immediately surrounding the vehicle, but also the area of the danger lights at the same time. Monitoring these two areas, as well as the holding of additional reference frames due to screen orientation could have been competing for limited resources, thereby affecting the performance variable completion time. It was not the case, however, that screen orientation alone was contributing in this way. Camera placement was a much stronger predictor of completion time, with participants in the overhead camera condition taking significantly longer to complete the task than those in the attached camera condition.

Camera position also may have influenced performance due to scanning difficulties. In the attached camera condition, the danger lights take up significantly more screen real estate than in the overhead camera condition. This is because the lights are positioned at the end of the course, so the attached camera view shows them in front of the robot the whole time, whereas the overhead view shows the lights always at the right side of the screen as the vehicle approaches it from the left. The overhead camera view requires the participant to scan back and forth between the vehicle and the lights in order to complete the task. This added scanning time may have contributed to the performance decrease in the overhead camera condition on the danger lights task.

The effect of information scanning time has implications for display system design, as well as task design. For tasks that require watching the immediate surroundings of the vehicle, as well as stimuli further away from the vehicle, it may be advantageous to have a view that compresses this visual data, such as the attached camera view. For the danger lights course, the participants in the attached camera condition completed the task more quickly.

Camera Placement

Camera placement was the most common aspect of viewpoint to influence the performance variables of the tasks. Camera placement has a very strong effect on actual performance data, as can be seen by the time taken to complete the road course, barrel task, and danger lights task. In these cases, participants in the overhead camera condition on average took longer to complete the tasks. Participants in the overhead camera condition were required to hold one more representation, and therefore one more translation, in their mind while working with the robot than those in the attached camera condition. In the attached camera condition, the right and left turns needed to navigate were aligned – the participant's view matched that of the robot. In the overhead condition, the participant's view was different from the robot's view, and the mental translation had to be made continuously. This added frame of reference at first may be expected to add to workload, but NASA TLX measures did not indicate an effect from camera placement. Participants did rate a significantly higher frustration level with the task when in the overhead condition than in the attached condition.

In the road course, participants in the attached camera condition self-corrected more slowly than the overhead condition, or sometimes, not at all. This is most likely due to a few reasons. First, the attached camera view, while it did show the front of the robot, did not show the actual wheel placement. Most cars do not allow the driver to see where the wheels are from the normal point of view. So in a regular car, the driver must learn to infer where the car ends or the wheels are located, to know if they are about to run over a curb. In the teleoperated task, the participants had to infer the relative size and placement of the vehicle from the vantage point of the attached camera, as if they were driving a car of unknown size. Thus, given no external feedback, such as a bump or sound, they were relying on the visual feedback only, which provided scant information about the size of the vehicle or the placement of the wheels. This may be the biggest reason that the participants in the attached camera view were slow to self correct the driving error of running over the lines. The second reason the participants in the attached camera condition made these types of errors in the driving course may have to do with the degree to which there was perceived movement in the visual display. In the overhead camera condition, the course appears to remain constant or still in the display, with only the robot moving. However, in the attached camera condition, the all aspects of the scene appear to be moving whenever the robot travels. Therefore, it is likely that the participant's visual field was saturated with the moving scene and so had fewer attentional resources to spend on the task of staying within the lines.

It may be that the participants in the overhead camera condition were running into the limit of resources of their visuospatial sketchpad. This working memory structure may be unable to hold multiple 'pictures,' in this case frames of reference, in the sketchpad and may effectively rehearse them all simultaneously. In this case, the frames of reference would need to be continuously reentered into the sketchpad in order to navigate the robot's controls, which could increase the time needed to perform the tasks, even though the tasks were still completed effectively. This finding is consistent with research on expertise and working memory that shows that mentally 'redrawing' pictures can tax resources (c.f., Baddeley & Hitch, 1974; Sims & Mayer, 2002).

Interestingly, the participants rated a higher frustration when in the overhead condition, but not a higher task load, indicating that while they realized that the task was frustrating and perhaps they could have done better, they did not recognize the task as overloading, even though they experienced a reduced completion time effect. This finding may indicate a potential danger for systems in which the operator is expected to recognize when he or she is being overloaded. This type of performance decrease due to added frames of reference may be too subtle for, or hidden from, the operator's self awareness.

It was expected that the overhead camera placement would give an advantage to the participants in task 3, the barrel gathering task, since the entire area can be assessed at the beginning of the task, and the most efficient order to gather the barrels can be a worked out rather quickly. This bird's eye view advantage is well known, and it is a common method of strategic planning models. In the case of teleoperated robots, however, the advantage of the overhead view seems to be overshadowed by the *disadvantage* of the additional frame of reference added by the overhead placement of the camera. Although the opportunity to assess the whole area and plan out a course is present, the burden of working with the additional frame of reference while executing the navigation is so strong that the expected overhead advantage cannot be seen in the performance data. Camera placement was not a predictor in efficiency for the barrel task. *The difficulty of manipulating the robot can overshadow the advantage of a better understanding of the problem due to the camera placement.*

Screen Size

It is important to note that the large and small screen conditions both had the same field of view. Participants in the large screen condition were further away from the screen than those in the small screen. This means that the effective size of the screen on the visual field was the same. For instance, if the participant was looking at the left side of the screen, and then looked at the right side, his or her eyeballs would travel the same distance in both conditions. Therefore any differences that participants experience in the dependent variables are not a result of actual difference in size of their view. These differences may be caused by a different impression of the task.

The scores on the NASA TLX indicate that participants in the small screen condition reported a higher total workload, with a greater contribution of mental and physical demand, as well as effort on workload than those in the large screen condition, yet there were only isolated significant main effects on performance. These effects included a more efficient strategy for collecting barrels in the round up task, and more time spent in error (outside the lines) in the danger lights task for participants in the small screen condition. Neither completion times, nor success indicators, were predicted by screen size in any of the tasks.

Additionally, there was an increase in galvanic skin conductance for tasks 1 and 3 in the small screen, indicating an increased arousal, which parallels the increased perceived workload. Often large screens, such as the 30 inch screen in the study, are used for playing games, watching television, or other fun activities. Perhaps the small screen was reminiscent of a book or other reading material that triggered a schema of “work” versus “play.”

Screen size did seem to have an effect on the importance of camera placement for estimating distance traveled in the parking task. In large screen conditions, there was an effect of camera placement, with attached camera, predicting a greater amount of unnecessary distance traveled before turning toward the ramp. The effect of camera placement was not significant in the small screen conditions. In previous studies, it has been suggested that the tendency to underestimate traveled distance may be due to effects of the visual flow patterns. The visual flow cues may be stronger in the large screen, causing this effect to be of more influence in those conditions.

One consideration that should be mentioned is that although we controlled for field of view, participants in the small screen would only need to lean forward a small amount in order to increase their field of view in an attempt to individually optimize their view. Since we did not use a head restraint system, this may have occurred. However, it seems unlikely that this was the case, since we should see some evidence in increased performance, or a reduction in task load, which was not present.

Screen Tilt

Screen tilt alone did not seem to be a very important predictor for the dependent variables, with the exception of the parking task. This task contained two challenges that could explain this finding. The task involved estimating the vehicle’s size and speed, and this task was the only one to include height challenges; all the other tasks involved simply driving on a flat course.

In the parking task, the participant was required to drive to a ramp and then drive up the ramp to park on a platform. Parking the vehicle on the platform involved estimating distance in relation to the size of the vehicle and fine control of the vehicle's movement. The upright screen condition seemed to provide a better viewing interface than the flat screen for this task. Of the 20 participants who failed the task, 14 were in the flat screen condition. These failures were of the type that the robot either fell off the platform, or ineffectively drove up the ramp. In the horizontal screen, the optic flow pattern would be slightly altered, as the upper and lower portion of the screen is farther and closer respectively to the participant's eyes than the upright screen. Additionally, the unconventional nature of the display may have influenced the participant to attend to the visual information differently.

The screen tilt was an important factor of the viewing interface when taken together with screen size in the attached camera view. For example, these variables interacted during the road course task in ways that affected driving errors. In the case of a mismatched viewpoint (attached camera and flat screen), the small screen condition had more driving errors than the large screen. In the case of the matching viewpoints (attached camera and upright screen) the reverse was the case; large screen had more driving errors. These driving errors were in the form of percent of time spent outside the lines, where participants would drive outside the lines and take longer to self-correct. The interaction of these two variables was expected to be specifically of interest, as described in several of the hypotheses regarding mismatched viewpoints. The following section addresses this expected interaction more clearly.

Mismatched Viewpoints

It was expected that mismatching viewpoints would make staying within the lines more difficult (i.e., there would be an interaction of screen tilt by camera in both directions for percent of time spent out of the lines). But, in fact, only the mismatched viewpoint involving the attached camera seemed to influence this performance variable in this way. In the case of the mismatched viewpoint of overhead camera and flat screen, the participants performed better in regard to staying in the lines than the matched viewpoint of overhead camera and upright screen.

The added frame of reference due to orientation of the presentation of the visual information seems to have much less of an impact than the added frame of reference of the source of the information. This may be due to a certain degree to the commonality of screen angles available in everyday life. Using laptops, handheld video games, televisions, and other screens, such as automatic teller machine kiosks, and touch menus in checkout lines, the average person encounters many screens in various orientations that seem to be unrelated to their content. Perhaps the population in this study is well trained at accessing visual information from display screens at many angles, and they are relative experts at working with the particular frame of reference addition caused by a horizontal or flat screen. Although the participants were asked to rate their experience with video games, this question did not distinguish the display systems used for this experience. Future research may wish to explore further the relationship of previous experience with particular screen types that are commonly displaying video data in a horizontal orientation, such as handheld video games and laptops, and the relationship of that experience to performance using that type of screen orientation for teleoperation.

Physiological Measures

The physiological measures were exploratory variables in this study. The results did not reveal strong correlations between the pulse measure and the ECG heart rate measure, which should have been strongly correlated. These two measures are linked, in that they both represent heartbeats, and should have been redundant. The lack of evidence of this redundancy indicates significant noise in the measurement, which casts doubt on the validity of these two physiological measure results.

Galvanic skin conductance did show some interesting results and seemed to be less sensitive to noise than the heart rate and pulse measures. Although Galvanic skin conductance worked out well as a marker of arousal, this study did not look at valence, so there is no way to know if the participants were excited or upset as a reason for increase or decreases in arousal. Future studies should measure valence or direction of mood changes perhaps with the PANAS mood scale (Watson and Clark, 1997; Watson, Clark, and Tellegen, 1988).

There were a number of areas regarding the physiological measures that could be improved in future studies. Heart rate is a complex variable to work with; it is affected by numerous internal and external complications. Externally, the measurement of the signal can be obfuscated or even obscured entirely by misplaced or loose sensors. The electrodes used in this study were disposable stickers that contain their own electrode gel. This gel can be dried out and the stickiness often needs to be augmented with medical tape to keep the electrodes in place. Additionally, movement by the participant runs the risk of dislodging or altering the contact of the sensors with the skin. Internally, heart rate is affected by more than arousal as well. Breathing, talking, and other movement by the participant alters their heart rate. Also, some individuals have irregular heartbeats or may have substances in their system, such as medications or caffeine. For example, one participant actually finished off an energy drink just before the experiment.

In addition to complications in the measurement, the physiological measures could have been better recorded. The minimum amount of time at the beginning of each session for the sensors to stabilize was used in this study, but it may have been better to allow the sensors more time to come to a baseline. In addition, a more substantial baseline could have been taken at the beginning of each task. An attempt was made to keep the participant's movement to a minimum on the hand with the sensors, but still participants were sometimes using that hand to support the controller. Lastly, the tasks were very short, with short breaks in between. The length may have been too short to see differences in these types of measures. Future studies may wish to control for these types of noise in the physiological measurements and collection techniques.

Applications to task design

In summary, the varied performance measures that were observed in the four tasks highlight the importance of evaluating each type of task. Optimum viewpoint or display setup will change depending on many aspects of the task. One aspect is complexity of navigational requirements, as can be seen with the turning errors in the road course, and the poor distance estimation in the parking task. Another aspect is inclusion of three-dimensional components, such as the ramp and platform. Tasks that require planning of goals and execution of plans may be influenced negatively by poor display setup, such as the barrel round-up task in the small screen. Although the tasks in this study were designed to be varied and to elicit different setup-induced influences on performance, the results were often not as expected. The display setup of any teleoperated system should be tested with the specific type of task for which it is designed due to the complexity of the interactions of the display components.

Limitations

It is important to keep in mind that this research was conducted in a laboratory, using relatively simple terrain and robot simulations. The participant population was sampled from undergraduates in a university setting, which is not necessarily descriptive of the population that may be teleoperators in the field. Although the implications of this research indicate that there are important aspects of display that may interact with perception of task and performance, these considerations underscore the importance of the need for further testing of teleoperational setups under more realistic environments.

The current research, while presenting a large amount of information on individual influences of aspects of viewpoint on the teleoperation of robots, could have benefited from different and additional measures. The NASA TLX revealed unexpected interaction of screen size, perception of task, and performance, but the measure was taken only once at the end of the experiment. Since the tasks were so varied in design, it may be valuable to administer the TLX after each task to pinpoint specifically which types of activities interact with viewpoint to affect perception of the task. Additionally, mood ratings should be included, such as ratings of how participants feel beyond fun or frustrated, such as if they feel relaxed. Perception of the task could also include more general indicators: was the experience like a video game, or did it seem like hard serious work? Future research should definitely look further at the influence of screen size on the operator's perception of the task, even when there is little influence on performance.

Future research

Future research of display interfaces for teleoperation is needed. This dissertation was a start for understanding the implications of the various components of viewpoint on the display, but it was limited in scope, regarding the camera placement options, screen sizes, and angle adjustments. Placing the camera on the front, back or sides of the robot may interact in different ways with the other aspects of the viewpoint. The small screen was not as small as some teleoperated screens can be, and the large screen was very large for a field-deployed environment. A common screen size—laptop size—was not tested and should be tested in future research, as it may indicate whether the screen size effects are due to some continuous size-dependent factor or if there is a size threshold that may occur for particular effects. Screen angles in this dissertation were limited to the extreme cases of vertical and horizontal, which are not as common as slightly angled screens. A range of screen angles in between the two extremes may prove to offer improved performance or to minimize some of the adverse effects on performance found in this study. Perhaps most important, the interaction of multiple viewpoints needs to be explored. This study looked at only a single viewpoint, while many teleoperated robot setups may support multiple viewpoints, from several cameras and screens.

APPENDIX A: IRB APROVAL LETTER

THE UNIVERSITY OF CENTRAL FLORIDA
INSTITUTIONAL REVIEW BOARD (IRB)

IRB Committee Approval Form

PRINCIPAL INVESTIGATOR(S): **Linda Upham** **IRB #: 06-3167**
(Supervisor: Valerie Sims, Ph.D.)

PROJECT TITLE: Perception and Display for Teleoperated Robots

[X] New project submission [ ] Resubmission of lapsed project #_____
[ ] Continuing review of lapsed project #_____ [ ] Continuing review of #
[ ] Study expires [ ] Initial submission was approved by expedited review
[ ] Initial submission was approved by full board review but continuing review can be expedited
[ ] Suspension of enrollment email sent to PI, entered on spreadsheet, administration notified ______

Chair
[X] Expedited Approval

Dated: 1/24/06
Cite how qualifies for expedited review:
minimal risk and #7

[ ] Exempt

Dated: ___________
Cite how qualifies for exempt status:
minimal risk and _________

[✓] Expiration Date: 1/23/07

IRB Reviewers:

Signed: ______________________
Dr. Sophia Dziegielewski, Vice-Chair

Signed: ______________________
Dr. Jacqueline Byers, Chair

Signed: Tracy Dietz
Dr. Tracy Dietz, Designated Reviewer

Complete reverse side of expedited or exempt form
[ ] Waiver of documentation of consent approved
[ ] Waiver of consent approved
[ ] Waiver of HIPAA Authorization approved

NOTES FROM IRB CHAIR (IF APPLICABLE):
Please see revised protocol & original for signatures

APPENDIX B: INFORMED CONSENT FORM

Informed Consent Form

The University of Central Florida and the UCF Department of Psychology support the protection of human subjects participating in research. We are presenting the following information so that you can decide whether you wish to participate in this study.

This study, Perception and Display for Teleoperated Robots, is part of a dissertation project for Linda Upham, for the Ph.D. Modeling and Simulation Program here at UCF, under the direction of Dr. Valerie Sims. The Dissertation involves research into types of displays and their effectiveness in teleoperated tasks, such as the one you will be performing today.

In this study, you will be asked to guide remote control vehicle through an obstacle course from a remote location. During the session, we may record various physiological measures including: blood pressure with an arm cuff, heart rate and galvanic skin resistance (a measure of skin conductance) using a finger cuff, facial EMG with sensors on your cheeks and forehead. You will also be videotaped. The videotaped recording and all physiological data will be kept locked up after you have completed the study, and will be destroyed once the entire research study has been completed. After the completion of the remote control task you will be asked to complete several questionnaires. You will also be asked to answer a few questions about yourself. As researchers we are interested in how people in general answer questions. We are not interested in any particular person's specific responses. Furthermore, all of the data collected in this study will be kept completely confidential and throughout the study, you will be identified by a subject number only. No names will be used. This subject number will not be linked to your name in any way.

The study should require less than two hours of your time. If you have signed up for this study through ExperimenTrak, standard extra-credit will be awarded to your account. No other compensation will be awarded besides this extra credit. Your participation is strictly voluntary and you may withdraw at any time without consequence. You must be 18 years or older to participate. If you choose not to or cannot participate, an alternative assignment will be available for you for the same extra credit.

There are no anticipated risks to you as a subject in this study. The benefit to you is added knowledge about participation in psychological research. The results of this study will be incorporated in a dissertation, which will be available from UCF. Additionally, some results may be published in to the Field of Human Factors or Modeling and Simulation in the form of journal articles, posters, or presentations. These results will be analysis in aggregate form; individual answers and physiological data will not be published.

If you wish to see the results of this study, you may request a write-up of them from the investigators listed below. Additionally, you may contact the investigator with questions about this research.

(Cont.)

Primary Investigators:
Valerie Sims, Ph.D.
Department of Psychology
University of Central Florida
(407) 823-0343
vsims@pegasus.cc.ucf.edu

Linda Upham
Inst. for Simulation and Training
University of Central Florida
(407) 882-1300
lupha@ist.ucf.edu

This research study has been reviewed and approved by the UCF Institutional Review Board. Questions or concerns about research participants' rights may be directed to the UCF IRB office, University of Central Florida, Office of Research & Commercialization, Orlando Tech Center, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246. The telephone number is (407) 823-2901.

If you believe you have been injured during participation in this research project, you may file a claim with UCF Environmental Health & Safety, Risk and Insurance Office, P.O. Box 163500, Orlando, FL 32816-3500 (407) 823-6300. The University of Central Florida is an agency of the State of Florida for purposes of sovereign immunity and the university's and the state's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the university's and the state's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description, and I am 18 years of age or older.

____________________________ ____________________________

Signature of Participant Date

APPENDIX C: POST QUESTIONNAIRE

Demographics and Post Questionnaire

Your sex: ________ Your age: ________

In the task you just performed, how many times was a mistake made?

Mission 1 _______ Mission 2 _______ Mission 3 _______ Mission 4 _______

I found the task fun.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I found the task frustrating.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I was comfortable with the complexity of the task.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I was comfortable with the remote control mechanism.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I found the biometric sensors distracting.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I have a great deal of experience with video games.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

I have a great deal of experience with remote control vehicles.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

What do you think is the purpose of this study?

APPENDIX D: NASA TLX SUBSCALES

NASA Task Load Index Subscales

RATING SCALE DEFINITIONS		
Title	**Endpoints**	**Descriptions**
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

APPENDIX E: SPATIAL ABILITY APTITUDE SURVEY

The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

Name ______________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.

This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

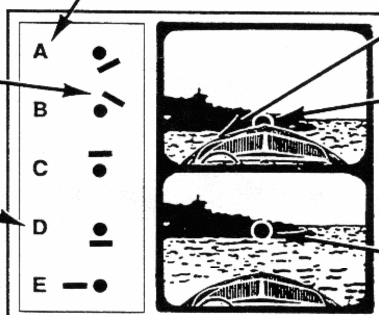
Here is Sample Item 1.

These bars represent the boat's prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)

These are the five possible answers to the item.



Sample Item 1

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

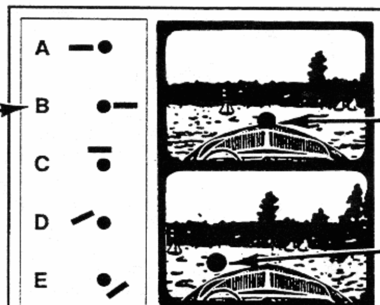
This is the same aiming point shown above. Note that the prow has dropped below it.

To work each item: **First**, look at the top picture and see where the motor boat is headed. **Second**, look at the bottom picture and note the CHANGE in the boat's heading. **Third**, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)



Sample Item 2

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

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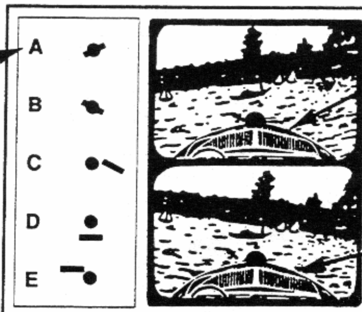
Now try Sample Item 3.

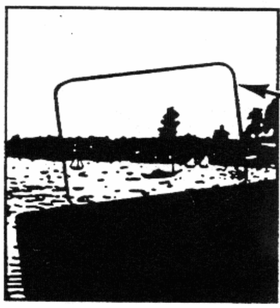
This is the correct answer. It shows that the motor boat changed its slant to the left, but is still heading toward the aiming point.



Sample Item 3

Here the motor boat is slanted slightly to the right. (Note that the horizon appears to slant in the opposite direction.)

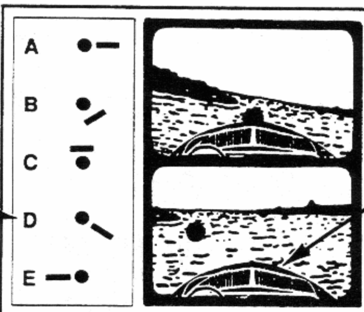
Here the boat has changed its slant toward the left. (To become level, the boat slanted back toward the right.)



Imagine that these pictures were taken with a motion picture camera. The camera is fastened rigidly to the boat so that it bobs up and down and turns and slants with the boat. Thus, when the boat tips or slants to the left (as in the lower sample in SAMPLE ITEM 3), the scene through the camera view finder looks slanted like this.

Look at Sample Item 4.

D is the correct answer. It shows that the boat changed its heading both downward and to the right; also that it changed its slant toward the right.



Sample Item 4

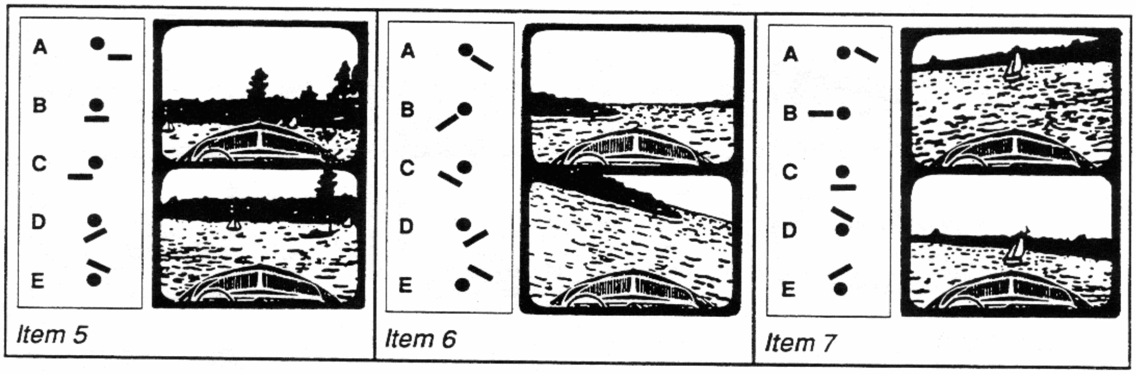
The prow of the boat has moved downward and toward the right. Also, it has changed its slant toward the right.

Now do Practice Items 5, 6, and 7. Record your answers on the separate answer sheet.

The aiming point is not marked in the test items. You must see the change in the boat's position without the aid of the dots.

To review:

First – Look at the top picture. See where the motor boat is headed.
Second – Look at the bottom picture. Note the change in the boat's heading.
Third – Mark the answer that shows the same change (in reference to the aiming point before the change).



C is the correct answer. The prow appears to have moved to the left and downward. It has not changed its slant.

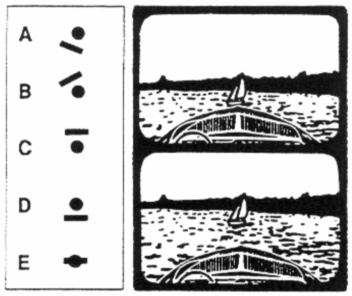
B is the correct answer. The prow appears to have moved to the left and downward. Also, it has changed its slant to the left.

E is the correct answer. The prow appears to have moved upward, and to have tipped left. It has not turned.

If you have any questions, ask them NOW.

At the signal of the examiner, not before, turn the page and begin working on the test. Mark all answers on the separate answer sheet. Work rapidly. If you are not sure of any item, you may guess, but avoid wild guessing. Your score will be the number of answers correct minus a small fraction of the number wrong. You will have ten minutes to work on the test. WAIT FOR THE SIGNAL TO BEGIN.

DO NOT WRITE IN THIS BOOKLET.



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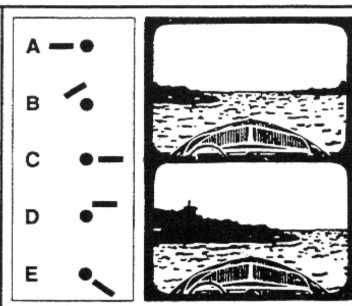

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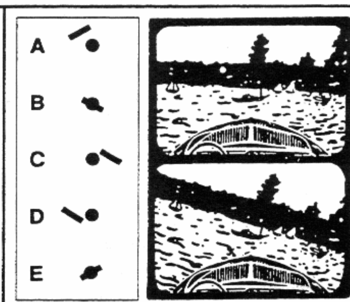

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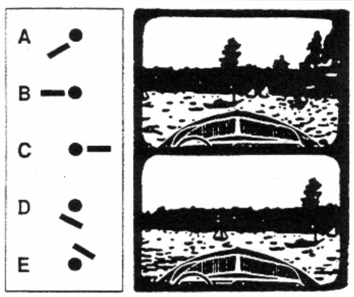

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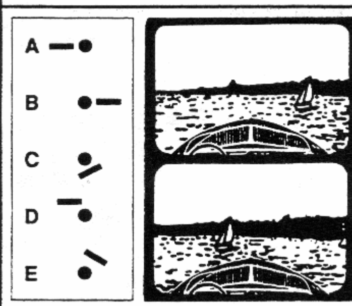

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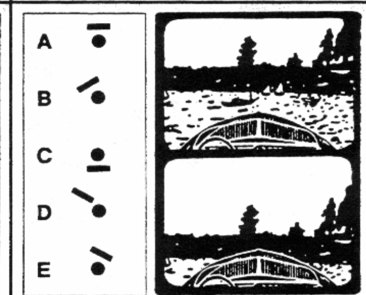

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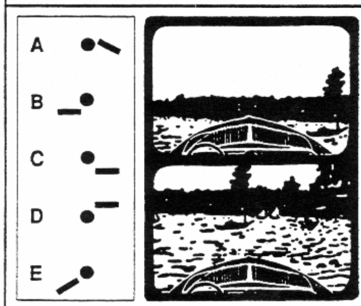

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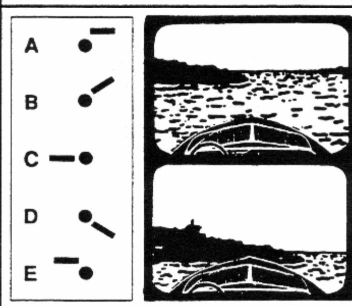

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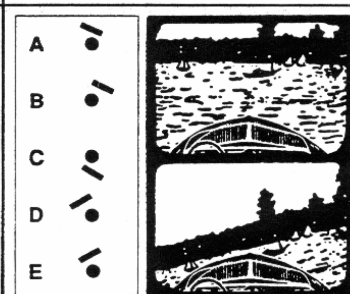

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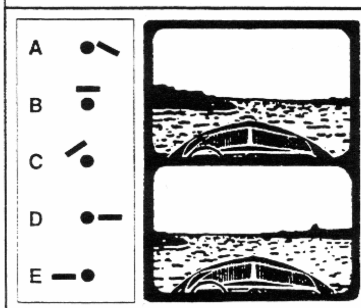

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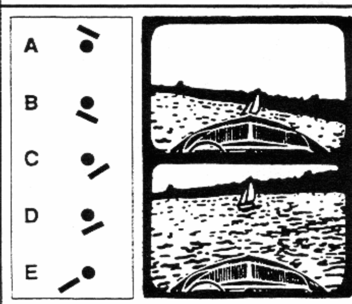

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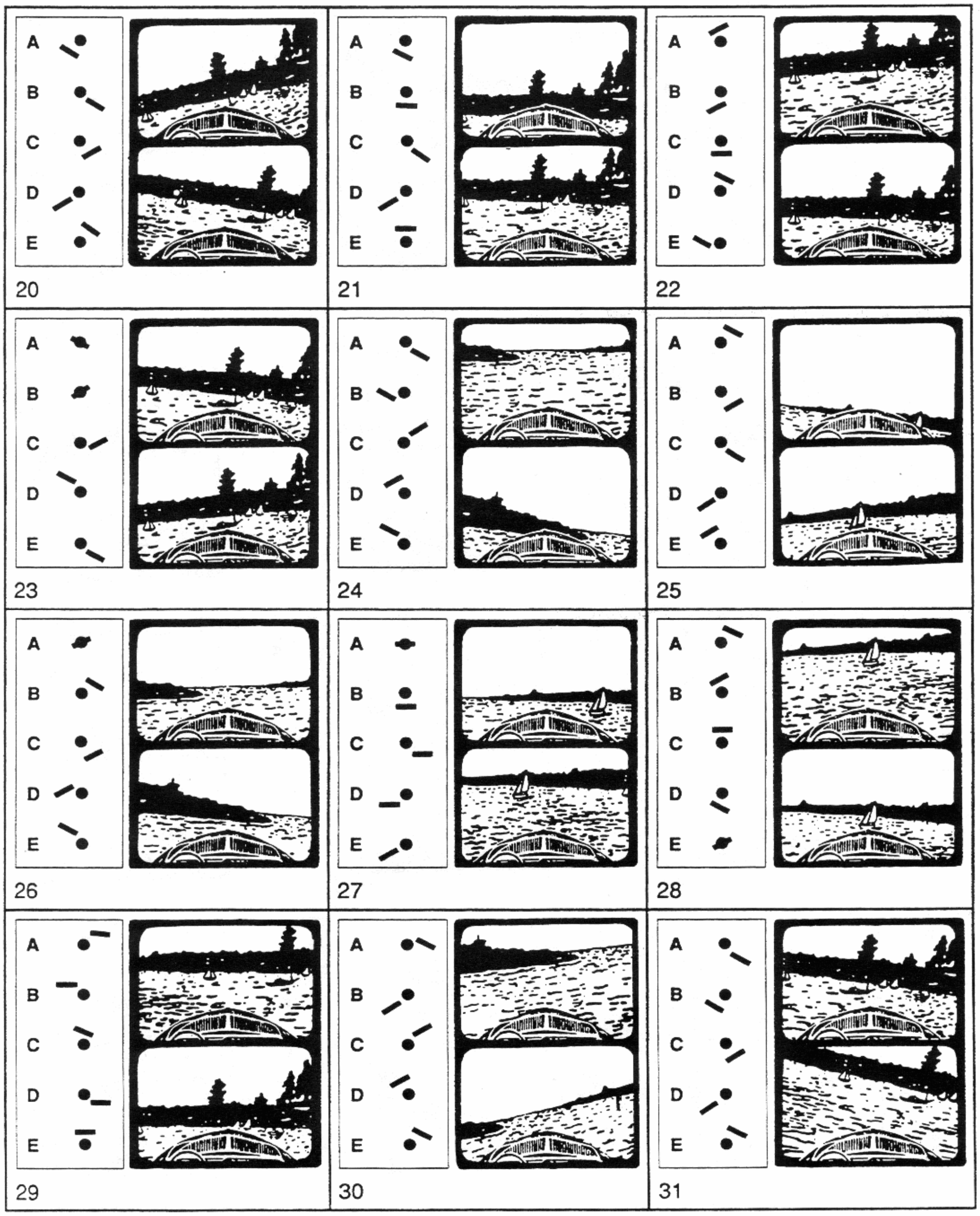
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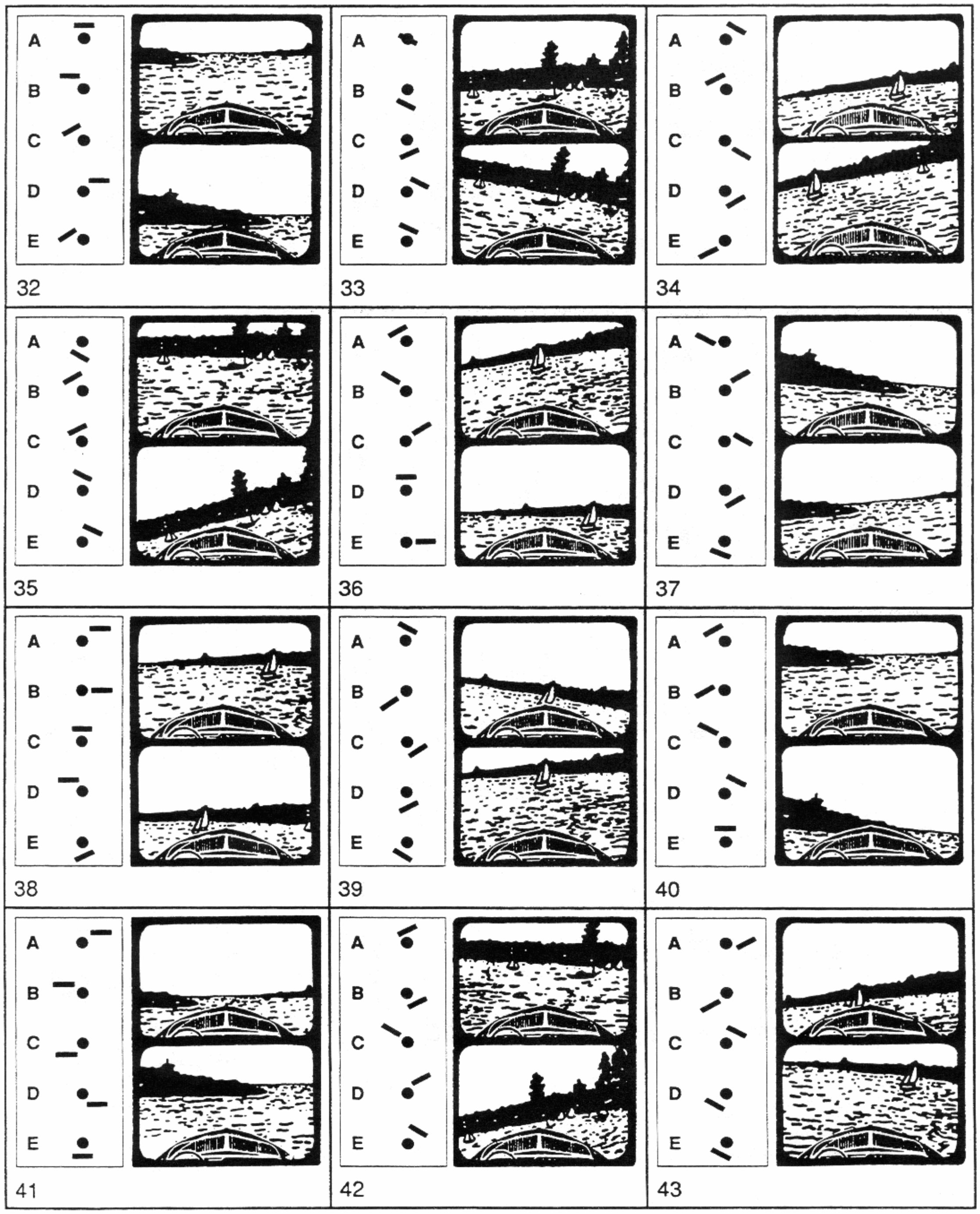
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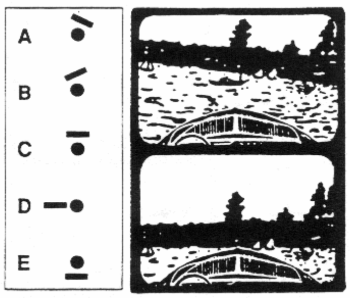

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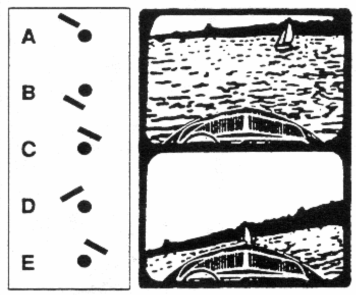

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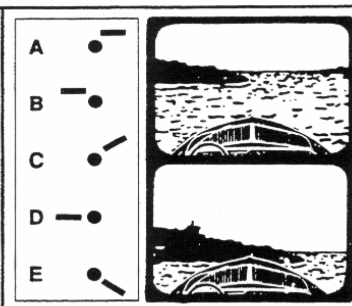

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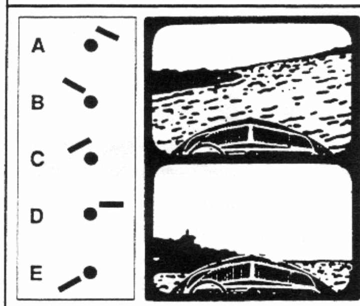

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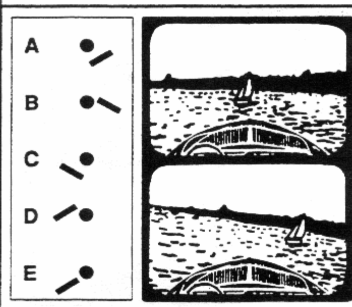

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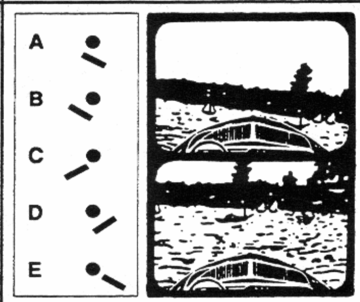

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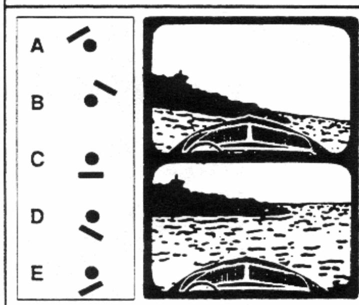

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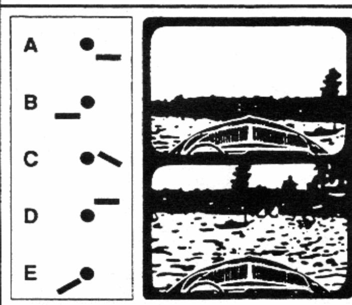

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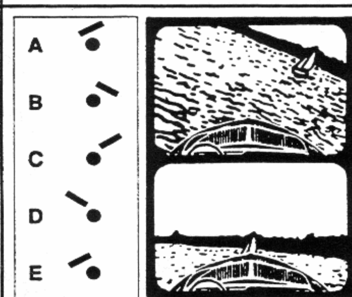

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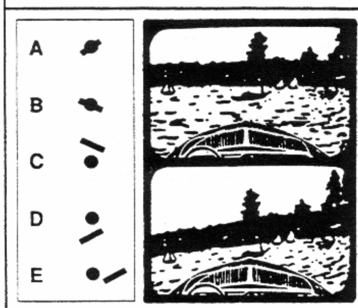

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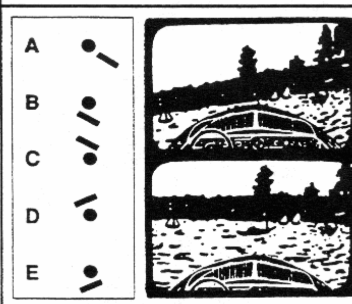

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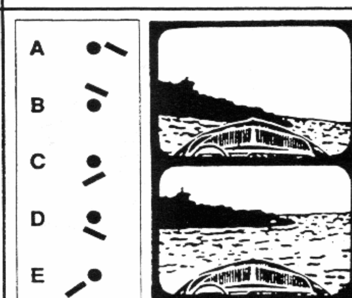

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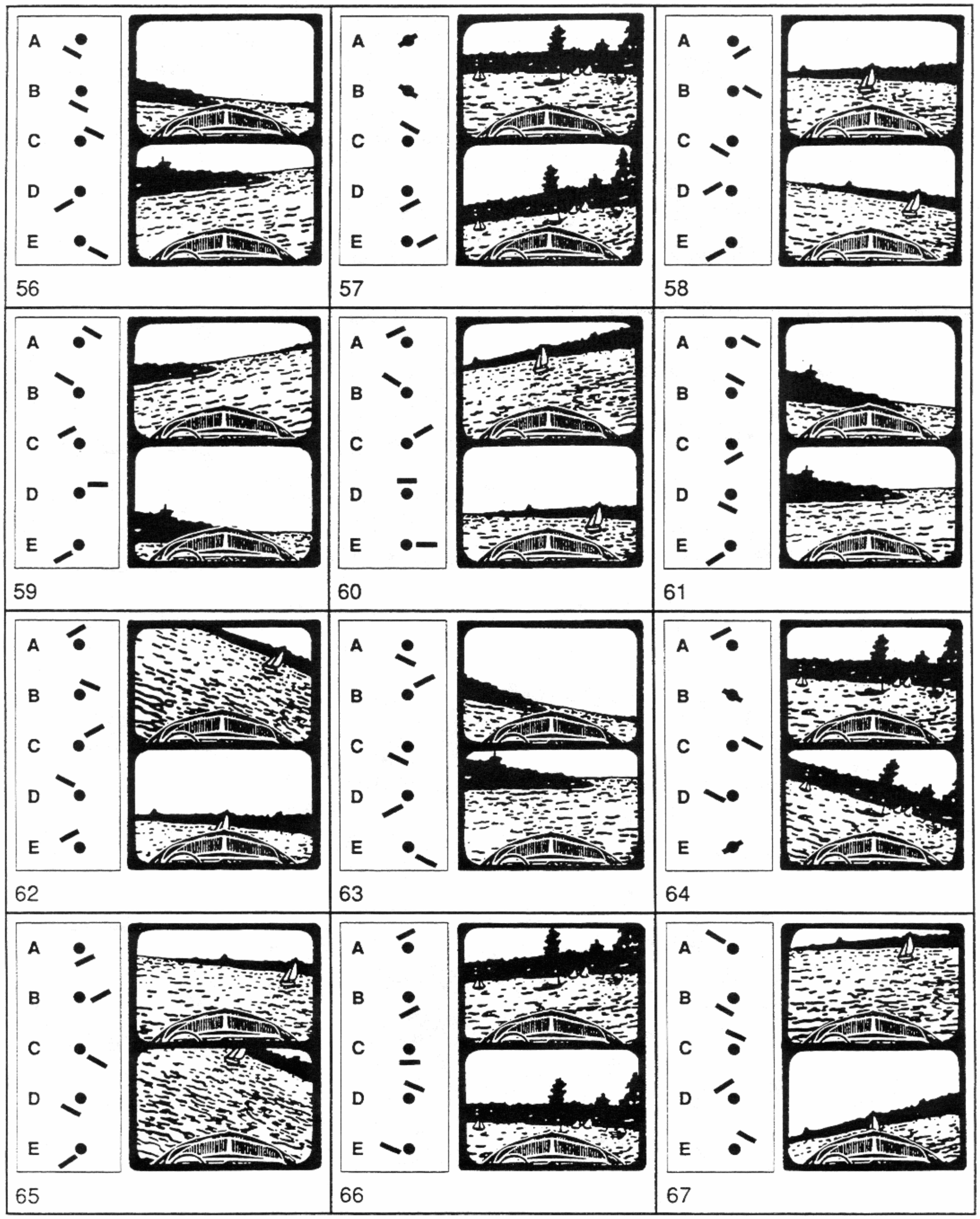
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APPENDIX F: MENTAL ROTATION TASK

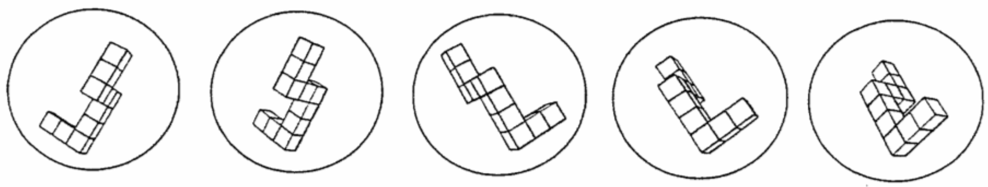
M.R.T. Test

Name ____________________

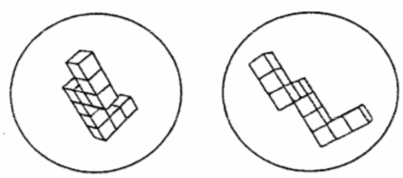
Date ____________________

____

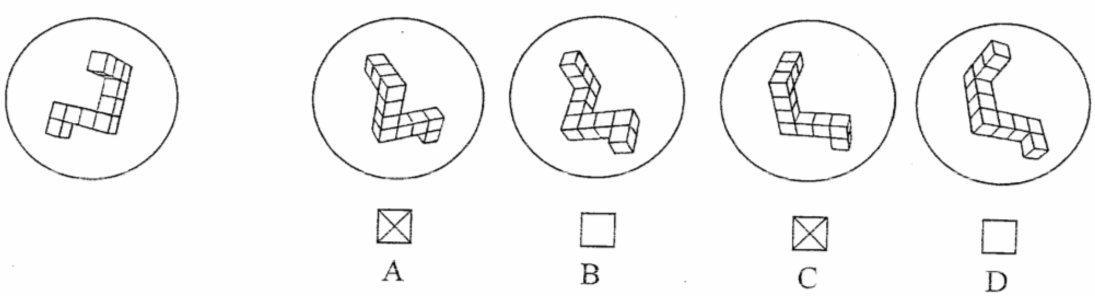
This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original objects and the chosen object will be that they are presented at different angles. An illustration of this principle is given below, where the same single object is given in five different positions. Look at each of them to satisfy yourself that they are only presented at different angles from one another.



Below are two drawings of new objects. They cannot be made to match the above five drawings. Please note that you may not turn over the objects. Satisfy yourself that they are different from the above.



Now let's do some sample problems. For each problem there is a primary object on the far left. You are to determine which two of four objects to the right are the same object given on the far left. In each problem always <u>two</u> of the four drawings are the same object as the one on the left. You are to put Xs in the boxes below the correct ones, and leave the incorrect ones blank. The first sample problem is done for you.



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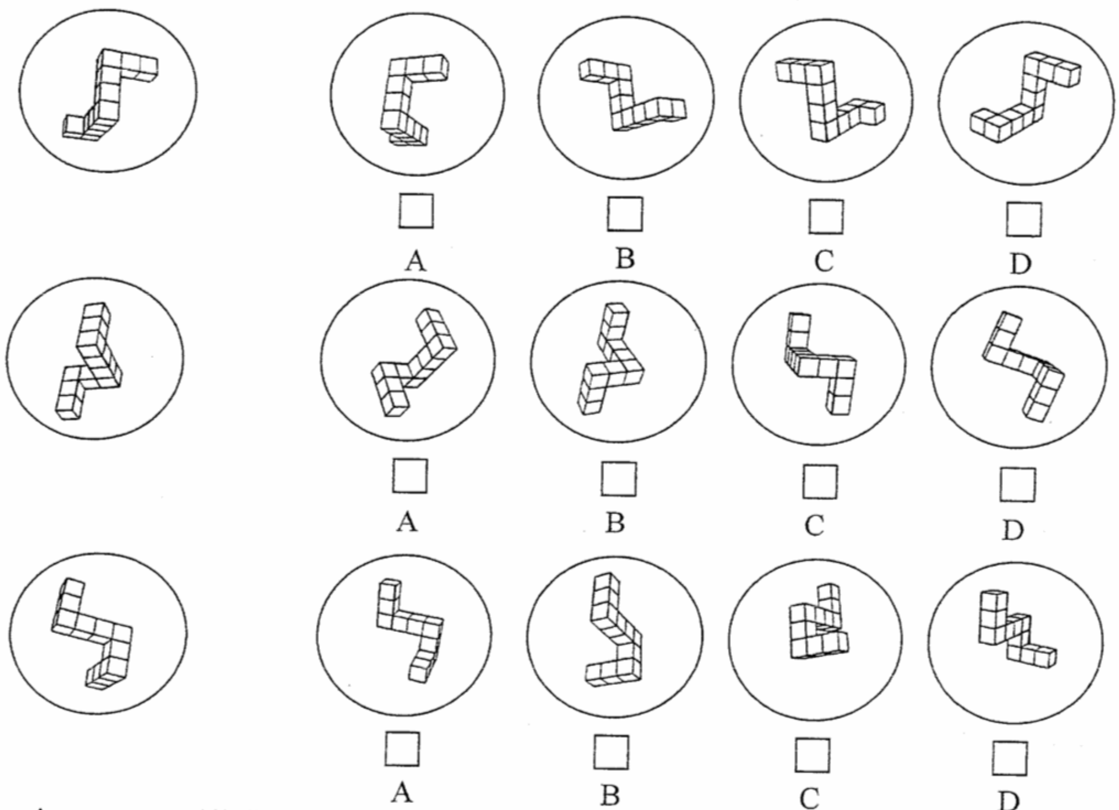
Adapted by S.G. Vandenberg, University of Colorado, July 15, 1971
Revised instructions by H. Crawford, U. of Wyoming, September, 1979
Digitally remastered by S. Rehfeld and S. Scielzo, U. of Central Florida, July 2005

Do the rest of the sample problems yourself. Which two drawings of the four on the right show the same objects as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.



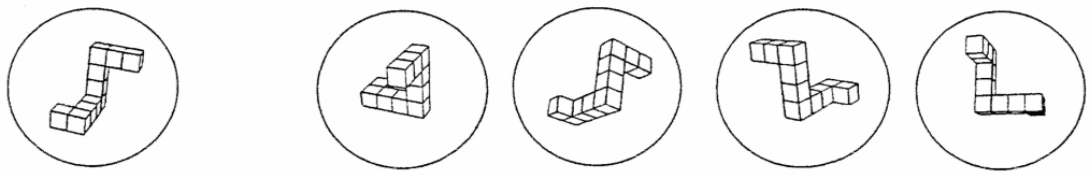
Answer: (1) first and second drawing are correct
(2) first and third drawing are correct
(3) second and third drawing are correct

This test has two parts. You will have <u>3 minutes</u> for each of the two parts. Each part has two pages. When you have finished Part I, STOP. Please do not go on to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

Work as quickly as you can without sacrificing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

1.



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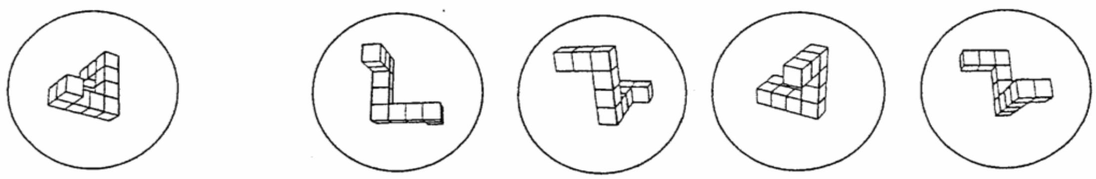
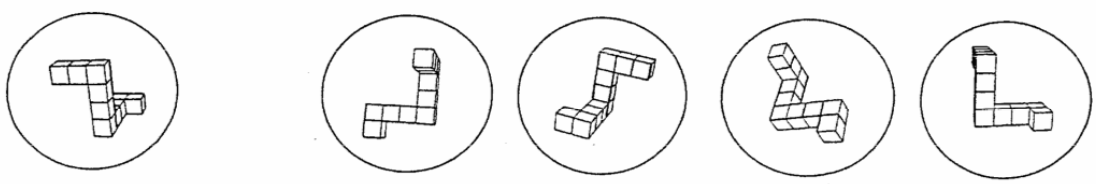


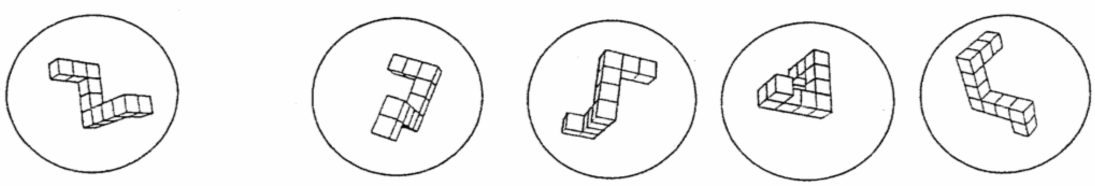
A B C D

3.



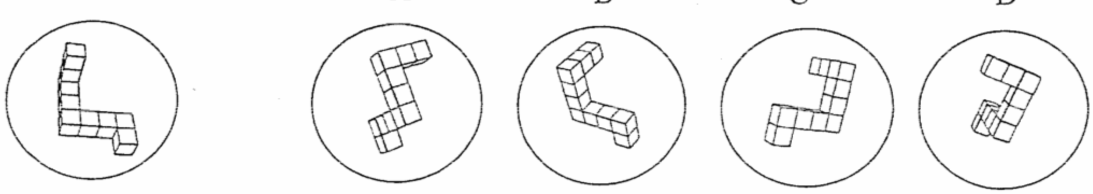
A B C D

4.



A B C D

5.



A B C D

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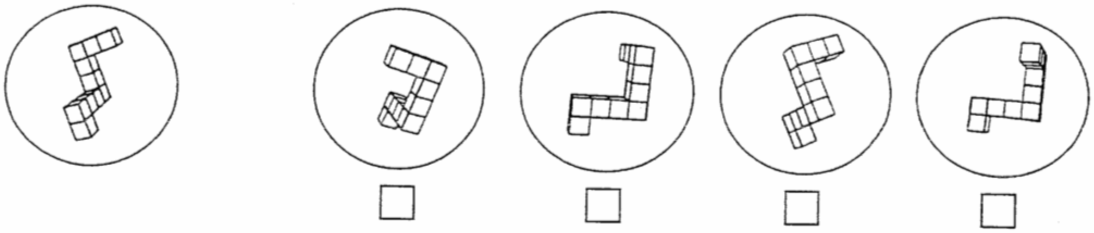
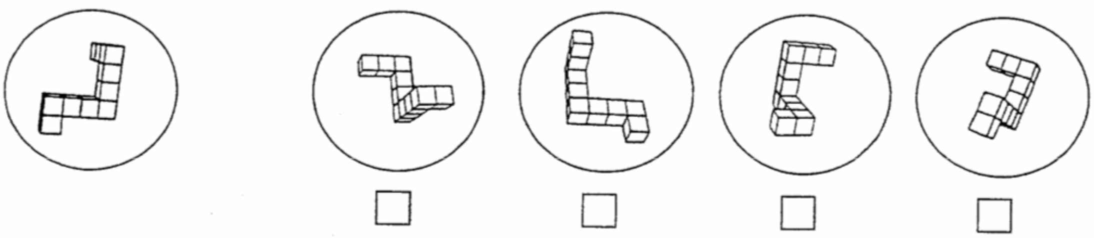
6.



A B C D

7.



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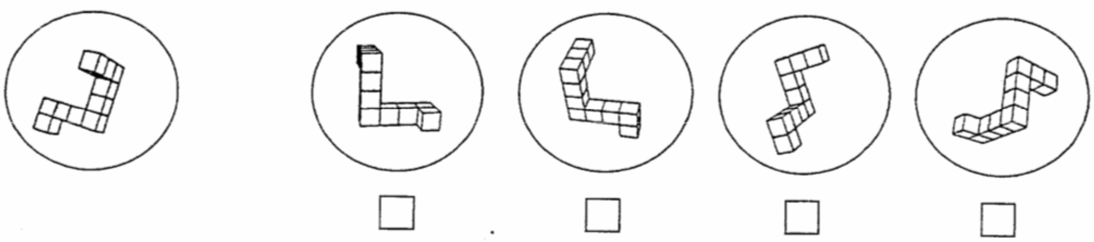
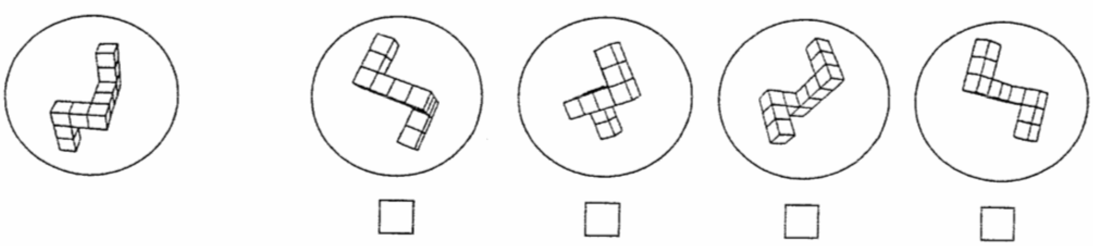


A B C D

9.



A B C D

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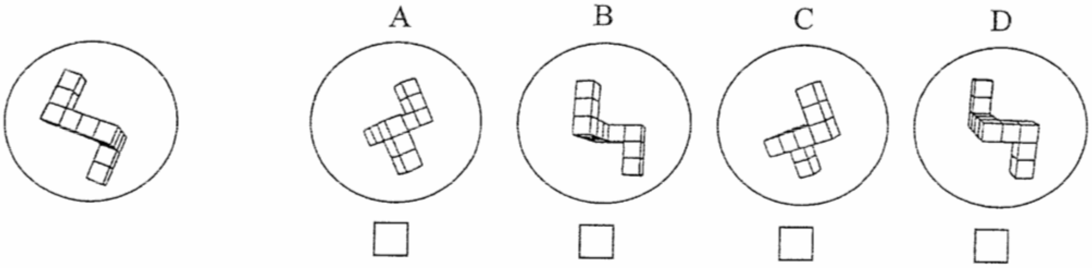

A B C D

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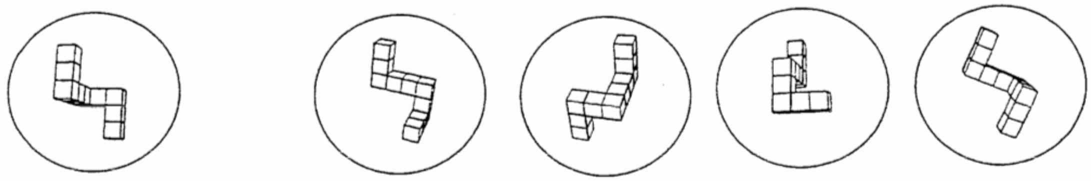
STOP

11. 

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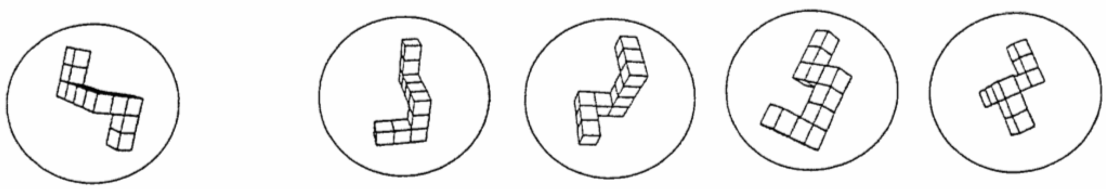
12. 

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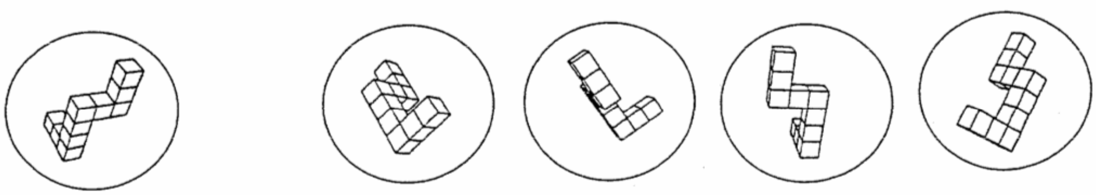
13. 

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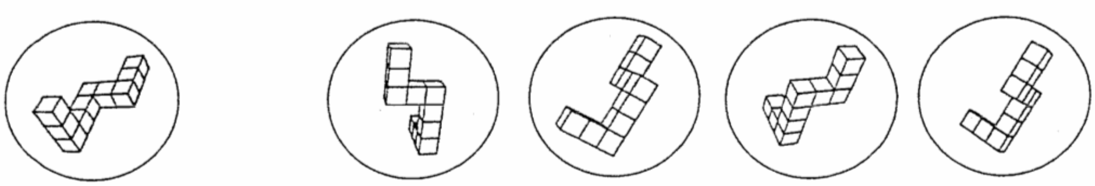
14. 

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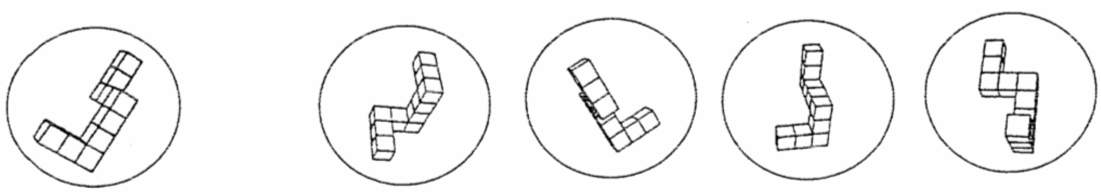
15. 

A B C D

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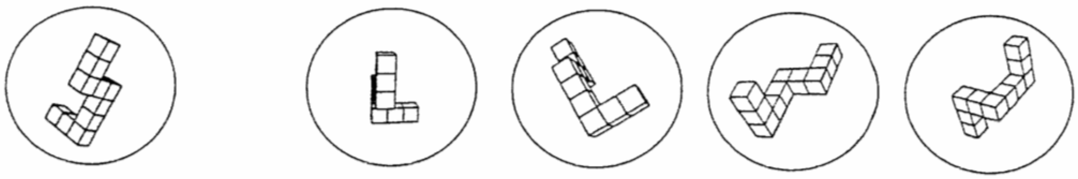
16. 

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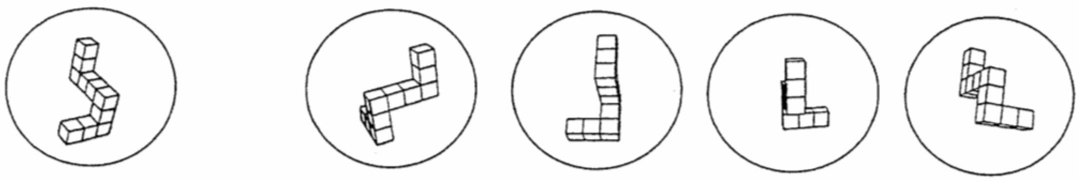
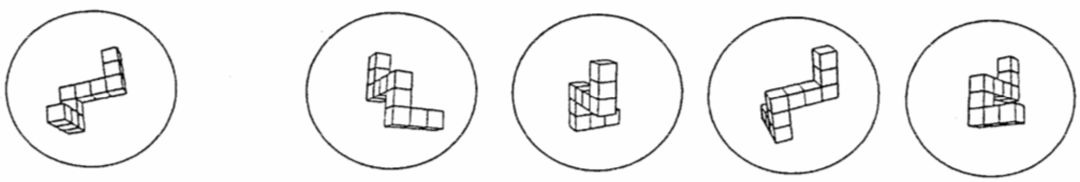
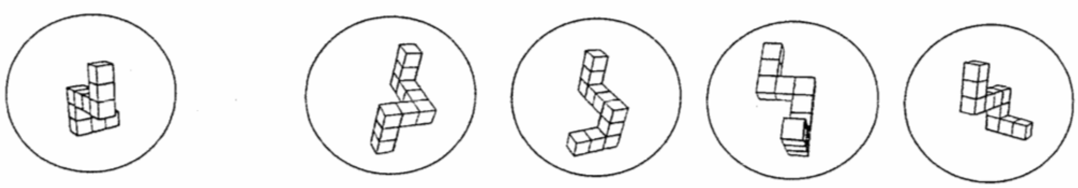
17. 

A B C D

18. 

A B C D

19. 

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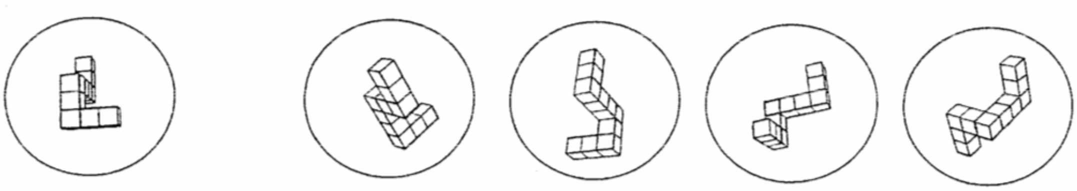
20. 

A B C D

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STOP

Mental Rotation Test Answer Key:

Part 1

1.	A	C
2.	A	D
3.	B	D
4.	B	C
5.	A	C
6.	A	D
7.	B	D
8.	B	C
9.	B	D
10.	A	D

Part 2

11.	B	D
12.	B	D
13.	B	D
14.	A	D
15.	B	D
16.	B	C
17.	A	C
18.	A	D
19.	B	D
20.	B	C

APPENDIX G: DEBRIEFING

Debriefing Statement

Perception and Display of Teleoperated Robots

Thank you for participating in this study. The purpose of this study is to investigate effects of various displays on the performance and physiological state of the operator of a remote control (or Teleoperated) task. We suspect that size and orientation of the display will change how well people perform the task, as well as how difficult the task seems to them, and how comfortable they are with the task, as indicated by their report, and their physiological state.

If you have any questions about your participation in this study, please feel free to contact the Principal Investigators listed below.

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APPENDIX H: SCRIPT

Script for Perception and Displays for Teleoperated Robots Study
For Linda Upham's Dissertation
Created 2/26/07, modified 3/26/07

Check with front desk, let them know when people are expected and where the participant should go, tell them your name and that the participants will be looking for "The Teleoperated Robots Study", and may mention "Linda Upham." They may want to go to the DART Lab, since that is how it is labeled on Experimentrak, but make sure the Front desk knows to direct them to our lab.

Room Setup
Batteries: The robot battery is charged using an all purpose charger, the setting for the dial is the black marker line, and the switch should be set to the middle. To charge the battery: first unplug the unit, then attach the red and black alligator clips to the red and black pins on the battery, then plug the unit in and press the Start button. The battery will take over an hour but under 3 hours to fully charge, it will then trickle-charge until unplugged. When it is charging, the charging status light will be solid green, when it is done, it will blink.

Robot Maintenance:
Each day, check to robot for any loose parts or malfunctions.
Verify alignment of the camera on the robot (should just see screws in view).
Check plugs on controller, camera, and battery.
Tighten wheel screws if necessary.

Obstacle Course Area:
Check tape, position of ramp.
Check projector tape, and position of projection surface.
Log into both cameras on recording station computer.
Check the visibility of both cameras through the web browser on the participant computer, colors are good, can see whole area.

Computers Setup:
Start laptop, Linda's account, no password. Load SimpleColors (not the .fla).
Load recording station PC:
Internet Explorer: load overhead camera:
http://192.168.1.??? Where ??? is somewhere between 200 and 210
Log into camera if needed

Biopac:
Open program using "Biopac Setup" icon on the desktop
Turn on Biopac, (switch is in back left),
Wait for busy light to go off, then hit retry to connect.
Set Length!! : In menu PM35 ->Setup Acquisition -> length: Hours, 1 hour.
Save File As: P followed by 3 digit participant #, in a folder of same name. for example third participant: E:/BiopacData/P003/P003.bpr

Morae:
Open Morae recorder software using "Morae Recorder" icon on desktop
Set save location to in proper folder ex: E:/BiopacData/P003/
Each task is recorded separate, and saved separate, so there should be 4 videos when done in the participant folder.
Use Ctrl-Alt-Shift-F9 to start and stop recording. When stopped, type save name as: P followed by 3 digit participant # dash task #
ex E:/BiopacData/P003/P003-task1

Paperwork:
Desk area is clear.
Backup Questionnaires are printed and ready.
Pen available.
Schedule of conditions is ready.
Gel, napkins, and medical tape are ready

Running a Participant:
Informed Consent:
"Thank you for participating in this study. We are studying robots that are operated by remote through a camera and monitor. We greatly appreciate your help. The whole study should take about an hour."

If there is a participant still running, they can start on Informed consent and pre-questionnaires in the hallway. Give them the informed consent clipboard (if 18+).
"First, are you 18 or over? Ok, good, here is an informed consent form for you to read over and sign."

Experiment Log:
Write down the participant in the Log: participant number, date, time, sex, age, condition code (A-H), Age Handedness, eye height, Color plate test, fill in notes or troubles as they are needed during experiment, if not through experimentrak then mark in notes, be sure to write down when you give extra credit. Also indicate in Log if there is a no-show!

After informed consent, Check the schedule of conditions to know which condition is appropriate for the participant, Males and Females have a different schedule.
Tell participant their Participant number so they can write it on their worksheets and surveys.

Orientation:
Bring them into the room, *"In this study, you will be driving this robotic vehicle through a series of short tasks on this obstacle course. You will be standing over here, and using that screen to navigate. There is a camera mounted there, so you can see where the robot is going on your screen. You will be using this playstation controller to drive."*

"During the tasks, we will record your performance as well as your pulse, skin conductance and heart rate. These measures are obtained through sensors on your fingers, wrist, and ankles. The finger sensors go on your non-dominant hand so that you can still use the controller. They work best if you don't move your hand around too much, so try not to grip the controller too hard with that hand."

Vision Color Test 1
Use the color plates, ask participant to identify the numbers shown on the plates. *"Please tell me if there are any numbers in this circle … and what are they … and this picture."* Write their response in the log, what numbers they say, or if none. If they are color blind, partial or full, that is ok, wait until second color vision test before modifying instructions.

(if participant asks, the plates are a small part of color vision tests used by eye-doctors. They do not measure all types of color-blindness. If they are interested in having their color vision tested, they should go to a vision specialist.)

Measure Height
"I need to measure your eye-height in your current shoes, so if you could please stand in the doorway, there is a tape measure there. Stand with your nose against the doorway here." Show them how to stand in doorway, looking at door frame, standing normal. Verify height of participant relative to the line marked A, ex: A-2 is 2 marks below A, A+1 is the line above A.

Screen Setup
Set up screen while they put on electrodes. Put down tape at their toes in case they move.

Set up Biopac Sensors
These sensors go on your fingers, this one measures pulse, and these two are for skin conductance. (If they ask, skin conductance is like how sweaty their palms are). *There are three disposable stickers used to measure heart rate, wrist, and each ankle. The sensors need to be calibrated, so we can put them on now and then they can calibrate while you practice driving the vehicle.*
ECG: electrode on wrist, ankle, ankle.
Skin conductance: middle and ring finger, electrode gel in the little hole, then wrapped on like band-aid on the pad of finger.
Pulse: index finger, square part on pad of finger, wrapped like a band-aid

Vision Color Test 2
Set up the barrels in the obstacle course in order, be sure to put them left to right for the participant's current condition (on-board camera versus overhead) in the order left to right: White - Red - Blue - Yellow - Green - Black. Ask the participant to identify the colors of the barrels by looking on the screen left to right. Mark any anomalies in the participant's answers in the log. If they can't identify the barrels' colors, modify the directions for the Barrel Round-up to not have the color restrictions.

Begin Training:
Set controller (Square for Left, Circle for Right)
"With this controller, use the hat-stick (point) to steer the robot. Forward, reverse, left and right are all possible. The other buttons are not used. Going backwards is a little slower than forwards. This robot can turn in place: if you turn all the way right or left (straight to the side) without going forwards or backwards, it just spins in place. So remember to use that if you need to maneuver around a tight space."

"The study will involve several sections. First, in a moment, you will have a chance to practice driving the vehicle; then there will be a series of short tasks for you to perform in the obstacle course. After that, there is a questionnaire on the computer and several questionnaires on paper."

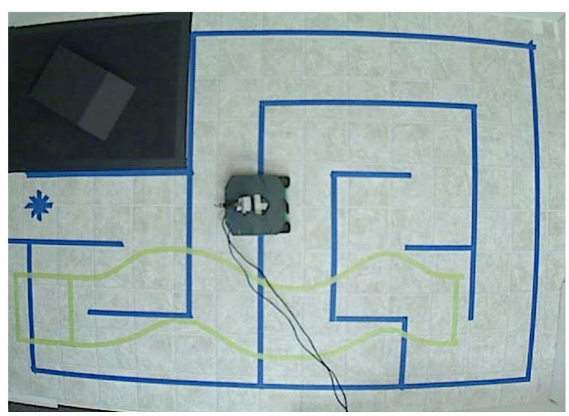
Start Biopac recording (play button on bottom right of screen). Make sure they are standing in place and not fidgeting. Ask for a deep breath if the results are wacky, if no pulse, re-adjust the pulse, it is probably too tight or too loose.

"During the practice time you can drive around within the obstacle course however you like, except stay out of the black area for now. Also, try not to go outside the edges of the obstacle course, (or try not to run into the wall for attached camera condition) since you may run into the wall then, and they are paper and may fall down. I will let you know when time is up."

Press F9 to mark time in Biopac, type "practice".

Time them 2 minutes. Hold cords out of the way, answer questions if they have any. If they stop early let them know how much time is left, and that they can drive around more if they want.

Free Practice time starting position -->



<u>Task Procedure:</u>
Read out instructions and setup course.
Ask: *Are you ready to begin?* So they know to be still and ready.
F9 to mark beginning of task (label as "task # start")
Ctrl-Alt-Shift-F9 to Start Morae recording
Make sure that after screen blinks and Morae is started recording (little camera is in taskbar) you can see the time scroll by in Biopac, so we can sync it up later.
Switch to Internet Explorer view (overhead camera)
Right click on camera view area, choose "Full Screen"
Say: "*When I say, you may begin…*"
As you say "*Begin*", click the mouse so we can time it later.
Watch the cord.
As participant ends task, press Escape, so we can time the end of the task later.
Ctrl-Alt-Shift-F9 to stop Morae recording.
Save video as Participant num, Task number in E:/BiopacData/*Participant folder*
As Morae is saving the video, switch back to biopac,
press F9 to mark end of task (label as "end task #")
Write all problems in the log.

Task 1: Precision Parking:
"This task is timed. Your goal is to park the robot on the raised platform. The robot must be all the way on the platform, with no wheels hanging off the on any side. If you go to far, or fall off one side, it does not count. You only get one try. Since this task is timed, please announce when you are done – when the robot is up on the platform all the way, so that I can stop the timer. I will let you know when to begin."

Place the robot in the starting position, green box facing East (door to the robot's right). If the participant is in the on-board camera position, show them the platform by holding the robot next to it so they can see it. Then slowly put the robot into the starting box, so they are clear how to get to the platform. Make sure all participants understand which side the ramp is on, and where the platform is, it is especially hard to see on the Horizontal conditions due to the glare.

Task 1 starting position, ending position.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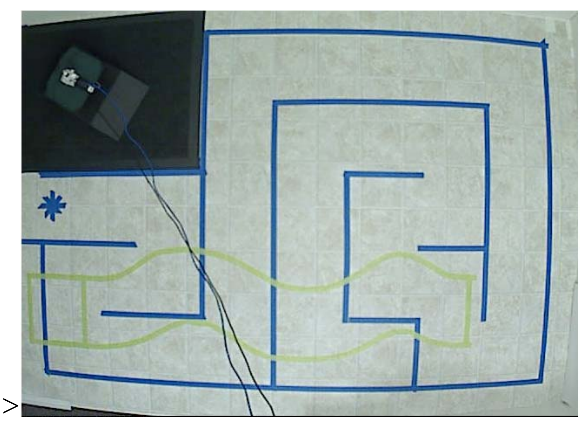
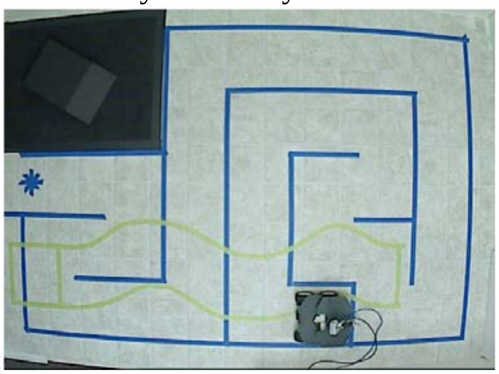
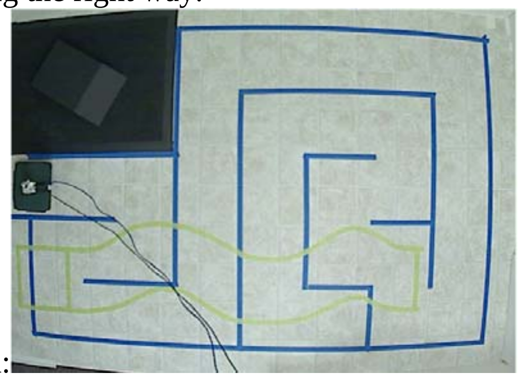
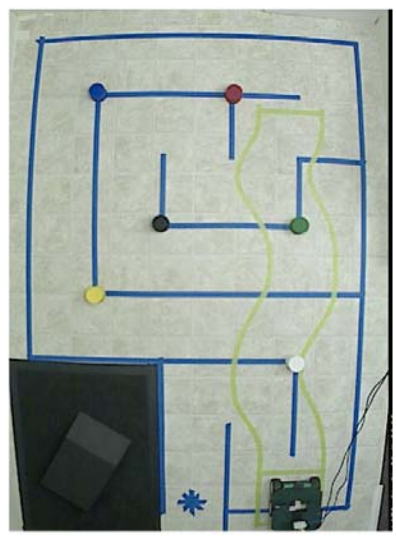


<u>Task 2: Road Course:</u>
"This task is timed. Your goal is to drive the robot through the course to the end, while staying within the lines. Each time you go over the line, points will be deducted from your score. The time it takes to get to the end will also affect your score. Try to use a constant speed, and be as quick and accurate as possible to get to the end of the course, marked with a star."
Place the robot in the starting position, near the projector, facing west (with door on robot's left). If they are in On-board camera position, show them the start position from a foot away or so, and explain how they will be going immediately to the right. For overhead, just point along the path a turn or so so they know they are started out facing the right way.

Start:  end: 

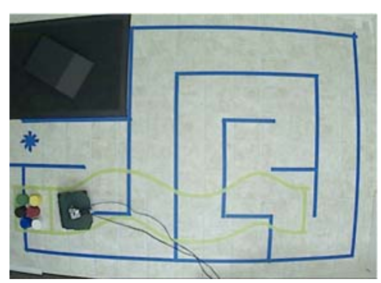


Task 3: Barrel Round-up
"The goal of this task is to gather the colored barrels into the pen. This task is timed. Your robot will start in the pen, and time ends when you get all the barrels into the pen. You may gather the barrels in any order you wish, except for these restrictions, and I will repeat these again:

- Green before Red
- Blue before Yellow
- Black and White may go in whenever.

If you are careful, you can sometimes gather more than one at a time. Gather the barrels by pushing them with the front of the robot. Be sure not to push them out of the viewing area, because then they will be lost. If any of the barrels become stuck or lost, you may leave it but you will lose points for not corralling it into the pen. Please announce when you have all the barrels into the pen, so I can stop the timer. So it is Green before Red, and Blue before Yellow. Any Questions?"

For On-board camera, show them the pen with the camera a foot away or so. Place the robot in the starting position, and be sure the participant understands what the pen is. Lastly, set up the barrels in their spots. Remind them of colors one last time.



Task 4: Danger Light Course:
Turn on projector program on the laptop, make sure warning light can be seen. (if it is on from last experiment, exit the program form the file menu (or press Alt-F-4) and reload it.) Be sure to click with the trackpad in the stripped part, to focus the screen. Important!! Otherwise when you press space, nothing will happen.

"During this task, your goal is to drive along the path marked in green towards the end, but you can only proceed when it is safe. There will be a warning light at the far end of the path that will indicate when a danger-time is in effect. When the Warning Light pattern is lit, you should not drive forward - stop the robot, and keep it still until the warning light goes off. Try to get to the end of the path as quickly as you can, but be sure to stay within the marked route. The end of the path is marked with a line, be sure to drive past that line to finish."

Verify they understand the task with: "Can you see the warning light pattern?" *Start the program by pressing Space to demonstrate how it works.* "So the way it works is when I say begin, the task will start, but you should only go when it is safe. This is an example of when the warning light is on so you should be stopped, now it is off, so you can go, now stop, go… It is just like red-light green-light. Any questions?"

Place the robot in starting position, green box, facing down the green path. Start recording data, *"When I say begin, the task will start, but you should only proceed when it is safe… Begin"*, as you say begin, hold Space bar for a second or two on the laptop, as well as clicking on the recording PC with the mouse. If the program doesn't start, the window may not be in focus, or you may need to reload the program

Finish up, and NASA TLX
After all tasks are done, let them know to take off all the sensors. Give them a napkin. They can throw away the stickers. Try not to crowd them in the small space, but make it easy to get to the big screen to do the NASA TLX questionnaire. Load up NASA TLX program on the Large Screen (horizontal) for them to do. Type participant number, and give them the definitions page. Tell them that all of the driving the robot is one task.

<u>Questionnaires</u>:
When finished give them the Packet.
"This is a set of questionnaires many of them are timed. Go ahead and start with reading the directions for the first one and let me know when you are ready to begin, I will time you."

Boat: 10 min, MRT 3 min, Rotation 3 min. Demographics on own.

They get to keep the Debriefing, and experiment experience form (to be turned into new Psych building main office)

APPENDIX I: PHYSIOLOGICAL DATA CODING

Process for cleaning Biopac Data from ECG, EDA, and PPG readings.
Created by Linda Upham Ellis, Nov 15, 2007
Open the Analysis file, if it's not already open:
Find the most recent copy of the Excel file
(Located F:/Biopac Data/Analysis/ *most recent.xls*)
Duplicate the file:
Select the file, Right-click> copy
Select blank space, right-click> paste
Rename the copy to today's date,
Select the file, Right-click> Rename
Open the new file into Excel by double-clicking it

Load File into Biopac:
Go to F:/Biopac Data/DATA/
Select Biopac file for next participant, inside the folder ex: P050/p050.aqc
Duplicate the file it to make a working copy:
Select the file, Right-click copy
Select blank space, right-click paste
Open the copy by double-clicking it
Choose Analyze Only in dialogue box

Clear away any extra waveforms at the bottom if they are there:
Select desired wave form, Click on left edge where the name is
    On Menu: Edit> Remove Waveform
    There should only be 3 Three channels now: EDA, ECG, PPG

Create ECG template waveform:
Select ECG wave form
Click on left edge where the name is
Duplicate wave form
On menu: Edit > duplicate
Rename duplicate:
    Double-click edge, type "template ECG", click ok

Apply Filter to reduce noise on the ECG template:
Select template ECG wave form
Click on left edge where the name is
On Menu: Transform-> Digital filters-> FIR > Band Pass
    In window, Change:
        Low Freq to .5000
        High Freq to 35.00
        Coefficient to 1600
        Click ok and wait for it to finish

Transform ECG template wave using example heartbeat:

Set scale at bottom to 1 second to get close
Click the time once to bring up scale,
set it to 1 second,
click ok
scroll over to a reasonable looking area of measurement
Set example heartbeat
Click I-beam pointer tool
Click and drag black area
Highlight one pulse-beat interval
See picture,
If one heartbeat is a thub-dub: little hump for thub, big for dub,
In channel, select an area from just before one ‘thub’
to the just before next ‘thub’
On menu: Transform> Template Functions> Set Template
Transform using template:
On Menu: Edit> Select All
On Menu: Transform> Template Functions> Correlation
On Menu: Display> Autoscale Waveforms

Create PPG template waveform:
Select PPG wave form
Click on left edge where the name is
Duplicate wave form
On menu: Edit > duplicate
Rename duplicate:
Double-click edge, type “template PPG”, click ok

Apply Filter to reduce noise on the PPG template:
Select template PPG wave form
Click on left edge where the name is
On Menu: Transform-> Digital filters-> FIR > Band Pass
In window, Change:
Low Freq to .5000
High Freq to 35.00
Coefficient to 1600
Click ok and wait for it to finish

Transform wave for data for PPG:
Set scale at bottom to 1 second
Click the time once to bring up scale,
set it to 1 second,
click ok
scroll over to a reasonable looking area of measurement
Set example heartbeat
Click I-beam pointer tool

Click and drag black area
Highlight one pulse-beat interval
*In ECG channel, Select an area from just before one 'thub' to the just before next 'thub' (one heartbeat is a thub-dub)
see picture
*Reselect template PPG channel by clicking left name
On menu: Transform> Template Functions> Set Template
Transform using template
On Menu: Edit> Select All
On Menu: Transform> Template Functions> Correlation
On Menu: Display> Autoscale Waveforms

Create EDA template waveform:
Select EDA wave form
Click on left edge where the name is
Duplicate wave form
On menu: Edit > duplicate
Rename duplicate:
Double-click edge, type "template EDA", click ok

Apply Filter to reduce noise on the EDA template:
Select template EDA wave form
Click on left edge where the name is
On Menu: Transform-> Digital filters-> FIR > Low Pass
In window, Change:
Cutoff Freq to .5
Coefficient to 1600
Click ok and wait for it to finish

Create ECG Rate Channel:
Select template ECG wave form
Click on left edge where the name is
On Menu: Transform> Find Rate (it's at the bottom)
In box, keep values default (5% of Peak)
A new channel is created called Rate
Rename new Channel
Double-click edge, type "ECG Rate", click ok

Create PPG Rate Channel:
Select template PPG wave form
Click on left edge where the name is
    On Menu: Transform> Find Rate (it's at the bottom)
        In box, keep values default (5% of Peak)
        A new channel is created called Rate
    Rename new Channel
    Double-click edge, type "PPG Rate", click ok

Set up the Boxes to get Means:
    In boxes at top of screen
    In first small box, select channel: template EDA
        First larger box, set to Mean
    In second small box, select channel: Rate ECG
        Second Larger Box set to Mean
    In third small box, select channel: Rate PPG
        Third Larger Box set to Mean

Open the Journal Area:
Menu: Display->show > check Journal to make it appear below
Put the time and date in the journal (buttons are at top left of journal area)

Save the Biopac file,
    If the Journal stuff goes away, there is a scroll bar on the bottom right, just scroll all the way up

Go to the Excel Tab called BioData
(you may need to scroll the Tabs to the right, since there are so many Tabs)
(the Tab scroll arrows are on the bottom left)
Find the next participant to do, make a note of it.
On a paper, Note the times for:
task1: Start, Ramp, End; task2: Start, End; task3 start, end; task4 start, end

Process each time interval onto a new line in the journal using the Typical Processing:
Task1: before start, before ramp, after ramp, before end, after end
Task2: before start, before end, after end
Task3: before start, before end, after end
Task4: before start, before end, after end

Typical Processing:
In Biopac, Go to Desired time:
Click on time area to open the scale window
Confirm scale is set to be 5 seconds
Insert desired time in select box
Click ok
Desired time appears at extreme left
Highlight time interval (before or after)

 Select I beam pointer (lower right of screen)
 Point at marker (decimal point to decimal point),

Click and drag black area to select 5 seconds
Process Means for selected area

 Press control-M
 3 values will appear below in the Journal
 Reposition curser at the right end of those values to add on next 3

Transfer data to the spreadsheet

 Get data to transfer:
 Point curser at the beginning of the data line

Press and hold shift, press End key – this should highlight the whole line
On menu select Edit > Copy

 Put data into new location in spreadsheet
 Go to spreadsheet
 Place curser on 1st space in task
 On menu select Edit > Paste
 Scroll over to the right on the row to confirm transfer

Put asterisk *** in the space to the right if there was something odd about the values (rates of over 150=heart attack, under 40= comatose) You can often tell the reason for oddities if there was an irregular heartbeat in the time interval.

Save and close the Biopac file,

 If the Journal stuff goes away, there is a scroll bar on the bottom right, just scroll all the way up

Save the Excel File, then go on to next participant.

APPENDIX J: DEFENSE PRESENTATION

Defense Presentation

Perception and Displays for Teleoperated Robots

Linda Upham Ellis

Modeling and Simulation

Outline

- Introduction
- Current Research
- Method & Materials
- Results/Discussion
- Applications

2

Teleoperation

- Teleoperation typically involves
  - directing a robot's motions (navigation)
  - using information gained from the robot (such as a camera view)
  - using display screens and control mechanisms by the operator
  - from a remote location

3

Previous Research: Navigation

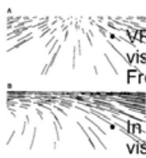
- Navigation and self-motion is aided by
  - Visual stimulus (what we see)
  - Vestibular (inner ear and balance)
  - Somatosensory (what we feel)
  - Proprioceptive (knowing where our body parts are)
    - Studies show people can store motion and velocity patterns without visual, Berthoz et al., (1995)
    - But can they do the same with Only visual cues?
    - In teleoperation, as in VR, there is no actual self motion
    - This can lead to contrary sensory input

4

Introduction

Previous Research: Visual Cues

- Judging motion with only visual cues
  - Optic flow
  - Motion Parallax

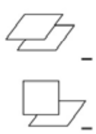


- VR studies show people can judge self-motion using only visual cues, but tend to underestimate travel distance, Frenz & Lappe, (2005)
- In teleoperation, camera placement may distort or hide visual cues

Introduction 5

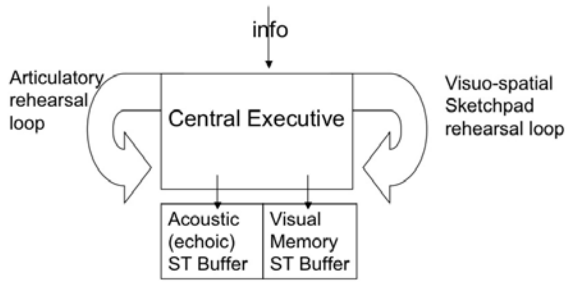
Previous Research: Frames of Reference

- Reference Frames
  - Particular perspective or axis used as a place to judge the position and motion of other bodies within the system
  - Teleoperators must maintain multiple
    - Own self, display system, robot, control mechanism
  - Matching reference frames can be simplified, but mismatched ones cannot
  - May use the limited cognitive resources



Introduction 6

Previous Research: Working Memory



Introduction 7

Previous Research: Working Memory

- Navigation (plan routes & think about the spatial relationships) utilizes both visuo-spatial sketchpad & central executive
  - Hindering attention to memorized locations impairs spatial working memory, c.f. Using spatial and letter dual task (Edward, Jonides, & Reuter-Lorenz, 1998)
- Central exec. plays active role in sketchpad
  
  - c.f. helping to design a route from one block to the next within the Corsi Block pattern (Rudkin, Logie, & Pearson, 2007)

Introduction 8

Previous Research: Working Memory

- Working memory is a limited resource
- Continual reloading of FoR into sketchpad
  - Self, Control, Screen, Display, Robot
  - Manipulation of sketchpad needed to drive, but limited space requires reloading
- Overload of the cognitive resources may affect performance and perceived workload

Introduction 9

Perceived Workload

- Operator's perception of Workload is measured though self report (c.f. NASA TLX)
- Research has shown perceived workload is correlated with performance in several domains (Alexander, Wickens, & Merwin, 2005)
- Expected that aspects of the viewpoint will influence perceived workload

Introduction 10

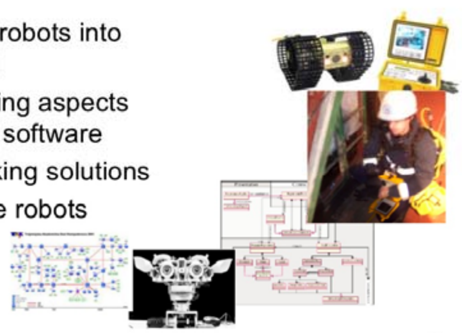
Spatial Navigation

- Egocentric Displays
  - Orienteers turn the map, heading up
  - Viewer centric maps are preferred to exocentric maps (Hegarty and Ferguson, 1995)
- Rotation and turning
  - Given the same or different 3D perspective drawings of objects: reaction time increase linearly with angular difference (Shepard and Metzlers, 1971)
  - Shows: more mental manipulation (ex: angular rotation) requires more cognitive processing

Introduction 11

Current Robotics Research

- Getting robots into the field
- Optimizing aspects of robot software
- Networking solutions
- Sociable robots



Introduction 12

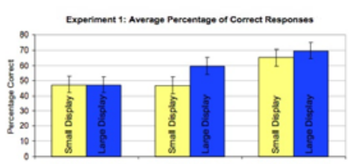
Robotics & the Gap

- Psychological aspects of the operator
  - Workload
  - Human performance
  - Cognitive processes
- Only a few projects

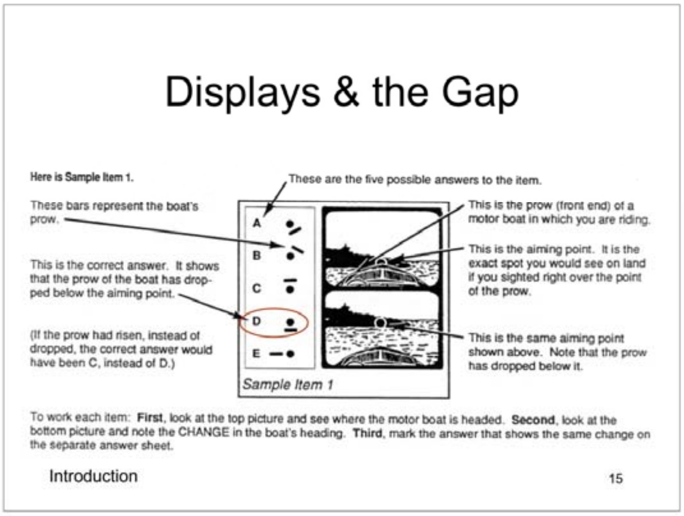
Introduction 13

Displays & the Gap

- Physically Large Displays (Tan, Gergle, Scupelli, & Pausch, 2006)
  - Showed: large displays help users perform better on mental rotation tasks, 3D navigation, & mental map creation
  - Independent of visual angle & factors that increase immersion or performance (textures, landmarks, etc)
  - 76`` vs 14'' wide
  - Large display immerse user & so bias egocentric strategy



Introduction 14


Displays & the Gap
Here is Sample Item 1.
These are the five possible answers to the item.
These bars represent the boat's prow.
This is the prow (front end) of a motor boat in which you are riding.
This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.
This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.
(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)
This is the same aiming point shown above. Note that the prow has dropped below it.
A
B
C
D
E
Sample Item 1
To work each item: First, look at the top picture and see where the motor boat is headed. Second, look at the bottom picture and note the CHANGE in the boat's heading. Third, mark the answer that shows the same change on the separate answer sheet.
Introduction
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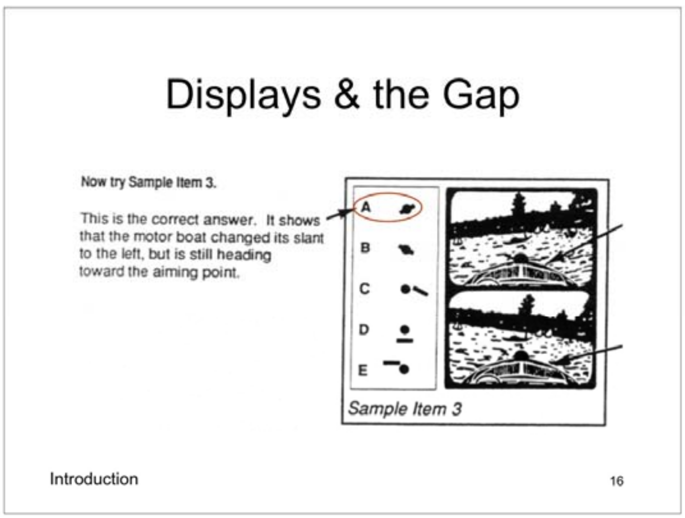

Displays & the Gap
Now try Sample Item 3.
This is the correct answer. It shows that the motor boat changed its slant to the left, but is still heading toward the aiming point.
A
B
C
D
E
Sample Item 3
Introduction
16

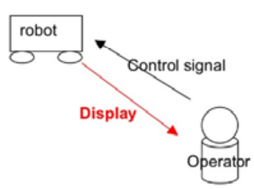
Displays & the Gap

- Limitations of the Physically Large Displays study (Tan, Gergle, Scupelli, & Pausch, 2006)
  - Used projected screen but desktop CRT/LCD also, only med and large displays
  - Only *performance* on spatial tasks was measured, not physiological or workload
  - Looked only at *size* of display

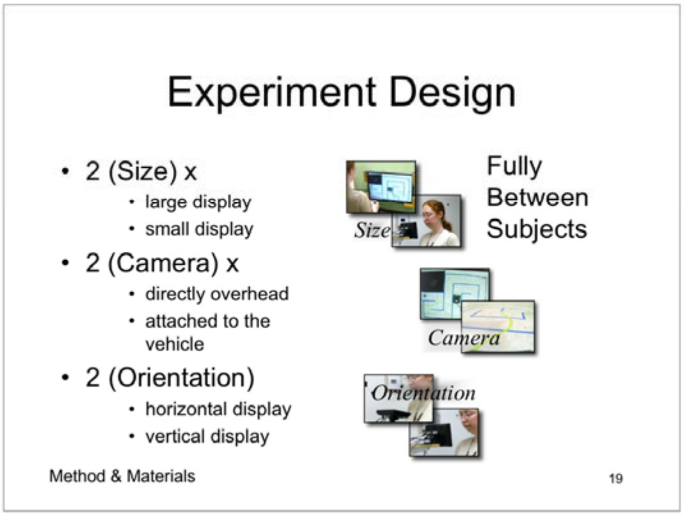
Introduction 17

Current Research Scope

- Investigate display system of a robot teleoperation task
  - Camera
  - Screen



Current Research 18


Experiment Design
• 2 (Size) x
• large display
• small display
• 2 (Camera) x
• directly overhead
• attached to the vehicle
• 2 (Orientation)
• horizontal display
• vertical display
Fully Between Subjects
Size
Camera
Orientation
Method & Materials
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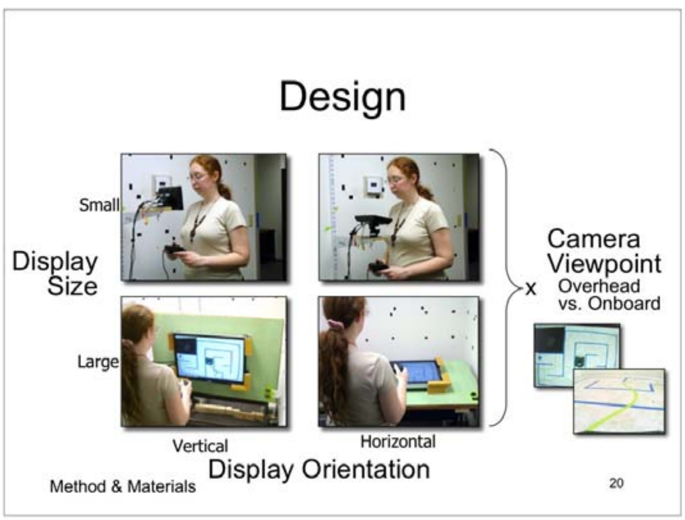

Design
Small
Large
Display Size
Vertical
Horizontal
Display Orientation
x
Camera Viewpoint
Overhead vs. Onboard
Method & Materials
20

Dependent Variables

- Performance
  - Basic Navigation
  - Turning Navigation
  - Precision Navigation
  - Strategy
  - Overt Time Pressure
  - Distance Estimating
- Perception
  - Workload
  - Frustration
  - Fun
- Physiological
  - Heart Rate
  - GSR

Current Research 21

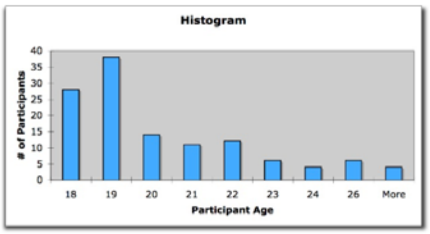
Expected Results

- Mismatched frames of reference add difficulty
  - People will perform poorly
  - People will report higher workload, frustration and have higher arousal
- Large screen and flat screen are novel
  - Increased arousal & fun

Current Research 22

Participants

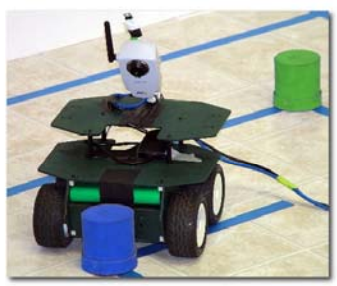
- 123 Participants from UCF
- 48 F, 75 M



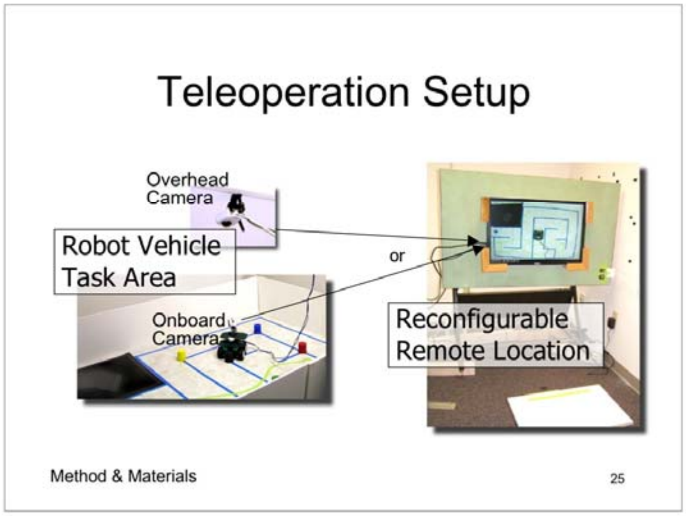
Method & Materials 23

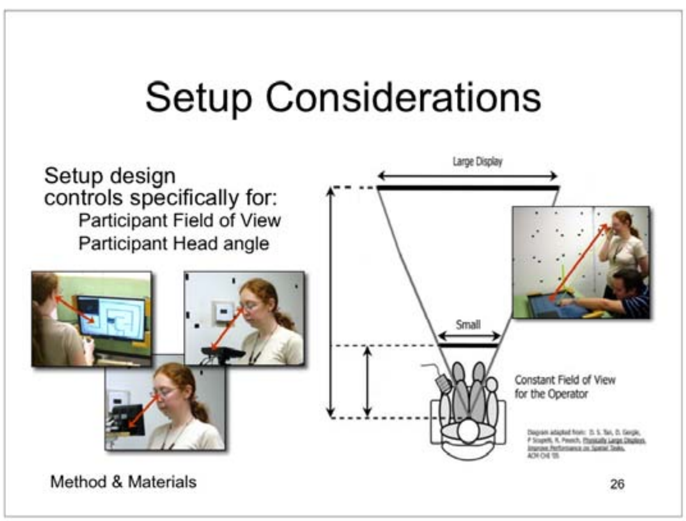
Robot

- Lynxmotion
- Small
- 4 Wheels
- Turns in place
- Wireless



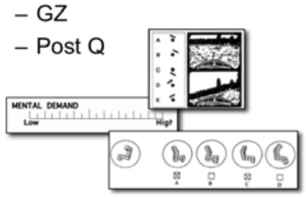
Method & Materials 24


Teleoperation Setup
Overhead Camera
Robot Vehicle Task Area
or
Onboard Camera
Reconfigurable Remote Location
Method & Materials
25


Setup Considerations
Setup design controls specifically for:
Participant Field of View
Participant Head angle
Large Display
Small
Constant Field of View for the Operator
Method & Materials
26

Materials & Apparatus

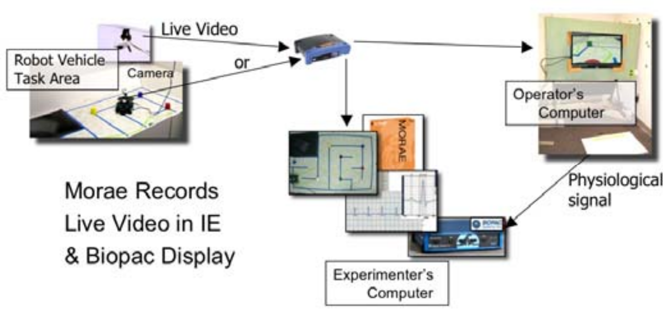
- Tests
  - NASA TLX
  - MRT
  - GZ
  - Post Q
- Setup
  - Morae Recorder
  - Internet Explorer
  - Biopac



Method & Materials

Images courtesy of BIOPAC, Axis & TechSmith websites 27

Recording Setup



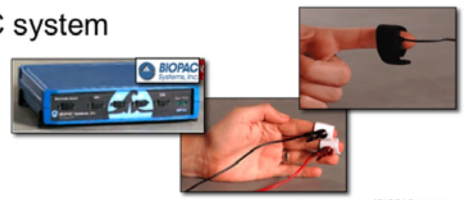
Morae Records
Live Video in IE
& Biopac Display

Method & Materials

Images courtesy of BIOPAC, Axis & TechSmith websites 28

Physiological Measures

- Arousal
  - Heart Rate & ECG
  - Galvanic Skin Resistance
- BIOPAC system

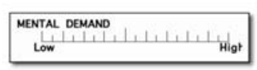


Images courtesy of BIOPAC website

Method: Measures 29

Perceptions Measures

- NASA Task Load Index
- Questionnaire



Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Method: Measures 30

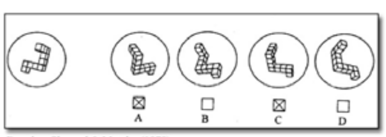
Perceived Workload

- NASA Task Load Index:
  - Total Workload: 6 weighted subscales
    - Mental Demand
    - Physical Demand
    - Temporal Demand
    - Performance
    - Effort
    - Frustration
- Computer scored in two parts
  - Scored by ratings 0-100
  - Weights by pair-wise comparisons

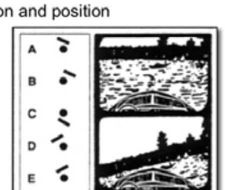
Introduction 31

Individual Differences Measures

- Mental Rotation Test
  - A measure of ability to mentally manipulate three-dimensional objects in a rotational manner (Shepard & Metzler, 1979)
- Gilford-Zimmerman Aptitude Survey
  - Part 5, Spatial Orientation (Guilford & Zimmerman, 1948)
  - A test of ability to see changes in direction and position



Based on Shepard & Metzler (1979)



Method: Measures 32

Tasks

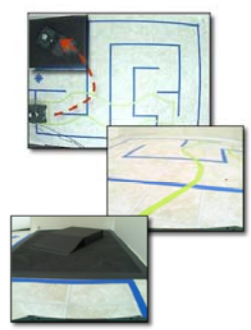
Designed to cover a variety of challenges and performance variables

- Task 1:
  - Distance Estimation
  - Precision Navigation
  - Implied Time Pressure
- Task 2:
  - Basic Navigation
  - Implied Time Pressure
  - Turning Errors
- Task 3:
  - Strategy
  - Navigation & Strategy
- Task 4:
  - Overt Time Pressure
  - Precision Under Pressure

Method: Tasks 33

Task 1 Precision Parking

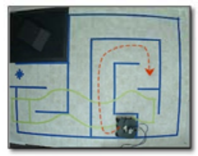
- Drive over & park on raised platform
- Performance Constructs
  - Distance Estimation
  - Precision Navigation
  - Implied Time Pressure

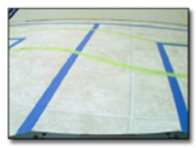


Method: Tasks 34

Task 2: Road Course

- Travel within lines quickly and accurately
- Performance Constructs
  - Basic Navigation
  - Implied Time Pressure
  - Turning Errors





Method: Tasks 35

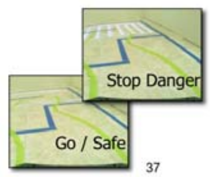
Task 3: Barrel Gathering

- Gather barrels, but green before red & blue before yellow
- Performance Constructs
  - Strategy
  - Navigation & Strategy

Method: Tasks 36

Task 4: Danger Lights

- Go when safe, stop when lights are on
- Performance Constructs
  - Overt Time Pressure
  - Precision Under Pressure



Method: Tasks 37

Results:

Performance (by task)

Measure	Main Effect	Direction	Interaction Effect
T1: Parking Success	Tilt	Upright: better	.
T1: Time Complete	.		.
T1: Extra Distance	Camera	Attached: extra distance	Size x Camera[1]
T2: Time Complete	Camera	Overhead: Longer Time	.
T2: # times outside	.		.
T2: Time outside	.		.
T2: % Outside	Camera	Attached: more % time outside	Size x Tilt[2], Size x Tilt x Camera[3]
T2: Turns	Camera	Overhead: more turning errors	.
T3: Success	.		.
T3: Time	Camera	Overhead: Longer Time	.
T3: Strategy	Size	Small: Higher Efficiency	.
T4: Time Complete	Camera	Overhead: Longer Time	.
T4: Time outside	Size	Small: more time outside	.

1: Large overhead had short extra but attached had far extra; no significant difference in Small
2: Small flat high %, upright low %; Large flat low %, upright high %
3: Attached Camera: small flat high %, upright low %; Large flat low %, upright high %

Results 38

Results:

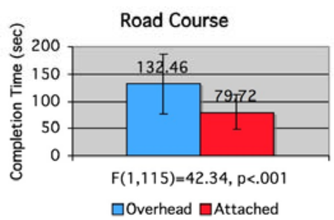
Performance (by construct)

Constructs	Measure	Effect	Direction
Basic Navigation	T2 Road Course: Time Complete	Camera	Overhead: Longer Time
Basic Navigation	T2 Road Course: % Outside	Camera, Size x Tilt x Camera	Attached: more % time outside Attached: Small flat more %, upright less %; Large flat less %, upright more %
Navigation & strategy	T3 Barrel Gather: Time Complete	Camera	Overhead: Longer Time
Strategy	T3 Barrel Gather: Strategy	Size	Small: Higher Efficiency
Navigation: Turning	T2 Road Course: Turning Errors	Camera	Overhead: more turning errors
Overt time pressure	T4 Danger Lights: Time Complete	Camera	Overhead: Longer Time
Precision Navigation	T1 Parking: Parking Success	Tilt	Upright: better
Precision: in time	T4 Danger Lights: Time outside	Size	Small: more time outside
Distance estimate	T1 Parking: Extra Distance	Camera, Size x Camera	Attached Camera: more extra distance Large: attached more extra, overhead less extra; Small: no significant difference

Results 39

Basic Navigation Results

- Main effect for camera position for time to complete T2 Road Course



Discussion: Performance 40

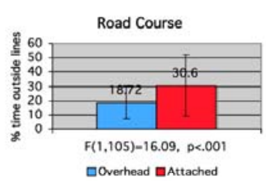
Basic Navigation Discussion

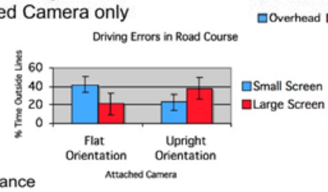
- Why did Overhead take longer to complete task in road course?
  - Additional Frame of Reference
  - Continual reloading of FoR into sketchpad
    - Self, Control, Screen, Display, Robot
    - Manipulation of sketchpad needed to drive, but limited space requires reloading

Discussion: Performance 41

Basic Navigation Results

- Main effect for Camera Position for % time outside the lines in Road Course
- Interaction effect of Size x Orientation, $F(1,115)=5.78$, $p<.05$, which was significant for the Attached Camera only





Discussion: Performance 42

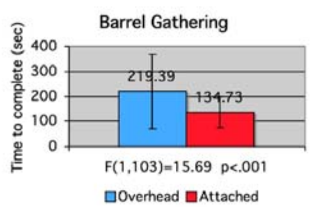
Basic Navigation Discussion

- Why did Attached self-correct more slowly?
  - Unknown vehicle size
  - Only visual feedback from camera
  - Visual field saturated with movement, causing loading of attention resources
- Points for design
  - Camera that shows more of robot
  - Additional feedback cues
  - Careful not to overload cognitive resources with attached

Discussion: Performance 43

Navigation & Strategy Results

- Main effect for camera on time to complete barrel gathering task



Discussion: Performance 44

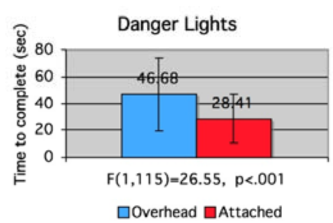
Navigation & Strategy Discussion

- Why did Overhead take longer to gather barrels?
  - Poor overhead Navigation (turning) in overhead conditions
- Points for design
  - Negative effect of camera placement can overshadow benefit of better vantage point

Discussion: Performance 45

Navigation:
& Overt Time Pressure Results

- Main effect for Camera on time to complete in danger lights



Discussion: Performance 46

Navigation:

& Overt Time Pressure Discussion

- Why did Overhead take longer time to complete in danger lights?

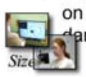
  - Visual space between robot and lights is greater, so scanning adds time
  - Additional Frame of Reference from camera occupying cognitive resources (central executive) needed for decision making about attention

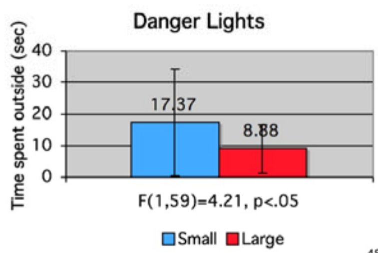
Discussion: Performance 47

Navigation:

& Overt Time Pressure Results

- Main effect for Display Size on time outside the lines in danger lights





Discussion: Performance 48

Navigation:
& Overt Time Pressure Discussion

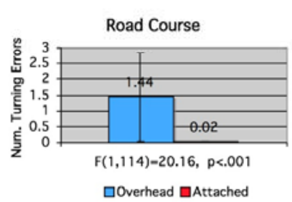
- Why did Small take more time outside in danger lights?

- Greater workload causing reduced focus on secondary task (staying within the lines)

Discussion: Performance 49

Navigation Turning Results

- Main effect for Camera in turning errors on road course.
  - Of the 26 people who made turning errors, 25 of them were in the overhead condition.



Discussion: Performance 50

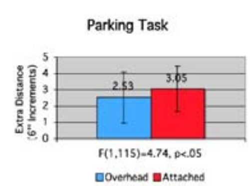
Navigation Turning Discussion

- Why does Overhead have more turning errors in road course?
  - Additional Frame of Reference added by the camera takes up cognitive resources.

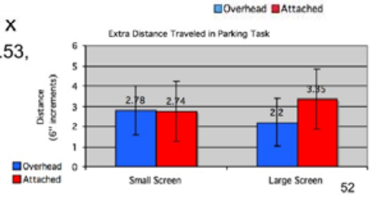
Discussion: Performance 51

Distance Estimation Results

- Main effect for Camera on extra distance traveled in parking task



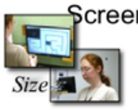
- Interaction of Size x Camera F(1,115)=5.53, p<.05.
  - Small, no sig. diff.
  - Large, p<.05

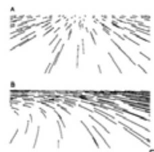


Discussion: Performance 52

Distance Estimation Discussion

- Tendency to underestimate the distance traveled are due to effects of the displayed visual flow patterns.
- These effects are stronger on the Large Screen



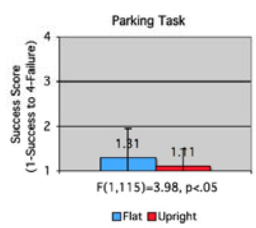


Discussion: Performance 53

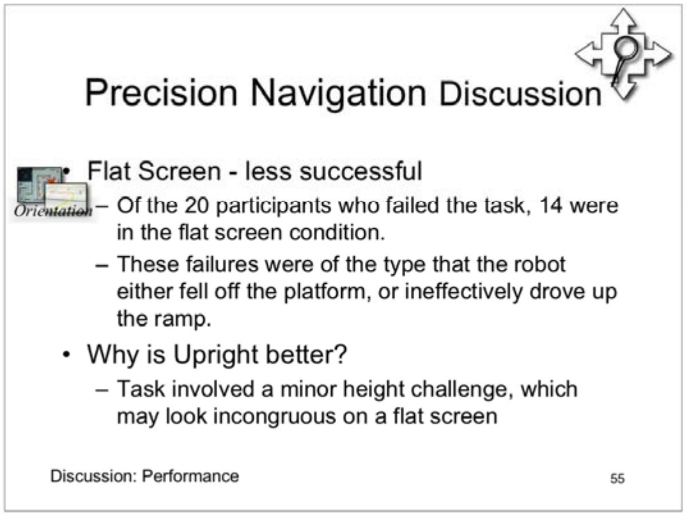
Precision Navigation Results

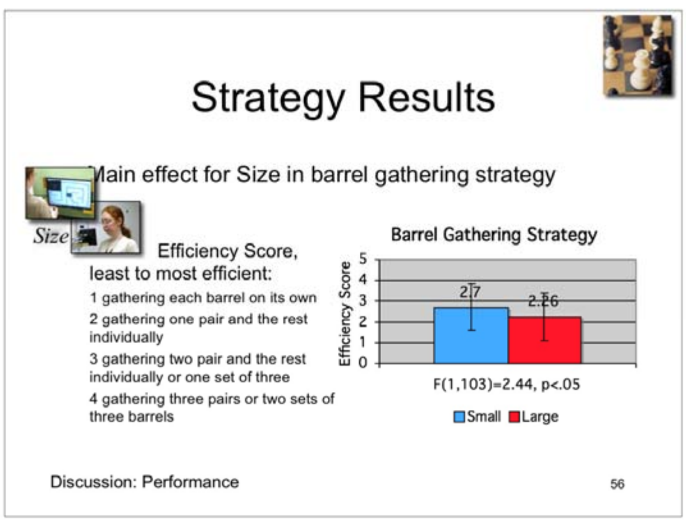
- Main effect for Orientation on parking success

Score:
1- parked correctly
2- fell off the platform (15 people)
3- made it partially up the ramp (4 people)
4- never even entered the ramp (1 person)



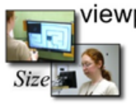
Discussion: Performance 54


Precision Navigation Discussion
Orientation
• Flat Screen - less successful
– Of the 20 participants who failed the task, 14 were in the flat screen condition.
– These failures were of the type that the robot either fell off the platform, or ineffectively drove up the ramp.
• Why is Upright better?
– Task involved a minor height challenge, which may look incongruous on a flat screen
Discussion: Performance
55


Strategy Results
Main effect for Size in barrel gathering strategy
Size
Efficiency Score, least to most efficient:
1 gathering each barrel on its own
2 gathering one pair and the rest individually
3 gathering two pair and the rest individually or one set of three
4 gathering three pairs or two sets of three barrels
Barrel Gathering Strategy
Efficiency Score
5
4
3
2
1
0
2.7
2.26
F(1,103)=2.44, p<.05
Small
Large
Discussion: Performance
56

Strategy Discussion

- Why do small screen condition participants use more efficient barrel gathering strategy?
  - Small screen may bias exocentric viewpoint, which may help plan route



Discussion: Performance 57

Results:

Physiological Overview

Measure	Main Effect	Direction	Interaction Effect
T1: ECG	.		.
T1: PPG	.		.
T1: EDA	Size	Small: Larger Positive Change	.
T2: ECG	Camera	Overhead: Larger Positive Change	.
T2: PPG	.		.
T2: EDA	Camera	Overhead: Larger Negative Change	.
T3: ECG	.		.
T3: PPG	.		.
T3: EDA	Size, Camera	Overhead: Larger negative,	Size x Tilt[4]
T4: ECG	.		.
T4: PPG	.		.
T4: EDA	Size, Camera	Overhead pos, attached neg, reverse for Large	Size x Camera[5]

4: Small and large upright: similar negative change; small flat: slight negative, large upright: very negative
5: Small overhead: positive, attached: negative; large overhead: small negative, attached: small positive

Results 58

Results:
Perception Overview

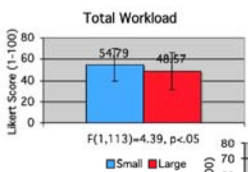
Measure	Main Effect	Direction	Interaction Effect
Total Workload	Size	Small: Larger Workload	.
Mental Demand	Size	Small: Higher contribution	.
Physical Demand	Size	Small: Higher contribution	.
Temporal Demand	.		.
Performance	.		Size x Camera[6]
Effort	Size	Small: Higher contribution	.
Frustration	.		.
Frustration Self	Camera	Overhead: Higher frustration	.
Fun	.		.

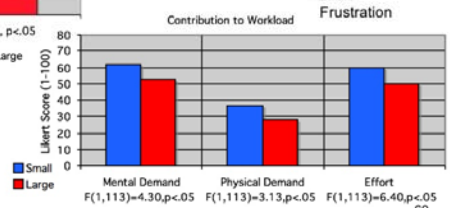
6: Small overhead: low, attached: high; large overhead: high, attached: low

Results 59

Perceived Workload Results

NASA Task Load Index:
Total Workload
* Mental Demand
* Physical Demand
Temporal Demand
Performance
* Effort
Frustration





Results 60

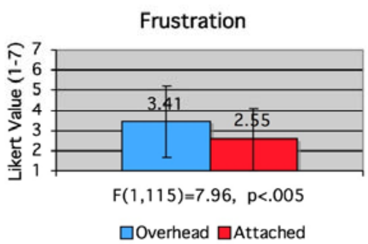
Perceived Workload Discussion

- Why is perceived Workload higher in small screen?
  - Novelty of the large screen may suppress perception of workload
  - Small screen may be too close (inside the personal space, 8 inches) causing uneasiness

Results 61

Results:
Perceived Frustration & Fun

- Main effect for Orientation on Frustration ratings



Results 62

Results:
Perceived Frustration & Fun

- Note the higher frustration in Overhead, but not higher Task Load
  - Did not recognize overloading even with reduced completion time for many tasks
- Potential danger for systems where operator is expected to recognize overloading

Results 63

Applications
Points of Design

- Design choices are task dependent
- Negative effect of camera placement can overshadow benefit of better vantage point
- First person viewpoint (attached camera) is much better than overhead for navigation involving much turning

Discussion 64

Applications
Points of Design

- Overhead camera may disguise overloading, as operator notes higher frustration & reduced performance, but not higher workload
- Overhead camera can tax central executive, so poor choice for tasks involving attention to timed stimulus & decision making
- Effect of camera placement can supercede orientation effects

Discussion 65

Applications
Points of Design

- Underestimation of distance traveled in attached camera views may be stronger in Large Screens
- Flat screens may be poor display for terrain with height

Discussion 66

Limitations & Recommendations

- Time, power, scope
  - Introductory study: additional Size, Orientation, Camera placements
- Physiological measures
  - Gathering techniques, analyze further, additional measures, valence + arousal
- Simulation
  - Adjust for realism of terrain and task
- Control x Display
  - Additional displays, control mechanism

Discussion 67

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