Tele-Presence: Bringing the Operator Back in the Loop

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SUMMARY

The importance of uninhabited vehicles in military environments has been recognised for many years. Much progress has been made in fields such as robotics and data communications, but not so much on the human factors issues. This is partly due to the trend to strive for ever higher levels of system autonomy, leaving the operator the task of supervising the system. However, by increasing system automation, the cognitive system of operators may become a bottleneck. A recent concept (which we call tele-presence) to tackle this problem is to design man-machine interfaces that allow operators to optimally use their perceptual motor system in order to relieve the cognitive system. Such an interface would enable sheer effortless looking and moving around in the remote environment by bringing the operator back in the front of the loop, resulting in a redistribution of task demands from the cognitive level to the perceptual level. A successful implementation would result in increased situational awareness and reduced cognitive load. This paper starts with describing the theoretical background behind tele-presence concept among others based on Endsley's Situational Awareness model. In the second part, we describe the design of a tele-presence interface for controlling an unmanned ground vehicle and an initial, exploratory study. The findings of this experiment show that we were not able to elicit a robust tele-presence effect yet. We discuss the results in relation to the present state of technology, interface characteristics such as delay between input and feedback, behaviour and motion sickness, and make recommendations on future research directions.

1 INTRODUCTION

Since the introduction of remotely controlled vehicles, an important trend has been to apply as much automation as allowed by the state of the art in the relevant technologies. An important reason for this is the assumption that a human in the loop is a weak link in the system. However, even nowadays, the human operator is still part of the system, partly to be responsible for the actions of the system, but also because state of the art technology has not advanced enough to implement intelligence and full autonomy. Because of this trend, the task of the human operator has changed dramatically over the years from an operator in the loop who has full manual control over the remote vehicle to a supervisory controller who monitors the status of the vehicle and is allowed not more than to provide instructions at a high level. As Van Erp [22] argues, automating tasks that can be automated on account of the technology does not necessarily result in better system performance. By leaving the tasks that can not be automated to the operator, he or she ends up with the tasks at which humans may also not be very good, or a task set that is not well balanced. Furthermore, by turning the operator into a supervisory controller, the system may not make optimal use

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of the human intelligence, knowledge, and skills. For example, reconnaissance experts are able to tell a complete story based on certain cues (like the presence of a specific type of vehicle at a specific location), while an automated system needs to search a large area to get a complete picture.

The advantages of remote sensing and acting are indisputable, despite the negative effects of taking the operator out of the loop. However, by bringing the human operator back in the front of the loop, we expect that system performance on certain tasks can be improved compared to a (semi-) autonomous system and a supervisory controller.

1.1 Theoretical basis for tele-Presence

Two theoretical models served as a basis for the tele-presence concept. The first is related to situational awareness (SA), in particular the model of Endsley [5] with three levels of SA, the second is related to navigation, in particular the prenav model by Van Erp [23].

1.1.1 Tele-presence and SA

Although there are numerous definitions of Situation Awareness (SA; see Van Erp [21] for an overview), we will use Endsley's [6, 7]: "Situation awareness is the *perception* of the elements in the environment within a volume of time and space, the *comprehension* of their meaning, and the *projection* of their status in the near future". Important themes of this definition (called levels by Endsley) are printed in Italic. It is important to notice that it is only useful to see SA in relation to a specific situation –a set of environmental conditions and system states with which the participant is interacting– that can be characterised uniquely by its priority goals and response options. SA becomes meaningless if the operator needs to know everything about everything. This means that SA requirements will change if the situation changes. For remote control situations, SA is a key element. However, acquiring and maintaining SA becomes increasingly difficult as the complexity and dynamics of the environment increase. Under some circumstances, many decisions are required within a fairly narrow time span, and task performance requires an up–to–date analysis of the environment. Because the state of the environment is constantly changing (often in complex ways) a major portion of the operator's job becomes that of obtaining and maintaining good SA.

Level 1 in Endsley's model (see Figure 1) refers to the perception of the elements in the environment and their relationship to other points of reference (i.e. internal model). At this level, relevant characteristics (colour, size, speed and location) and the dynamics of the objects in the environment are represented. This aspect is similar to what Barfield et al. [2] termed spatial awareness. Level 2 of SA goes beyond simply being aware of the elements that are present, and includes an understanding of the significance of the elements. Based on level 1 knowledge, the operator forms a holistic picture of the environment, comprehending the significance of objects and events. Thus, the integration of various level 1 data elements at level 2 of SA is crucial for the comprehension of the situation. Finally, the ability to project the future status of the elements in the environment forms the third and highest level of SA.

The critical level with respect to the current research is level 1. As Endsley states, perception, including pre–attentive processing and short–term sensory memory, is the core construct of level 1. Furthermore, attention, which affects information sampling (level 1), and can be guided by goals and objectives (box A). The fact is that in many remote control interfaces, SA is not based on perception and pre-attentive processing because the interface does not support the use of the perceptual motor system, but instead requires cognitive effort already at level 1. By bringing the operator back in the loop and enabling the use of the perceptual motor system to acquire and maintain adequate level 1 SA, cognitive resources become available to enhance SA at higher levels.

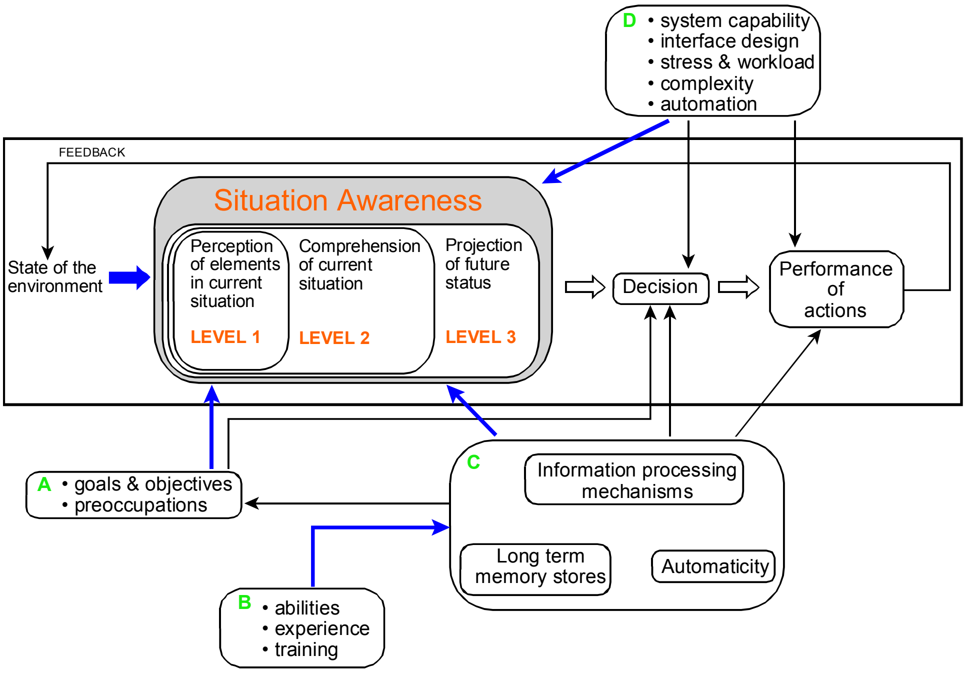

Figure 1: Endsley's Model of Situational Awareness (adapted from [20]).
See text for explanation.

1.1.2 Tele-presence and navigation

Besides building SA, navigation (including vehicle control) is a relevant task in remote control. Prenav (see Figure 2) is based on an integration of models for navigation and workload: Sheridan's model for supervisory (vehicle) control [19], Wickens' information processing model [30, 31], Veltman and Jansen's workload framework [29], and Rasmussen's framework of skill-based, rule-based and knowledge-based behaviour [16, 17]. An important loop in prenav is the information-processing loop (indicated by thick arrows): sensation=>perception=>decision=>action, and back via environment or a display. The perception and decision steps are called the cognitive ladder in prenav. The five parallel arrows as input to sensation denote that different modalities (e.g., touch, vision, and audition) can be involved and that the processing in these modalities is parallel at least up to the sensation level (Multiple Resource Theory [30, 31, 32]). Contrary to many other models, the information-processing loop in prenav is not a serial process in which all steps need to be completed. Specific for prenav and important for the tele-presence concept is the existence of two shortcuts, indicated with thin arrows in Figure 2. The first is the sensation=>action shortcut. When a sensation directly evokes an action, it bypasses the cognitive ladder completely. Examples include reflexive or highly trained tasks such as maintaining our balance and braking when a child suddenly crosses the road. The second shortcut is the perception=>action shortcut. A percept may also directly result in an action thus bypassing the decision process. This is the case for automated "if...then" rules. For example in driving: when you see a stop sign, you decelerate. This process does not involve a conscious decision, but does require the interpretation of the visual information as a stop sign.

The second loop in the prenav model is based on the workload framework of Veltman and Jansen [29] that stresses the role of the state of the operator on the information processing loop. In the prenav model, the operator state specifically affects the cognitive ladder, but not the sensation=>action shortcut. External stressors such as sleep deprivation, G load, vibration, and wearing night vision goggles may affect the state of the operator.

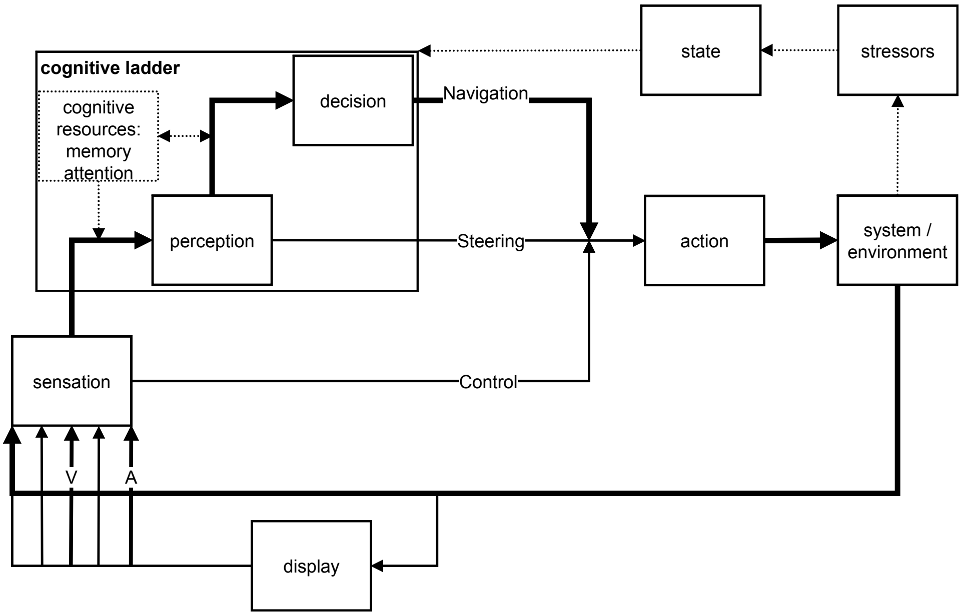

Figure 2: Prenav, an Integrated Model for Navigation by Van Erp. See text for explanation.

Both Endsley's SA model and the prenav model have a level at which tasks can be performed automatically without involving cognition. This level is based on very powerful perceptual motor mechanisms that have evolved over thousands of years and are trained everyday when we walk and look around, or when we drive a car or bicycle. To employ these powerful mechanisms in building SA and navigating, the operator has to be in the front of the loop. As we concluded before, the automation trend in remote control sends the operator backwards in the loop or even out of the loop. The consequences are that the operator has to use his cognitive system to perform tasks that in real life would have been accomplished at the perceptual motor level. The key to this lies in the design of the man-machine interface.

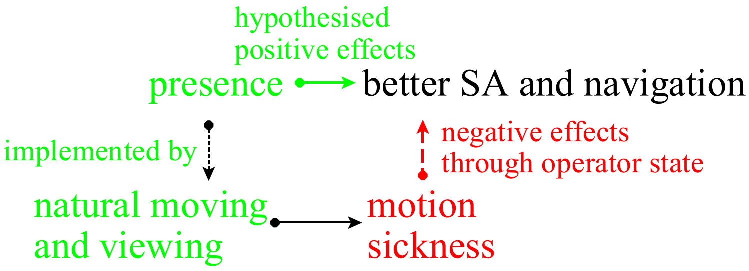

Figure 3: The Tele-Presence Concept Expects Positive Effects on SA and Navigation Performance. However, tele-presence is implemented by an interface that allows natural looking and moving about which may facilitate motion sickness. Motion sickness can act as an external stressor and affect the operator state which may negatively affect SA and navigation performance.

1.2 Presence and motion sickness

There may be one important drawback of the tele-presence concept. Since the operator is controlling the motion of her or himself, or that of a remote 'sensor unit', there is a possibility that motion sickness or simulator sickness, respectively, will arise. Simulator sickness, or motion sickness in general, arises when the (afferent) information on self-motion as sensed by the eyes, the vestibular system, and the somatosensory system, differs from the motion that is anticipated by the brain. Motion sickness may negatively affect the operator state and as a consequence the building of SA and navigation performance. Simulator sickness is a familiar problem to operators of flight- or ground-vehicle simulators. It also occurs in virtual environments and PC games such as first person shooters, and is then designated 'cybersickness'. Virtual Environment (VE) systems are notorious for cybersickness [8, 9, 10]. These systems often employ a visual display (e.g. HMD) that is controlled by head or body movements of the user. The VE user can be considered a very experienced 'pilot' with a very accurate internal model of his own body movements, so that differences in visual feedback, e.g. a time delay, have large consequences for the perceived motion, or, motion sickness. In other words, the more closely a motion interface mimics the own bodily movements, the more critical the motion feedback becomes, and the higher the risk of motion sickness. In the prenav model, a motion sickness evoking situation is an external stressor that affects the operator state and thus task performance (see Figure 3).

2 DESIGN OF A REMOTELY OPERATED GROUND VEHICLE INTERFACE THAT FACILITATES TELE-PRESENCE

2.1 Presence and man-in-the-loop interface design

The point of departure is that the interface should optimally comply with the perceptual motor system of the operator requiring a minimum of cognitive effort to navigate and build level 1 SA.

2.1.1 Tele-presence viewing

When looking around in the real world we have a large field of view at our disposal including stereoscopic and other cues, and adjust our viewing direction by body, head, and eye movements. The quality of current state of the art remote or indirect viewing systems is still far from that of direct view with respect to for example resolution, field of view, colour depiction and contrast range [25]. In a remote control situation, a further degradation may be caused by bandwidth limitations. Even if we had a sensor system with the specifications of the human eye, it is not very likely that the images could actually be transported from the remote location to the operator.

Based on a literature review [1, 3, 4, 12, 13, 14, 18, 21, 24, 25, 26, 28] we identified the critical image parameters for driving. These are: field size, image minification, the number of pixels per degree of field of view, availability of vehicle reference points, image quality, and stereovision (the latter for off-the-road driving only). Using current CCD technology as point of departure, we came to the following system design. First, a large field of regard is preferred with respect to both vehicle control and situation awareness. This cannot be realised by using a single camera with a fixed viewing direction, but only by a moving camera or by using multiple cameras. A moving camera has two important advantages. First, there are no artificial effects caused by the switching between cameras and second, a moving camera eases the introduction of stereoscopic viewing. To enable the use of proprioceptive cues on viewing direction, the remote camera should preferably be head-slaved and the images should preferably be presented in the viewing direction of the operator, either by a wide screen projection or by a head mounted display. Because an HMD makes it easier to implement stereoscopic images, it may be the preferred option. Although stereoscopic images may not be required with respect to vehicle control on flat terrain they may be beneficial in off the road situations and for manipulation tasks. Also, image minification must be avoided, that is, the field size of the sensor should match that of the display. Adding it all together, a system that consists of a head-slaved remote camera and a head-mounted display seems to have the most potential to facilitate vehicle control, natural viewing and tele-presence.

2.1.2 Tele-presence locomotion

Although the operator is controlling a platform and not a remote human being, walking may be the most natural way of controlling the platform's speed and direction. However, this would also restrict the characteristics of the platform to the limits of walking or running. This restriction will be most outspoken in the moving speed of the platform (i.e., in translations) and not so much in its direction (i.e., rotations). Furthermore, operators may experience difficulties in distinguishing vehicle and camera rotations. Therefore, the potential advantage of a natural locomotion may be most pronounced in platform rotations and be of less relevance to vehicle translation (i.e. forward speed). Maintaining the coupling between the direction and rotations of the body and those of the platform may be beneficial for situation awareness and also be a more natural control of the locomotion and thus be beneficial to the operator's presence. This coupling can be implemented either by measuring the body direction of a standing operator that turns around his body axis or of seated operator that rotates his chair like you rotate an office chair around its axis. It should be noted that the effects of whole-body interaction techniques on wayfinding performance in a virtual environment compared to joystick control (e.g. [15]) are not very outspoken and probably dependent on the amount of required manoeuvring.

2.2 Research questions

In the second part of this paper, we describe an exploratory experiment, designed to gain insight into the effect of tele-presence viewing and tele-presence locomotion. Based on the design issues above, we developed three remote control interfaces for a wheeled vehicle with an on-board moving camera and compared performance and behaviour with that of two control conditions in which the operator was on-board the vehicle (i.e., physically present in the 'remote' environment). The three remote control interfaces were (with ROV referring to remotely operated vehicle): [a] ROV joystick: an interface with a fixed monitor and two joysticks: one to control the platform and one to control the camera, this is a baseline ROV interface; [b] ROV HMD: an interface that enables tele-presence viewing, consisting of head-slaved camera control and a head mounted display, while the platform is controlled with a joystick; [c] ROV stepping around: an interface that enables tele-presence viewing as in ROV HMD and tele-presence locomotion. In this interface, heading changes (i.e. rotation about the vertical axis) of the vehicle are slaved to the heading changes of the chair on which the operator is seated. The operator can thus change the heading of the vehicle by stepping around. Forward motion of the platform is still controlled by a joystick. The two control conditions were: [d] wheelchair: with the participant seated on the ROV with unrestricted viewing; and [e] wheelchair goggles: with the participant on the ROV but wearing field size restricting goggles that had a fieldsize equivalent to that of the remote viewing system.

We had the following hypotheses: 1) the respective scores of remote control interface a, b, and c will increase in that order on performance, presence and SA; 2) interface c will result in different vehicle control behaviour than interfaces b and c; 3) compared to the wheelchair conditions, all three ROV interfaces may result in occurrences of motion sickness; 4) the degree of motion sickness will resemble the presence score of the three remote control interfaces; 5) SA scores will be higher for the interfaces that allow natural viewing, i.e., b and c.

3 METHODS

3.1 Participants

Fourteen university students participated in the experiment, seven males and seven females. The participants were on average 22 years old, ranging from 18 to 29 years old. All participants were in good physical health. The participants were right handed and had good eyesight, possibly corrected by contact lenses (participants wearing glasses were not selected, because of the interference with the apparatus used).

3.2 Apparatus

The control conditions were ran with the wheelchair depicted in Figure 4. In the wheelchair goggles condition, the participants wore the field restricting goggles depicted in Figure 4. In the wheelchair condition, the participant had unrestricted viewing.

The remotely operated vehicle (ROV) system consisted of two parts: the control station and the vehicle. The control station was located in a room adjacent to the driving course. The vehicle was based on an electronic wheelchair equivalent to the one used in the control conditions. Two small cameras were mounted on a moving base with three degrees of freedom (pan, tilt and roll) on the front of the vehicle. See Figure 5.

Figure 4: Left: the Electronic Wheelchair Used in the Control Conditions. The joystick is mounted at the end of the right armrest. Right: the tunnel vision goggles with the same rectangular fieldsize as the camera system in the remote control situation.

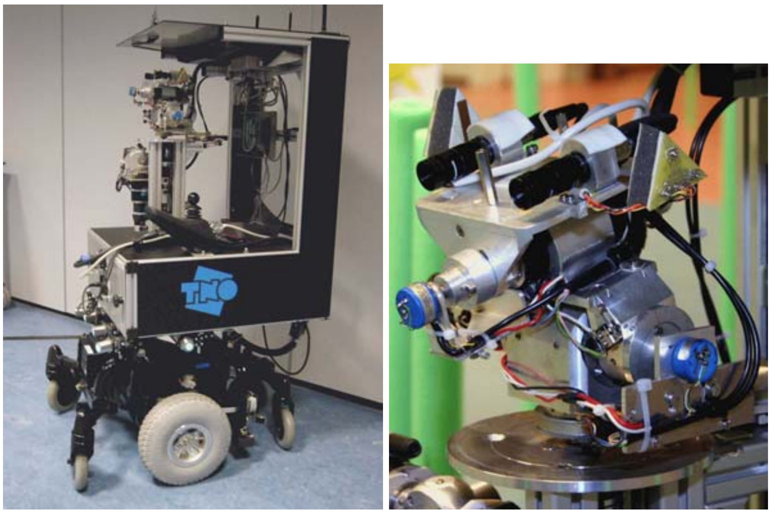

Figure 5: Left: the Remotely Operated Vehicle (ROV). Right: a close-up image of the camera system consisting of two CCD cameras and a pan-tilt-roll platform.

From the control station, the operator controlled the camera system and the vehicle itself. This was done with the following three interface variants. In the ROV joystick variant the camera platform's heading and pitch were controlled by a table mounted joystick with the left hand with the images of the right camera displayed on a table mounted CRT in front of the operator. The direction and forward speed of the vehicle were controlled with a table mounted joystick with the right hand. In the ROV HMD variant, the cameras were coupled to the head motions of the operator (which were tracked with a mechanical head tracker in three directions: pan, tilt and roll) with the images presented on an HMD. Vehicle control was as in the ROV joystick variant. In the ROV stepping around variant, viewing was as in the ROV HMD variant, but controlling the rotations of the vehicle was different. In this mode, the vehicle rotations were coupled to the rotations of the chair of the control station while forward and backward speed was controlled with a small joystick attached to the chair on the control station (see Figure 6).

Figure 6: In the ROV Stepping around Control Condition, the Heading of the Remotely Operated Vehicle is Coupled to the Heading of the Operator's Chair. Stepping around thus controls vehicle heading.

3.3 Tasks and measures

The participants had to drive through a course marked by poles that allowed the testing of different aspects of vehicle control, including lateral, longitudinal and speed control, distance estimation, positioning and manoeuvring in confound spaces. Task performance was measured with time to completion, number of poles hit on left and right side and distance estimation errors. To measure SA, we used a target identification task. Three different A4-sized target pictures were placed at random locations in the course. After completing the course, participants had to draw the memorised location and identity of the targets they had seen on a floor plan of the course. After the participants completed the course and the target identification, they filled out a questionnaire. The first part of the questionnaire discussed issues regarding the presence of the operator, i.e. to what extent did the operator feel present at the location of the vehicle (in the course). The second part dealt with motion sickness issues (how did the participants feel after completing the course). The Misery Scale (MISC) was used: an 11-point scale on which the participant could indicate how nauseated they felt after completing a condition.

3.4 Procedures and training

When the participants arrived, they received an extensive instruction about the tasks and the experiment. The five conditions, the course, the SA task, and the questionnaires were all explained. The participants signed an informed consent. After this, the experiment started. First, the participant was given time to practise driving. Especially in the remote conditions, participants needed to learn how to handle the vehicle and how to manage the HMD. Furthermore they had to learn speed and distances. When they were able to handle the vehicle they practised driving the course to learn the sequence of the tasks in the course and practise them. Each participant completed all five interface conditions in a within subjects design. The order of the conditions was balanced over the participants to the extent possible. Before a participant started with a condition he or she drove the course at least one time for practise. When they could drive the course faultless, the measurements started. During the training they received feedback on performance from the experimenter. After they completed the training, the participants had a short break. During that break, the experimenter placed the three targets in the course. Directly after finishing the course, the participants completed the SA task and filled out the presence and MISC questionnaires. When all the forms were filled out, the participant could begin with the practise for the next condition (after a break, if necessary). The experiment lasted a full morning or afternoon per participant.

4 RESULTS

4.1 Platform control

The data on course completion performance generally showed that performance in both control conditions was better than in the three ROV conditions (statistically significant). None of the platform control measures showed a difference between the three ROV control interfaces.

Besides task performance we were interested in the control input given in the three ROV conditions (i.e. vehicle control behaviour). The raw results are depicted in Figure 7. Inspection of the control strategy showed that the ROV stepping around mode differed on two important aspects form the two joystick controlled modes. First, the maximum output (± 5 in this plot) is not reached as often as in the other conditions. Second, there are more points on the x-axis. This indicates that there is often a rotation input without forward speed.

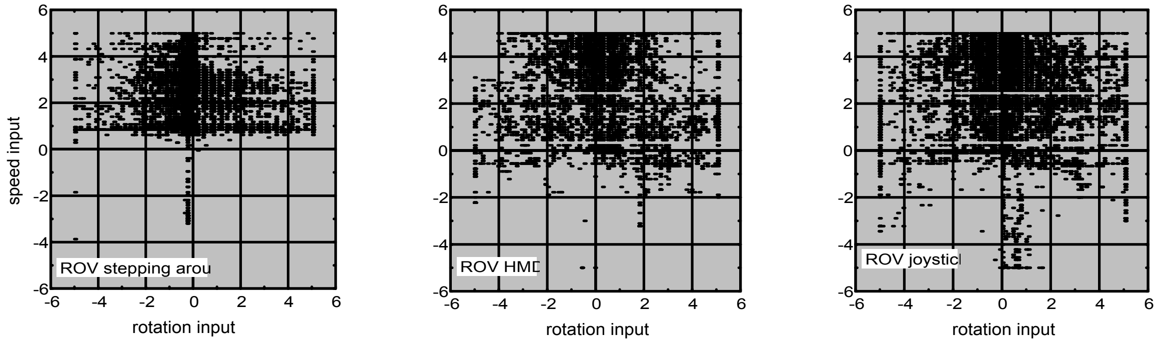

Figure 7: The Rotation Input (Horizontal Axis) and Translation Input (Vertical Axis) in the Three Remote Control Conditions: left: ROV stepping around, middle: ROV HMD, right: ROV joystick.

4.2 Situational Awareness

We analysed the score (object and location correct) and found a main effect of condition: F(4, 40) = 3.80, $p < .05$. The means are shown in Figure 8. The post hoc only revealed a significant difference between the ROV stepping around mode and both wheelchair conditions.

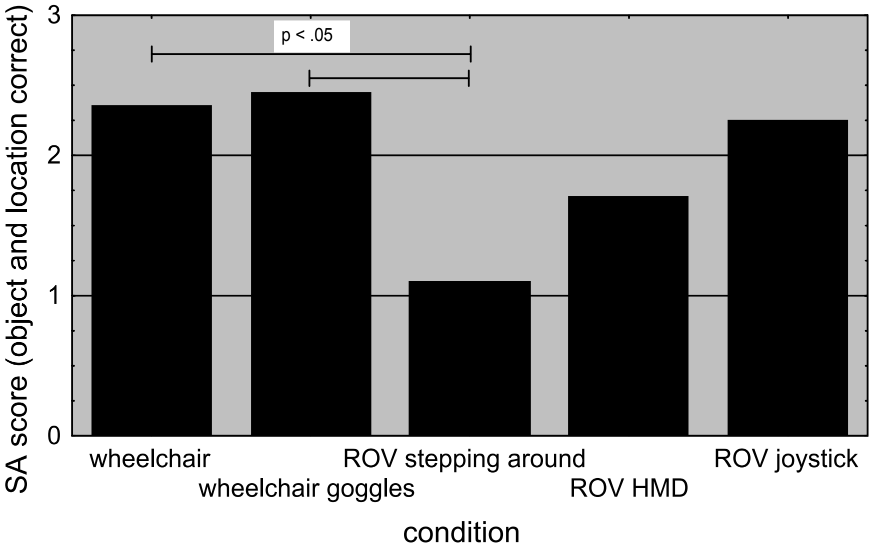

Figure 8: Scores (Object and Location Correct) in the Situation Awareness Task as Function of Condition.

4.3 Presence questionnaire

The presence questionnaire consisted of nine questions, each with an answer scale from 1 to 5. After appropriate reversing of some of the scales we performed an ANOVA on the mean scores. This revealed a significant effect of condition: F(4, 40) = 13.40, p < .01. The means over all nine questions is given in Figure 9. A higher score here indicates a higher presence. The post hoc analysis showed that both wheelchair conditions differed significantly from the three ROV conditions.

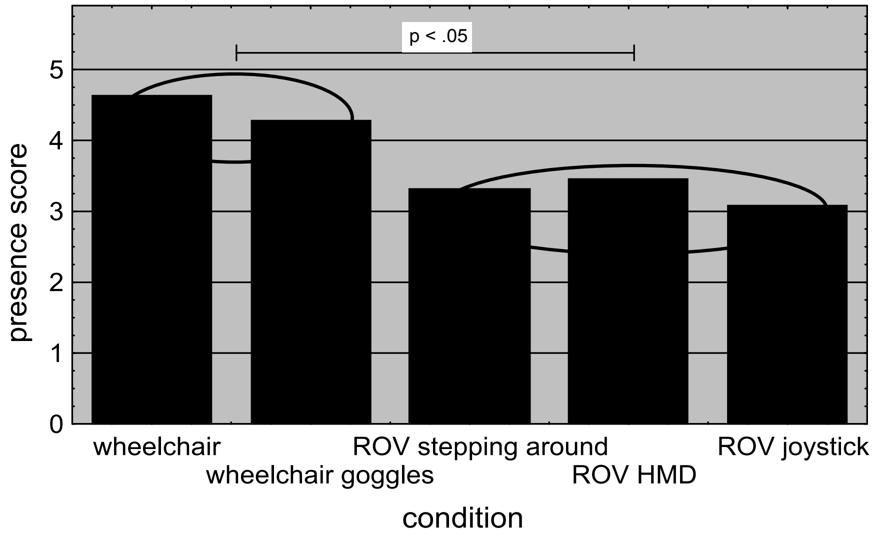

Figure 9: Mean Presence Score on a Scale from 1 to 5 for the Five Conditions.

4.4 Motion sickness questionnaire

In general, the motion sickness incidence was 50%. Seven out of 14 subjects rated minimally a MISC score of 5 ("nauseated") in one or more conditions, 22 of all 67 MISC ratings (3 scores were missing) were higher than 3 ("stomach awareness"). Three participants had to end a condition prematurely because of nausea. Two of them were able to recover sufficiently to continue with the other conditions. However, one of them suffered from severe nausea (9) in her fourth condition, and stopped the experiment.

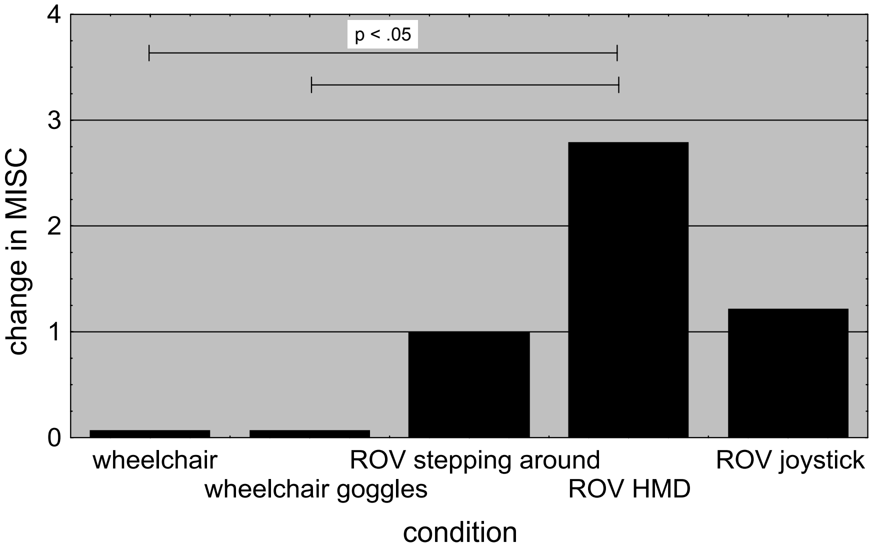

Figure 10: Change in the MISC (Misery Score) as Function of Condition. The MISC has an 11-point scale.

Since motion sickness is a cumulative phenomenon, and all conditions were performed within four hours, simply looking at the average MISC ratings may overestimate the problems in certain conditions. Participants who experienced the most provocative condition at the beginning, may have transferred their discomfort to the next conditions. Although participants were given an opportunity to recover from nausea, it is likely that they became more sensitive in the subsequent conditions. To correct for this order effect, we analysed the change in MISC score for each condition. In cases where the rating was lower than the rating in a previous condition, indicating that the subject had partly recovered, the negative change was set to zero. The results of this analysis are shown in Figure 10. There was a main effect for Condition: F(4, 52) = 6.15, $p < .01$). A Tukey post-hoc analysis indicated that the mean rating in the ROV HMD differed from both wheelchair conditions.

4.5 Remote control mode preference

Finally, we asked seven of the participants to rate the ROV modes (without taking the wheelchair conditions into account): a. which mode did you find best? b. Which one worst? And c. which one provided the best feeling of presence? This forced choice paradigm was thought to be more sensitive to small differences than the presence questionnaire. The raw results are depicted in Figure 11. The graph shows that the ROV stepping around and the ROV joystick mode were perceived as both the best mode, but also as the worst mode. The ROV HMD mode was never perceived as the worst mode. The ROV stepping around mode was for four of the participants the mode with the most presence.

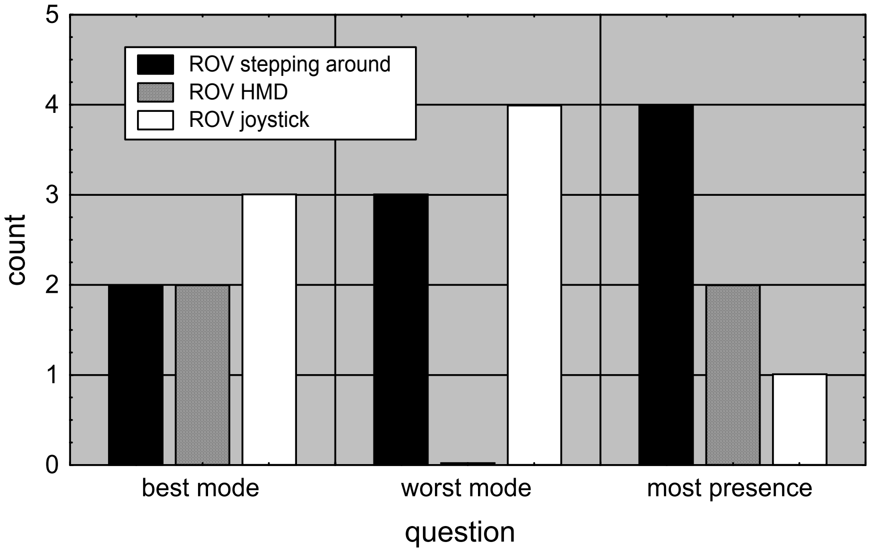

Figure 11: Preference Scores for the Three ROV Conditions.

5 DISCUSSION AND CONCLUSION

5.1 Discussion on the present results

In general the data show that the control conditions are better than the ROV conditions and that there is no significant effect of ROV interface variant. Although the three ROV variants were designed to mediate different levels of presence, these effects are not apparent in the data. In the Introduction we stated five hypotheses with respect to the differences between the five interface designs on presence, SA and performance.

The first hypothesis concerned the scores of the ROV conditions on performance, presence and SA. We expected that the scores would be lowest with the ROV joystick interface, intermediate with the ROV HMD, and highest with the ROV stepping around interface. This hypothesis is not supported by the present data. Actually, there are no significant differences at all between the three ROV conditions.

The second hypothesis was that the ROV stepping around mode would result in different vehicle control behaviour. We did find differences between the three ROV modes, indicating that the ROV stepping around mode differed from the two other ROV modes. The differences seem to indicate either more cautious behaviour or less bang-bang control in the ROV stepping around interface: the maximum output is reached less often and rotation is often used without forward speed. Interestingly, there is no disadvantage of the ROV stepping around on task performance, including the time to complete the course. This indicates that the observed control behaviour is probably caused by more cautious behaviour. The behaviour seems to reflect a. the fact that in the ROV stepping around, the participants moved the vehicle more smoothly than in the jerky bang-bang control like behaviour with the other two ROV interfaces, and b. the strategy to rotate the vehicle to look around in stead off moving the cameras. The change in sensor images of the environment is equivalent whether the vehicle and sensor platform rotate together with respect to the ground or whether the sensor platform rotates with respect to a ground-fixed vehicle. The preference for rotating the whole vehicle over rotating the cameras only seems to indicate that participants were not very comfortable with using the head-slaved viewing direction. The advantage of rotating the vehicle might be the fact that the sensor maintains a fixed viewing direction with respect to the vehicle's driving direction. A common problem for operators is the loss of camera direction with respect to the driving direction. The option of a vehicle that rotates around its yaw axis provides the option for operators to look around by rotating the vehicle including the sensors without loosing awareness of sensor and / or vehicle orientation.

The third and fourth hypotheses concerned motion sickness. We expected that the three ROV modes would result in higher occurrences of motion sickness than the wheelchair conditions and that the degree of motion sickness would correlate with the presence scores of the three ROV interfaces. There was a high (50%) incidence of motion sickness. This is probably due to delays in both the platform and camera control loop and the delay in the image system due to several conversion between the cameras and the HMD. The ROV HMD and ROV stepping around modes showed the highest increase in MISC rating. This confirms the provocative nature of the use of an HMD as the primary medium for orientation in a virtual or remote world. After correcting for possible order effects, it seemed that the ROV HMD was the most provocative. We should note, however, that the most susceptible participant, who reached a 9 (“retching”) in this condition, missed the ROV stepping around condition. It is likely that her missing data would have raised the average rating in this condition as well. On the other hand, the participants probably (mis-) used the stepping around functionality to look around therewith reducing the amount of head rotations. Based on these data it is difficult to decide whether active rotation about the yaw-axis affected the degree of discomfort. It should also be noted that in the stepping around mode the gain of the yaw-motion of the remote unit did not exactly equal 1, so that its yaw-rotation did not exactly match that of the operator. Certainly, this may have introduced a confounding in judgements of motion perception and discomfort. The judgements of presence and, more in particular, motion perception (data not presented in this paper), did not show significant differences between the ROV conditions. Therefore we cannot conclude as to whether a higher sense of presence (we had expected that this would be the case in the ROV stepping around condition) results in higher sickness ratings.

The fifth hypothesis stated that the SA scores would be higher for the interfaces that allow natural viewing, i.e. the ROV HMD and ROV stepping around modes. This hypothesis could also not be substantiated by the data. One out of the two conditions scored lower than the wheelchair conditions, while the other conditions didn’t significantly differ from each other. There may be several causes, amongst others the fact that the mechanical headtracker imposed restrictions on the field of regard in the natural viewing conditions as compared to the ROV joystick and the wheelchair modes. Also, motion sickness effects may have restricted the head motions of the operators to those necessary to build a good sense of SA.

The problem of the current hypotheses lies in the fact that they are difficult to reject because non-effects can be blamed on the state of the technology that is not sufficient to elicit tele-presence. However, we can conclude that the present exploratory experiment does not provide indications that support the hypotheses. The disadvantage of an interface that allows natural viewing and motion control (i.e., the ROV stepping around interface), namely the risk of motion sickness, does not outweigh the potential advantages. Because these potential advantages are very much dependent on the state of the technology it is also difficult to generalise the findings. The interface design was based on a reasonable starting point with respect to sensor, vehicle, and bandwidth technology, optimised on the basis of available human factors data on vehicle and camera control. The resulting interface was not powerful enough to result in a high degree of presence, at least not higher than in the ROV joystick mode.

The most important conclusion is therefore that we can neither accept nor reject the proposition that a man-in-the-loop interface results in higher presence, and that higher presence results in better performance and SA, simply because we failed to complete the first part: test an interface design that results in higher presence.

Figure 12: A Handheld Telepresence Interface that Allows the User to Steer the Remote Camera by a Device that Resembles a Pair of Binoculars.

5.2 Follow-on studies

After the initial study described in this paper, we decided that the system required an upgrade to be able to test the tele-presence concept. Encouraged by the anecdotal evidence we gathered in informal evaluations of the set-up by military personal and experts in tele-operated devices, we implemented several upgrades to improve the coupling of body and head motions to vehicle and camera platform motions, respectively. One such improvement is to change the analogue camera system that required several conversions between camera and HMD presentation with a digital system reducing the time lag in the image system. The second upgrade was to replace the analog link for vehicle control signals with a digital one that also allows to better fine tune the relation between operator input and vehicle and camera platform motions (e.g. in off set and gain). Furthermore, we introduced artificial vehicle reference points indicating the heading direction of the platform (both auditory and visual cues). Finally, we replaced the HMD and mechanical head tacking system by the hand-held display system depicted in Figure 12. This system senses the heading, pitch and roll of the tele-presence binoculars and feeds them into the camera system. Apart from being portable, the system allows behaviour that resembles the use of a pair of binoculars most military personnel is accustomed to. In follow-on experimentation with a ground control station with the updated data links and image system [11], advantages of a tele-presence interface over tele-operated and autonomous modes were found, confirming the potential of the tele-presence concept.

5.3 Conclusions and recommendations

The tele-presence concept claims that employing the human perceptual and psychomotor system for navigation and to build Situational Awareness at the lowest level frees cognitive resources that are needed to build SA at higher levels. In a remote control situation, the possibility to employ the perceptual motor system is mediated by tele-presence and the remote control interface: the experience of being present at the remote location and the possibility of using natural viewing and locomotion. The drawback of this philosophy is that tele-presence might also mediate motion sickness: higher levels of tele-presence or being immersed in the remote location might make the user more susceptible to a mismatch between the actual sensory input and what the brain expects. In the present experiment we were not able to elicit a robust tele-presence effect.

Future research directions include the following. The human perception system is not restricted to vision, a logical expansion is to include other senses. Three-dimensional audio and the sense of touch seem to be the trivial choices. In a real-life situation a soldier would not want to operate without auditory signals, while vibrations and forces are important to provide feedback on for example vehicle behaviour and condition. Future systems may also implement super-human sensory systems such as night vision and NBC detectors. Also, next to expanding the sensory side, acting in the remote environment must go beyond moving and looking around. A relevant example is defusing an explosive. Again, an interface that allows natural behaviour might be able to minimise the required cognitive capacity of the operator to control tools and eventually result in better performance. A third important issue is the preferred level of automation and the tasks that are better suited for high levels of automation (such as transit form A to B) and tasks where tele-presence has advantages (such as gathering intelligence). Because a remotely operated platform might not be operating alone in the theatre, collaboration between multiple uninhabited platforms and between uninhabited platforms and soldiers is an important research issue, including for example collaborative haptics and shared SA.

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