Preliminary Assessment of Single Amphibious Integrated Precision Augmented Reality Navigation System

Victoria Jolliff, Stacie Ringleb

Old Dominion University

Norfolk, VA

vjoll002@odu.edu
sringleb@odu.edu

Kevin Hernandez, Peter Crane

Virtual Reality Rehab Inc

Clermont, FL

khernandez@vrrehab.com
pcrane@vrrehab.com

ABSTRACT

Military personnel frequently operate under severe time constraints, requiring operators to make quick and accurate decisions. Marine and watercraft operators often rely on Head-Up Displays (HUD) to navigate dense minefields and identify targets such as mines, buoys, and other landmarks. Augmented reality (AR) can significantly enhance HUDs by overlaying information such as GPS location and target tracking. This paper presents preliminary results demonstrating the effectiveness and usability of AR marine navigation features, including a mini-map and gaze guidance lines. Subjects were required to complete three trials of navigating a simulated marine boat through a minefield to reach a shore with access to a mini-map and gaze guidance lines, only a mini-map, or neither of the features (control). Each trial included predefined safe lanes that stayed green when the user was near the center, yellow when approaching the edge, and red upon exiting the lane. Driving performance and reaction time were analyzed to identify five differently colored targets correctly. The results show that with a mini-map and gaze guidance lines, the lanes were green 97.2% of the time, 93.4% with the mini-map only, and 78.0% with the control group. The mean time to correctly identify the targets with the mini-map and gaze guidance lines was 1.50s (SD = 0.72), 2.29s (SD = 1.26) with the mini-map alone, and 2.57s (SD = 1.68) for the control group. Correct target identification increased by 50.8% when subjects had access to the mini-map and gaze guidance lines and 37.8% with access to only the mini-map. These findings suggest that these AR features can enhance decision-making in battlefield environments.

ABOUT THE AUTHORS

Victoria Jolliff is a graduate research assistant working towards an M.S. in biomedical engineering at Old Dominion University. She earned a B.S. in biomedical engineering at West Virginia University. Her main area of research is human performance, which is focused on software usability for military and civilian safe navigation through the use of augmented reality.

Stacie Ringleb, PhD is a professor in mechanical and aerospace engineering at Old Dominion University and the associate dean of diversity, equity, inclusion, and access in the Batten College of Engineering and Technology. Dr. Ringleb's primary areas of research are biomechanics, human performance, and engineering education.

Kevin Hernandez, M.Sc. in Robotics, is the Chief Operating Officer at VR Rehab Inc (VRR). His primary areas of research are mixed/augmented/virtual reality, mission situational awareness, sense of presence and transfer of skills from virtual simulators, and unmanned vehicle design, manufacturing, and operations for military and civilian uses.

Peter Crane, PhD is a Senior Scientist at VR Rehab, Inc and has over 35 years of experience in Human Factors with VRR, Inc. and Air Force Research Lab focusing on augmented reality for military applications.

Preliminary Assessment of Single Amphibious Integrated Precision Augmented Reality Navigation System

Victoria Jolliff, Stacie Ringleb

Old Dominion University

Norfolk, VA

vjoll002@odu.edu
sringleb@odu.edu

Kevin Hernandez, Peter Crane

Virtual Reality Rehab Inc

Clermont, FL

khernandez@vrrehab.com
pcrane@vrrehab.com

INTRODUCTION

Marine and watercraft operators are often required to make battlefield decisions in stressful environments quickly. Marine navigation instruments have evolved from basic tools such as compasses and sextants to more advanced technology like GPS systems and marine chart plotters. As technology advances, augmented reality (AR) emerges as the next advancement to fusing real-world visual data with geolocated synthetic vision overlaid on a Head-Up Display (HUD). AR can improve situational awareness by allowing users to visualize navigation data while remaining aware of their physical surroundings (Nordby et al., 2024). Essential information to the marine captain includes speed and direction, current GPS coordinates, mine or other target detection and tracking, distance to the nearest landmark of interest, desired navigation path, and distance to the seabed. The most critical challenge in designing an AR navigation system is only to include the most crucial information on the HUD, not negatively affecting the user experience with information overload. While recognizing the challenges of information overload, it is necessary to streamline what information is displayed to contribute to the overall enhancement of decision-making by the operator (Laera et al., 2021).

Two of the most crucial metrics in maritime scenarios include navigation performance and target identification. Marine and watercraft operators must follow their intended course to avoid deviating into unsafe territory (Okazaki et al., 2017). Maneuvers must be quick and accurate through dense minefields. Real-time feedback on the vessel’s position, course, and speed contributes to fewer deviations and overall mission success. Factors influencing navigation performance include the reliability of navigational instruments, the information and data provided by the instrument, and the user’s ability to process the information and make appropriate decisions efficiently.

Additionally, the most critical aspects of target identification are performance and efficiency. In maritime scenarios where marine captains must distinguish between objects such as mines, buoys, and landmarks, the efficiency of target identification directly influences the mission’s safety and success. Rapid cognitive processing and immediate decision-making are necessary to ensure timely course corrections or evasive maneuvers.

This study aims to measure the effectiveness of two AR navigation features on navigation performance and target identification. These features are available in HoloWarrior: SAIPAN (Single Amphibious Integrated Precision Augmented Reality Navigation system) and include minimap and gaze guidance lines. A minimap is a condensed and simplified portion of the user’s physical surroundings. It is usually either circular or elliptical to mimic a natural range of vision and includes information such as current location, intended path, nearby landmarks, and targets of interest. The location of the minimap on the

HUD is not standard across AR navigation systems but is typically placed either in the bottom center or the top right or left corners. The purpose of the minimap is to improve navigation by allowing the user to visualize their surroundings and path to safety more conveniently.

The assessment of gaze guidance lines (GGL) is the second primary evaluation in this study. GGLs are lines that connect the marker corresponding to a target of interest on the minimap to their location in the physical environment. The psychological basis for the benefits of the gaze guidance lines provided by the proximity compatibility principle asserts that two objects that need to be mentally related or compared (e.g., confirming the common identity of the scene and minimap object) should also be "linked" in the perceptual view (Wickens & Carswell, 1995). GGLs are thin enough not to obstruct the view of the environment but help the user quickly and accurately identify objects in the environment relative to their location on the minimap. Previous research shows that gaze guidance lines improve response time and accuracy in close air support (Mifsud et al., 2022), so the next step is demonstrating the effectiveness in maritime environments. Figure 1 shows barrels on a shoreline, an example of targets connected on the minimap with a GGL. The minimap is crucial in identifying targets (Warden et al., 2022). Therefore, using these AR features together should result in an apparent increase in navigation performance, accurate target identification, and reduced reaction times and distance.

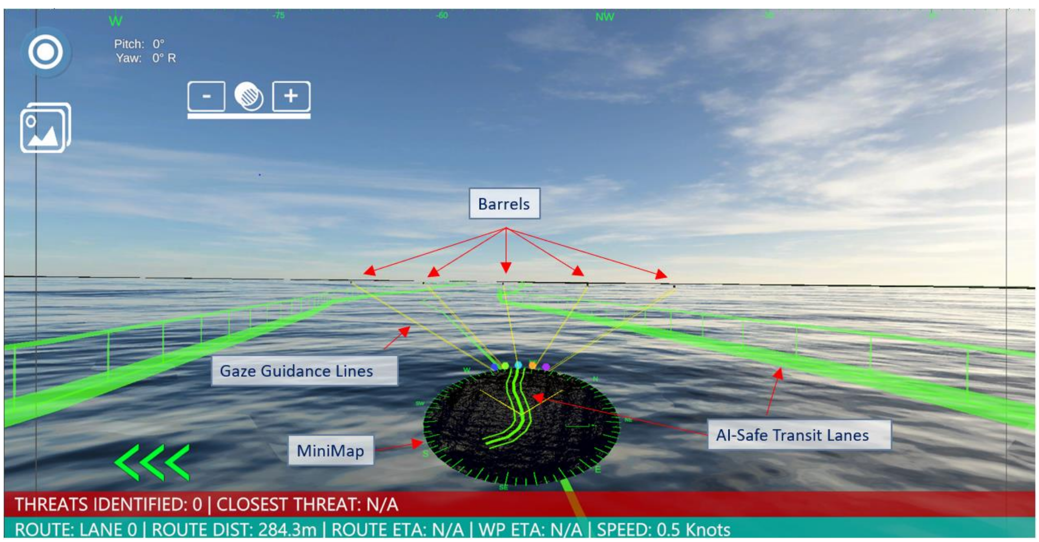

Figure 1. The minimap and gaze guidance lines work together to aid users in correctly identifying objects that are far away. The gaze guidance line extends from the barrel marker on the minimap to its respective location in the environment.

METHODOLOGY

The main software used in the study was HoloWarrior: SAIPAN, an augmented reality marine navigation system that allows the user to input geographical coordinates to create and simulate realistic maritime missions. Participants were expected to complete a pre-study questionnaire about computer usage and video gaming experience, three unique simulation trials, and a post-study system usability survey. A total of 14 participants, 7 males and 7 females, between the ages of 18 and 26, completed the study. Using a standard keyboard and mouse interface, each participant navigated a simulated boat from about 600 meters to the shoreline at 12 knots.

Participants were also asked to identify five differently colored barrels: green, orange, purple, light blue, and dark blue. Three scenarios were created in advance and given to each participant randomly to ensure that participants approached each scenario with fresh perspectives, preventing biases associated with predictable patterns. Each scenario featured a unique minefield distribution, safe lane route, and colored barrel layout. The lanes and minefield distributions were designed to mimic real-world scenarios and closely simulate a realistic environment. The lanes featured two sidewalls and a centerline, as well as colored safety indicators that remained green when participants were near the center, turned yellow when approaching the edge, and became red either on the edge or upon exiting the lane.

Before starting the simulation, each participant was required to complete a familiarization scenario to ensure a baseline level of proficiency in the software environment and access the visual aids shown in Figure 2. The conditions for the study were as follows: minimap and gaze guidance lines (MM + GGL), only the minimap (MM only), and neither for the control trial. In random order, each participant was assigned a scenario, condition, and order of barrel colors to be asked by the researcher. For example, a breakdown of trial 1 for participant 1 is as follows,

Scenario: 1

Condition: MM only

Barrel color order: Orange, light blue, dark blue, green, purple.

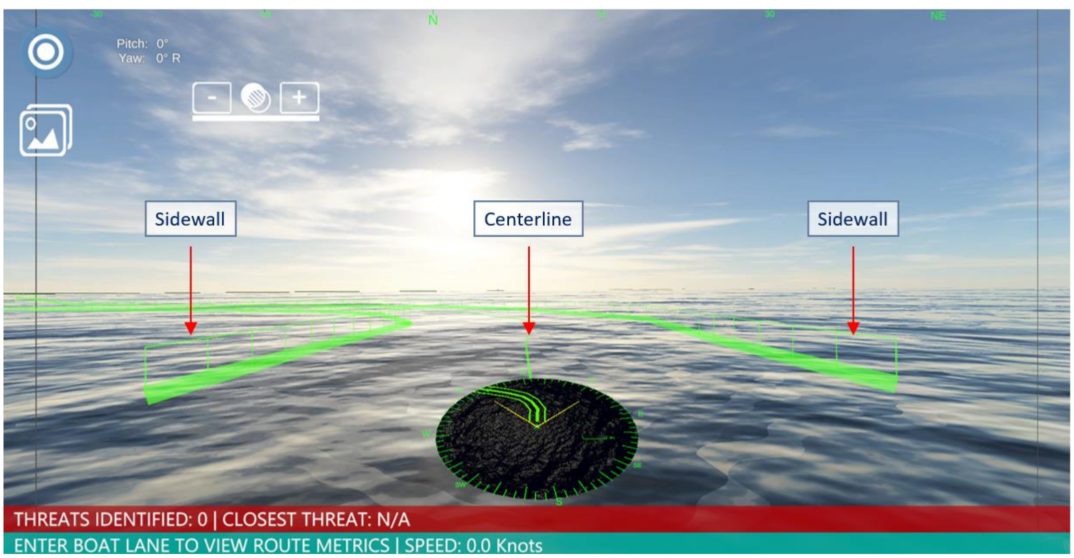

Figure 2. A simulated view of the safe lane showing the two sidewalls and the centerline.

For each trial, participants were asked to stay as close to the centerline of the lane as possible as they navigated through the safe lanes to the shore. Participants were instructed to use the minimap to aid this task in the non-control trials. To ensure consistency between trials and participants, we fixed the vessel's speed to 12 knots, and the participant could only steer left and right. The quantification of driving performance involved measuring the duration that the safe lanes remained in each color for every subject across the three trials. Automatically generated logs from the software for each trial provided the time the lanes were green, yellow, red inside, or red outside. Then, the times for each color were converted to percentages of total times to allow for variability in time and distance between each trial.

To measure the effectiveness of GGLs, participants were asked to identify each colored barrel one at a time while navigating through the safe lane. As the researcher called out a color, the participant was instructed to use the mouse to move the cursor to the correct barrel as fast as possible. Each trial was recorded and analyzed later for the number of correct barrels and the time and distance it took to identify the barrel correctly. Reaction time was measured by manually starting a stopwatch immediately after the barrel color was asked and ending when the participant moved the cursor to the barrel. This process was repeated five times per call and response, and the average time was considered in the data analysis. Another factor considered is the distance from the shoreline when asked for a specific barrel and when answered. Distance to the nearest barrel was displayed in the software hub and used to measure the distance to the shoreline. The distance, in meters, was recorded when the researcher asked the participant to locate the correct barrel and again recorded when the participant chose a barrel. The difference between when asked and when answered was used in the statistical analysis.

An ANOVA with repeated measures analysis was performed to determine significant differences between each condition. For navigation performance, the percentage of time the safe lanes were green as a percentage of total time was considered the most relevant metric in determining differences between each condition. We expect significant differences between the MM+GGL and control conditions and the MM only and control. However, we do not expect a significant difference between the MM+GGL and MM-only groups because adding GGLs should not affect navigation performance. We first manipulated the data to allow for missing data points and varying distances across each scenario to establish a significant difference between each target identification condition. The maximum distance a user can be from the shore is 600 meters. Because of the variability of the total distance across the three scenarios, we chose to use the distance taken by each participant to choose the correct barrel as a percentage of the maximum distance of 600 m. This allows for the data to be standardized across each trial.

Additionally, missing data arose from incorrect barrel identification or because the participant spent longer than 10 seconds to identify a given barrel. Because of this, the percentage of distance that it took for each participant to choose a barrel was scored. Participants were given a score from 0 to 20, with 0 indicating they did not respond within 10 seconds of being asked and a score of 1 indicating they picked the wrong barrel. Scores 2-20 indicate that they picked the correct barrel, with 2 being the highest percentage of distance (9-10%) and 20 being the lowest (0-0.5%). The complete scoring index can be found in Table 1. These scores were then compared using the ANOVA with repeated measures analysis to establish if there was a significant difference in the scores between each condition.

Table 1. Scoring index for distance percentage.

% Distance	Score	% Distance	Score
0-0.5%	20	3-3.5%	9
0.5-0.75%	19	3.5-4%	8
0.75-1%	18	4-5%	7
1-1.25%	17	5-6%	6
1.25-1.5%	16	6-7%	5
1.5-1.75%	15	7-8%	4
1.75-2%	14	8-9%	3
2-2.25%	13	9-10%	2
2.25-2.5%	12	Incorrect	1
2.5-2.75%	11	>10s response time	0
2.75-3%	10		

RESULTS

Navigation Performance

The distribution of time percentage for each safe lane color across the three trials is shown in Figure 3. The safe lanes were green 94.4%, yellow 5.1%, red inside 0.4%, and red outside 0.1% of the time when participants had access to the minimap and gaze guidance lines. The safe lanes were green 91.3%, yellow 7.4%, red inside 1.1%, and red outside 0.1% of the time when participants only had access to the minimap. In the control condition, the safe lanes were green 74.4%, yellow 15.6%, red inside 5.2%, and red outside 4.8% of the total time.

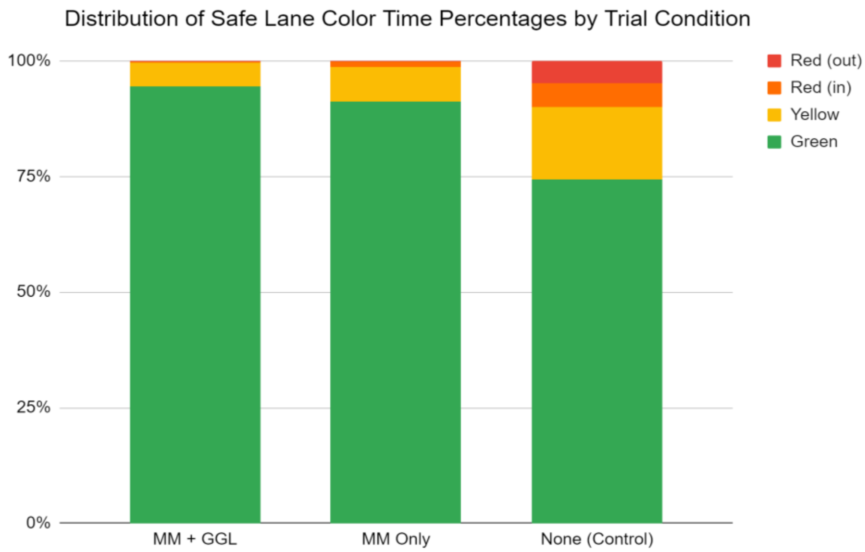

Figure 3. Distribution of time the safe lanes remained each color indicator as a percentage of total time across each trial.

A repeated-measures ANOVA was performed to evaluate the effect of the minimap and gaze guidance lines on the percentage of time the safe lanes were green to determine if there was a significant increase in navigation performance by adding a minimap. The means and standard deviations for green safe lane time proportions are presented in Table 2.

Table 2. Descriptive statistics for time proportions of green safe lanes.

Condition	*M*	*SD*	*N*
MM+GGL	.946	.079	14
MM only	.909	.118	14
Control	.738	.218	14

Mauchly's test indicated that the assumption of sphericity had been met, $\chi2$ (2) = 4.12, p = .128. The effect of the minimap on green safe lane time proportions was significant at the .05 level, F(2, 26) = 9.56, p = < .001, partial $\eta2$ = .424. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that there was no significant difference between the green safe lane time percentage for the MM+GGL and MM only conditions (p = 1.00). However, green safe lane time percentages were significantly increased between the MM+GGL and control groups (p = .002) and between the MM only and control groups (p = .05).

Target Identification

Reaction Time

Figure 4 displays the mean reaction times for each participant across the three trial conditions. The average reaction time for the MM+GGL condition was 1.50s (SD = 0.72), which measured the time it took for the participant to identify the barrel correctly. The mean reaction time for the MM-only condition and the control were 2.29s (SD = 1.26) and 2.57s (SD = 1.68), respectively. Figure 5 shows the average number of correctly identified barrels. With the minimap and gaze guidance lines, participants could correctly identify an average of 4.85 out of 5 barrels (SD = 0.36). With the minimap only, the average correct identification count was 4.43 barrels (SD = 0.65), and without the minimap, only 3.21 barrels (SD = 1.37).

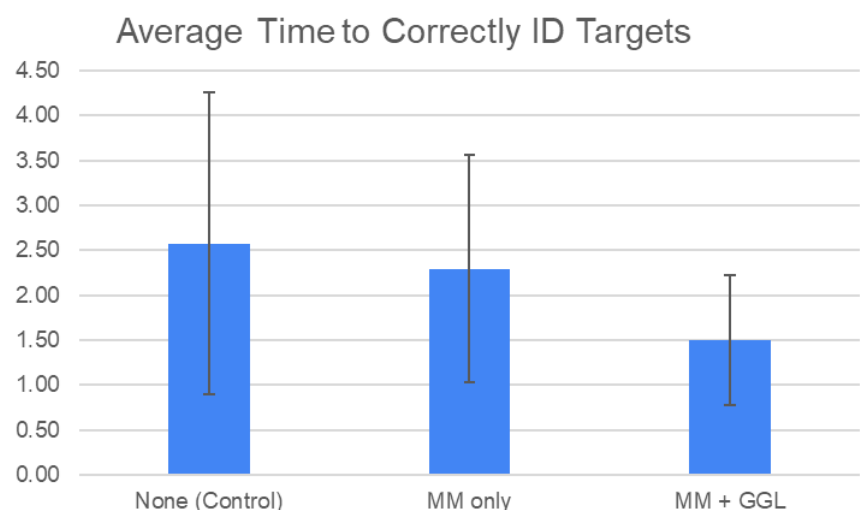

Figure 4. The average time to correctly identify targets for each trial condition.

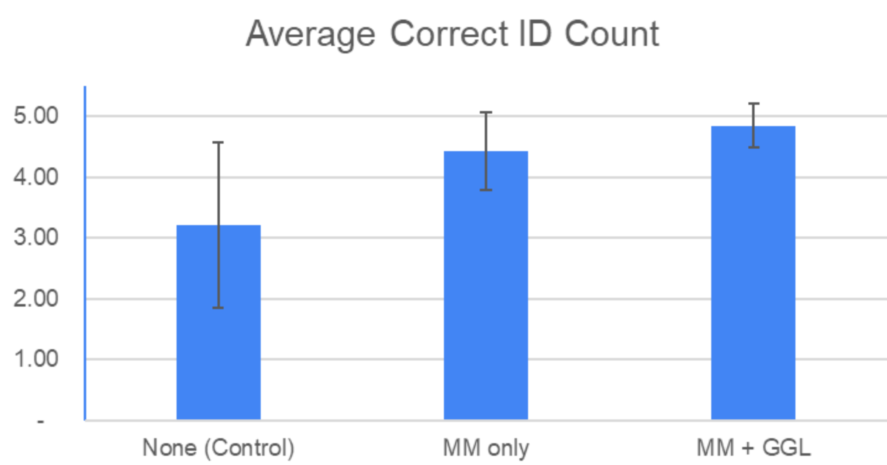

Figure 5. The average count of correctly identified barrels for each trial condition.

Distance Scores

The percentages of the total distance to correctly identify each barrel and incorrect identifications and non-responses were given a score ranging from 0 to 20. Figure 6 shows the average scores across the order in the barrels asked of participants. Average scores for barrel 1 (the first color barrel that participants were asked to identify) were 10.9, 6.9, and 4.5 for MM+GGL, MM only, and control, respectively. Barrel 2: 13.1, 8.4, and 7.6. Barrel 3: 14.6, 11.5, and 8.0. Barrel 4: 15.0, 13.0, and 11.5. Barrel 5: 16.8, 14.5, and 10.5.

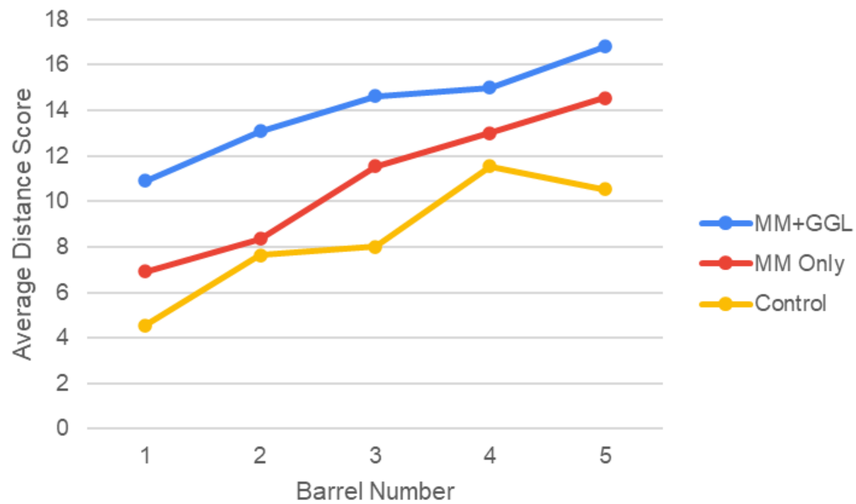

Figure 6. Average distance scores to identify barrels separated by barrel order.

A repeated-measures ANOVA was performed to evaluate the effect of the minimap and gaze guidance lines on the distance score for barrel 1. The means and standard deviations for distance scores are presented in Table 3. Mauchly's test indicated that the assumption of sphericity had been met, $\chi2$ (2) = 1.82, p = .402. The effect of the minimap and gaze guidance lines on distance scores for barrel 1 was significant at the .05 level, F (2, 26) = 9.29, p = < .001, partial η^2 = .42. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that there was no significant difference between the distance score for barrel 1 comparing the MM only and control conditions (p = .374). However, the distance scores for barrel 1 were significantly higher in the MM+GGL condition compared to the control (p = .006) and compared to the MM only condition (p = .02).

Table 3. Descriptive statistics for the distance scores of barrel 1

Condition	*M*	*SD*	*N*
MM+GGL	11.79	4.58	14
MM only	7.00	5.29	14
Control	3.79	4.90	14

DISCUSSION

This study investigated the efficacy of two AR marine navigation features present in HoloWarrior: Single Amphibious Integrated Precision Augmented Reality Navigation System (SAIPAN), namely the minimap and gaze guidance lines, in enhancing navigation performance and target identification within virtual environments. The results show an overall improvement in navigation performance and increased accuracy and efficiency in target identification when participants had access to both minimap and gaze guidance lines. When designing AR graphics, the information presented to the user must be valuable and non-obstructive to the environment. This study has demonstrated that these features aid users without contributing to information overload.

When participants were equipped with the minimap, the percentage of time the safe lanes were green was much greater than when participants were not given a minimap. For the control group, yellow and red safe lane percentages were increased, indicating that participants had a more significant challenge staying close to the center line without seeing a minimap. The minimap provides greater situational awareness to the user because it clearly shows the path from a more top-down view. This allows the user to make better judgments in preparing and executing left and right turns. This likely contributed to the performance enhancement for the two minimap groups compared to the control group. Additionally, performance was slightly decreased with the MM-only group compared to the MM+GGL group. Users simultaneously operated the controls to drive the boat while identifying targets, contributing to increased information processing. With the addition of gaze guidance lines, users were likely able to use less cognition for target identification and were better able to focus on the navigation task. This is one possibility as to why the MM-only group showed slightly poorer results than the MM+GGL group.

Target identification was also enhanced when participants accessed the minimap and gaze guidance lines. Reaction time was greatly reduced in the MM+GGL group compared to the MM-only and control conditions. Specifically, gaze guidance lines contributed to a 34.5% and 41.6% decrease in reaction time compared to the MM-only and control conditions, respectively. Additionally, there was a 9.4% and 50.8% increase in correctly identified barrels in the MM+GGL group compared to the MM-only and control groups. This shows that minimap and gaze guidance lines increase situational awareness to identify targets quickly. Participants spent much more time identifying the barrels without the gaze guidance lines.

Scored distances also showed that participants were quicker at identifying barrels with the minimap and gaze guidance lines. As shown in Figure 6, there was a consistent trend that the average score of each barrel increased as the user got closer to the shoreline. This was expected as it was much easier to visualize the five differently colored barrels the closer the user was to the shoreline. Another possibility could be the learning effect; the more time spent looking at the surroundings and the barrels, the less the user needs to search and find each barrel. Nonetheless, these results show that scores were consistently greater with the minimap and gaze guidance lines compared to the other two conditions. This further indicates that gaze guidance lines sufficiently aid the user in efficiently and accurately determining the location of targets.

Several limitations to this study were taken into consideration. The main limitation was that all trials were virtually simulated and performed in a lab setting. The challenges of performing these tests in a natural maritime environment were too significant to justify a preliminary assessment. The obvious next step for this study would be to recreate these tests in a vessel. A realistic environment would include factors interfering with the decision-making process, such as excess sunlight and waves, which create an uneasy balance. The results of this simulation study should be compared to results from operational use to demonstrate if the extrinsic factors of a natural maritime environment play a role in both navigation performance and target identification.

In conclusion, the present study demonstrates the substantial benefits of incorporating minimap and gaze guidance lines into AR marine navigation. These tools enhanced situation awareness while reducing cognitive load, resulting in better navigation performance and more accurate and faster target identification. Further research could explore the long-term effects of AR navigation on user learning and reliance, their effectiveness in more complex and dynamic environments, and the potential for personalization based on individual user needs and preferences. By optimizing user interaction and reducing cognitive load, SAIPAN holds great potential for enhancing the usability and accessibility of AR maritime navigation.

ACKNOWLEDGEMENTS

This research was partially funded a by VRR's IR&D and a Small Business Innovation and Research (SBIR) Phase II contract with the Marine Corps Systems Command **(**MARCORSYSCOM), contract # M6785422C6504, topic N202-090 "Single Amphibious Integrated Precision AR Navigation (SAIPAN) System".

REFERENCES

Laera, F., Fiorentino, M., Evangelista, A., Boccaccio, A., Manghisi, V. M., Gabbard, J., Gattulla, M., Uva, A. E., Foglia, M.M. (2021). Augmented reality for maritime navigation data visualisation: a systematic review, issues and perspectives. *Journal of Navigation*, *74*(5), 1073–1090. doi:10.1017/S0373463321000412.

Mifsud, D., Wickens, C., Maulbeck, M., Crane, P., & Ortega, F. R. (2022). The Effectiveness of Gaze Guidance Lines in supporting JTAC's Attention Allocation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 66*(1), 2198-2201. https://doi.org/10.1177/1071181322661143.

Nordby, K., Fauske, J. E., Gernez, E., Mallam, S. (2024). A user interface design framework for augmented-reality-supported maritime navigation. *Journal of Marine Science and Engineering, 12*(3), 505. https://doi.org/10.3390/jmse12030505.

Okazaki, T., Takaseki, R., Shoji, R., Matsubara, K. (2017). Development of sea route display system by using augmented reality *2017* IEEE *International Conference on Systems, Man, and Cybernetics*, 3403-3408. https://doi.org/10.1109/SMC.2017.8123156.

Warden, A. C., Wickens, C. D., Mifsud, D., Ourada, S., Clegg, B. A., & Ortega, F. R. (2022). Visual Search in Augmented Reality: Effect of Target Cue Type and Location. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *66*(1), 373–377. https://doi.org/10.1177/1071181322661260

Wickens, C. D., & Carswell, C. M. (1995). The proximity compatibility principle: Its psychological foundation and relevance to display design. *Human Factors, 37*(3), 473-494.