Augmented Reality Compensatory Aid for Improved Weapon Splash-Zone Awareness

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Abstract. One of the most important roles of the joint terminal attack controller (JTAC) in combat scenarios is accurately and efficiently communicating scene information with attack aircraft pilots. In this experiment we tested how the use of a north-up instant situational awareness display (ISA) impacts the performance of a task similar to the ones performed by JTACs, in terms of accuracy and response time. This experiment was a follow-up to verify the results of a previous experiment performed in virtual reality. The task involved determining the location of boxes relative to other boxes in an environment viewed from different simulated directions. An augmented reality head mounted display (AR-HMD) was used to project the ISA above the task as well as present the answers to the subject. Results showed an improvement in response time when subjects used the ISA after the control condition, and little change when the ISA was presented first. Participants who scored the lowest in accuracy appeared to benefit the most from the ISA. As expected, both the error rate and response time were lower in the north and south orientations versus the east and west directions.

Keywords: Head-mounted display · Augmented reality · Situation awareness · Mental rotation

1 Introduction

The joint terminal attack controller (JTAC) is in charge of integrating information about enemy attack units, nearby friendly forces, and using this information to safely coordinate and route fighter aircraft pilots to neutralize the enemy [7]. Part of this safe coordination is to describe the surrounding area verbally to the pilot, this effort is currently supported by a variety of nonintegrated, often head down information sources with little automation, such as binoculars, laser range finders, charts, notepads, radios, and even Android-based tablets. However, the current hardware is often bulky and not ideal for scenarios in which

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the JTAC must remain mobile and aware of his surroundings. Because of this, we explored using principles of head-mounted display (HMDs) design typical of aviation rotorcraft operations [2,8] to help the JTAC operator make spatial judgements. These spatial judgments are integral to the attack sequence because the JTAC operator must ensure that what they are visually describing is understood and easily seen by the pilots, to prevent attack on friendly units or civilians. These spatial judgements also must be made under intense time pressure, as the pilot they are in communication with is rapidly approaching the target area.

The objective of this experiment was to validate results produced in a previous virtual reality (VR) experiment [9] that examined the use of a north-up instant situational awareness display (ISA) to aid in making spatial judgements. In this previous experiment, subjects made spatial judgements at different viewing angles with the same virtual targets. Using the ISA resulted in either the elimination or a reduction in the time required to mentally rotate the environment, which is of high importance to aircraft pilot en-route to a target. We seek to validate the results by conducting a similar experiment as that performed in VR, but now in a real-world environment. The objects that participants make spatial judgments about are no longer virtual but physical, colored boxes placed on the ground surface. The ISA visualization used in the VR study was produced in an augmented reality head mounted display (AR-HMD), the HoloLens 2. The subjects still make allocentric or world referenced judgments, using terms like "north" or "west" to refer to relative positions (in contrast to the egocentric terms like "left of," "beyond," or "right of" because these terms are relative to the JTAC's perspective). The direction of north was changed on every trial by rotating a virtual compass to try and keep the subject from developing a world referenced frame of the area. Because mental rotation from a given scene into a world reference frame is costly and error prone [1,3–6,10], providing the JTAC operator with an allocentric display (the ISA) should increase accuracy and speed of coordinating attacks.

2 Methodology

2.1 Participants

The participants are twenty-five students, primarily undergraduates, from a local university. Eight of whom were in the first two years the Army Reserve Officer Training Candidate (ROTC) program, none had previous JTAC training. Participants received a gift card in exchange for participation.

2.2 Task

The participants viewed a total of 20 scenarios, each of which presented a mix of physical objects as well as the ISA visualization in augmented reality (AR). The task involved choosing the correct statement about the distance and direction of the given arrangement of four physical objects, relative to each other, from a list of 4 options presented in AR. To make this task more difficult, the relative direction from an object was classified with cardinal directions (N, S, E, W) and the position of north was changed between each trial with a virtual compass. We examined the impact of ISA by presenting the same scenario both with (ISA condition) and without (control condition) and analyzing the differences in response time as well as accuracy.

Fig. 1. The experimental setup. Pictured is the blue tarp with the blue and red boxes on top of it as well as the participant wearing the Hololens 2 with our AC cooling tubing attached. The non-participant standing next to the blue tarp has been covered with a silhouette to preserve anonymity. (Color figure online)

2.3 Materials

For the target objects we chose from a set of five colored (2 red, 2 blue, and 1 yellow) cardboard boxes. Two of the boxes were rectangular (2.0-feet by 2.0-feet by 4.0-feet) and three were cubic (2.0-feet by 2.0-feet by 2.0-feet). The rectangular boxes are referred to as "wide red box" or "wide blue box" while the other boxes were referred to as their color ("red box", "blue box" "yellow box"). Only four of the five objects were placed on the tarp at a time (outside of the practice trials). To keep the indicated the positions of the boxes static, a 30.0-feet by 30.0-feet blue tarp was used with 9 different designated object positions on it, the middle of this tarp was placed 37.5-feet from the subject. This distance emulated a look down angle of 8.34° for a subject who was 5-feet 5-in. A HoloLens 2 was used as the AR-HMD to overlay the visualizations. To input the responses indicated by the participant, the experimenter used the four-letter buttons (*A, B, X, Y*) on an Xbox-one controller connected to the HoloLens. A laptop was used to display what the subject was seeing to the experimenter through a streamed video. This experiment was performed outdoors, so to keep everything from getting too hot, as well as to prevent the sun from interfering with sensors, a tent was placed over the subject and laptop. To ensure that the HoloLens stayed cool enough to use outside without shutting down we attached an air conditioning (AC) unit to the back of the device via tubing. The experimental setup can be seen in Fig. 1.

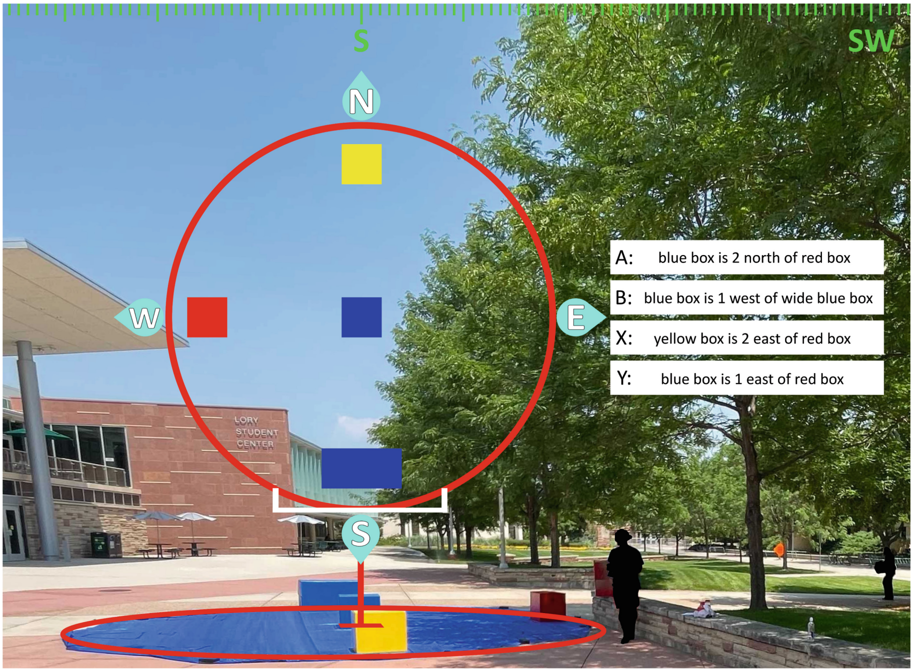

Fig. 2. An artificially augmented scene that shows the visualizations used in the ISA condition. Note the virtual compass at the top of the image shows south (in green), while the ISA always displays the North up view of the scene. The choices available to the participant are shown on the right-hand side, which correspond the buttons on the Xbox-one controller. The non-participants to the right of the blue tarp have been covered with a silhouette to preserve anonymity. (Color figure online)

2.4 Software

A shown in Fig. 2, the overlaid visualizations had 4 main components: (1) A 27-feet red circle with the middle aligning to our blue tarp called the "splashzone", along with a white -unit bar (for assessing distance) attached to either or both of the bottom of the splashzone or the ISA. (2) A virtual compass, displayed above the participant's forward line of sight at about 45° upwards. (3) The four possible answer choices along with their corresponding letters (*A, B, X, Y*) appears to the right above the tarp. (4) when not in the control condition, then the ISA map would also be displayed above the middle of the splashzone. Figure 2 depicts the image representing what a participant would see in the ISA condition. Twenty scenes were created that had the boxes positioned in different locations, these scenes contain one correct description for that specific arrangement of boxes as well as, in the ISA condition, their positions displayed from an overhead view. The answers were formatted such that three would contain incorrect descriptions with only 1 correct one. The descriptions, such as "the blue box is 2 north of the red box", involved relative positions of the boxes to each other (based off the white unit bar presented). The software would change the virtual direction the subject was facing via the virtual compass after every completed scenario. (This was done to avoid having to have the subject walk around the 75-feet circle between each trial to attain a different viewing orientation).

2.5 Procedure

The participants first completed a consent form, demographics survey and read the instructions indoors before heading outside to begin the experiment. They completed two practice trials before starting either the control or ISA conditions, each of which contained eight trials. The trial procedure was as follows: first the participant verbally indicated that they were ready to begin the trail, then they read the four virtual answers presented to them and selected which they thought was correct by speaking the corresponding letter. Once they read out their answer, the experimenter marked it with the controller. Then the experiment helper would move the real-world boxes to the positions for the next scene and indicate to the experimenter that the next trial was ready to begin. Once all twenty trials were completed, the subject completed a final survey before receiving their compensation.

2.6 Design

There were two within-participant variables: facing direction (the cardinal direction indicated by the virtual compass when looking forwards), and whether or not the ISA was presented (Control vs ISA). There were 3 between-participant variables:

1. the counterbalancing order (Control → ISA and ISA → Control),
2. the cohort group (ROTC vs non-ROTC), and

3. the specific order of facing directions of each trial.

Four trials were presented for each facing direction (N & W were shown in the practice trials so they were seen six time each). To counterbalance the ordering of the facing direction, both the first and second conditions were grouped based on facing direction (North and South, East and West), within those two groups the direction alternated between the two directions (e.g.: NS implies the sequence to be followed as N → S → N → S). This led to two possible trials direction orderings for both the first and second conditions: NS → EW and EW → NS. This left us with four possible orderings that are independent of whether ISA or control was the first condition; these were then indexed via a Latin square.

3 Results

Normality was checked with both the Shapiro test as well as QQ plots, this required us to $\log_{10}$ transform the response time variable as well as arcsine transform the accuracy variable to meet normality assumptions. A repeated measures ANOVA was used to determine statistical significance with a repeated-measures t-test post-hoc.

3.1 Response Time (RT)

There was a small (2.9 s), non-significant, benefit of the ISA display on response time ($F_{1,17} = 2.58, p > .1, \eta_p^2 = .13$). There was a highly significant effect of facing direction on response time as shown in Fig. 3 ($F_{3,51} = 19, p < .0001$, $\eta_p^2 = .13$).

The data reveals that responses made in the north oriented direction were 5.4 s faster than those made in the south direction, 8.2 s faster than the west direction, and 11.2 s faster than in the east direction. The differences in response time were significant ($p < .05$) between all directions except between east and west as well as between south and west. The presence of ISA did not significantly interact with facing direction ($F_{3,51} = .57, p > .5, \eta_p^2 = .03$) indicating that the small, non-significant benefit of the ISA was equal across all directions.

There was a marginally significant interaction between display and counterbalancing group ($F_{1,17} = 3.3, p < .1, \eta_p^2 = .16$), as shown in Fig. 4, which revealed that the $\left[\text{Control} \rightarrow \text{ISA}\right]$ group significantly ($p < .005$) benefited from the second-seen ISA display: RT shortening from 31.94 s to 25.43 s. While this effect could be attributed to practice effects, a corresponding benefit was not seen for the $\left[\text{ISA} \rightarrow \text{Control}\right]$ group.

3.2 Response Time Comparisons Based on Participant Performance

There was as wide range of accuracy across performers. Based on the assumption that best performers might show a different pattern of effects from those performing at a lower level, we performed a median split of the sample with the

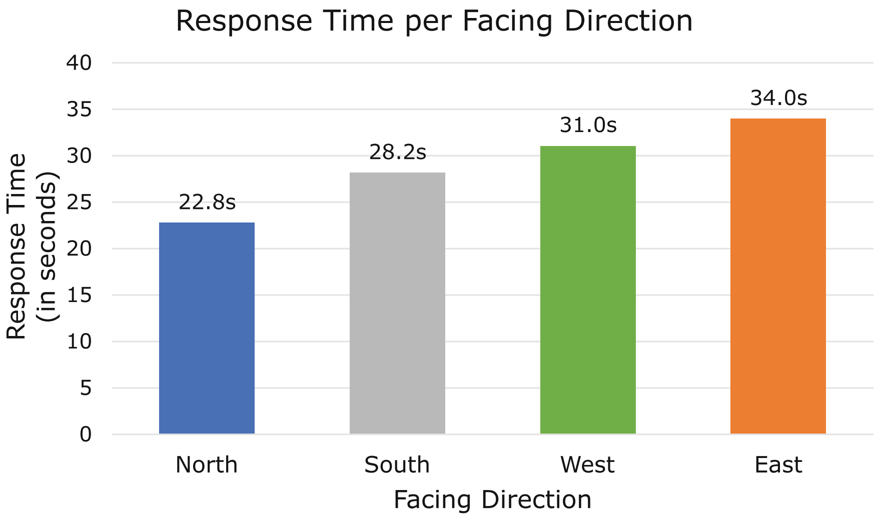

Fig. 3. Mean response time per facing direction (a lower response time is better). The bars indicate standard error. The North up direction had the fastest response time, while the East up direction had the slowest response time.

top half ($n = 9$) all performing perfectly (100%) and the bottom half ($n = 16$) showing a mean accuracy of 80%.

The best performers responded somewhat faster (mean of 24.2 s) than the worst performers (mean of 31.7 s) ($F_{1,17} = 2.8, p > .1, \eta_p^2 = .14$) and both groups showed the same non-significant 3 s benefit of ISA. As shown in Fig. 5, both groups showed the same pattern of RT effects of facing direction, reflecting the pattern of the two groups together in Fig. 3.

3.3 Accuracy Analyses

The analyses of accuracy revealed only one statistical effect, other than the obvious one that best performers were more accurate than the poorer performers since this was the criterion for the median split. This single effect of facing direction is shown in Fig. 6. Note that the best performers group scored 100% on all directions so the differences in this chart reflect the worst performers.

The ANOVA reveals a marginally significant main effect of facing direction ($F_{3,51} = 2.35, p = .08, \eta_p^2 = .12$), reflecting a pattern similar to that shown for RT in that North facing showed highest accuracy. As noted above, there were no interactions with other variables, nor was the main effect of modality significant (only a 2% benefit for ISA).

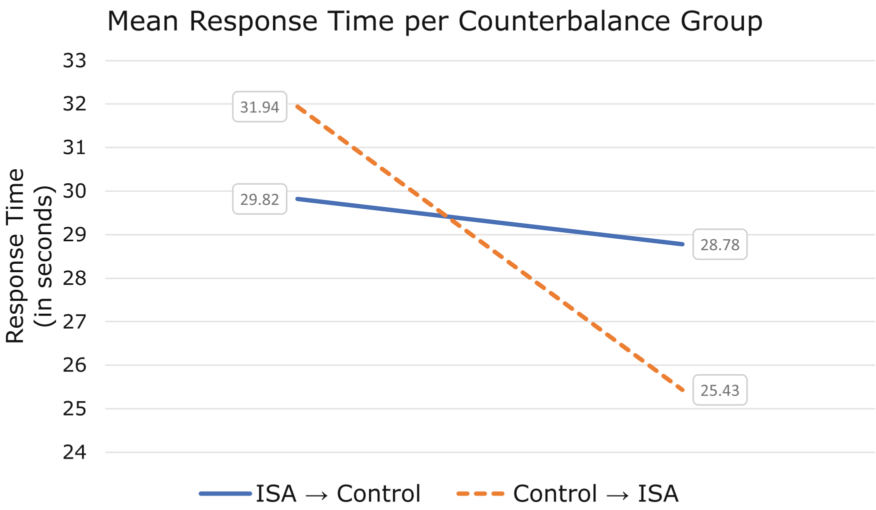

Fig. 4. Mean response time per counterbalancing group order. The response time in the ISA → Control group exhibited a small gain in RT when switching from the ISA condition to the Control condition (29.82 → 28.78). In contrast, the Control → ISA group a larger gain in RT when switching from the Control condition to the ISA condition (31.94 → 25.43). The latter gain is 6x faster than the former.

4 Discussion

This study examined the benefits of the ISA display on spatial judgements in a real-world outdoor environment. These spatial judgements are similar to those made by a JTAC observer when describing a target spatially to a pilot using contextual landmarks that are easily observable from the air. The trends that we observed in terms of response time benefit from the ISA were not statistically significant, but with such a low sample size even the marginal effects that emerged suggested that there was a difference. However, we showed that for both the high performing and low performing groups the same non-significant 3 s decrease in response time. This is good news for the JTAC operator because this implies that even with when already making extremely accurate spatial judgements, such as those from experienced JTAC operators, the use of the ISA still provides a 3 s decrease in response time which could be crucial if in a warfare situation. We also believe that while this study did not result in the same levels of significance as the previous experiment [9], which had considerably higher statistical power, the same trends emerged that show the ISA provides a benefit to both speed and accuracy when making spatial judgements.

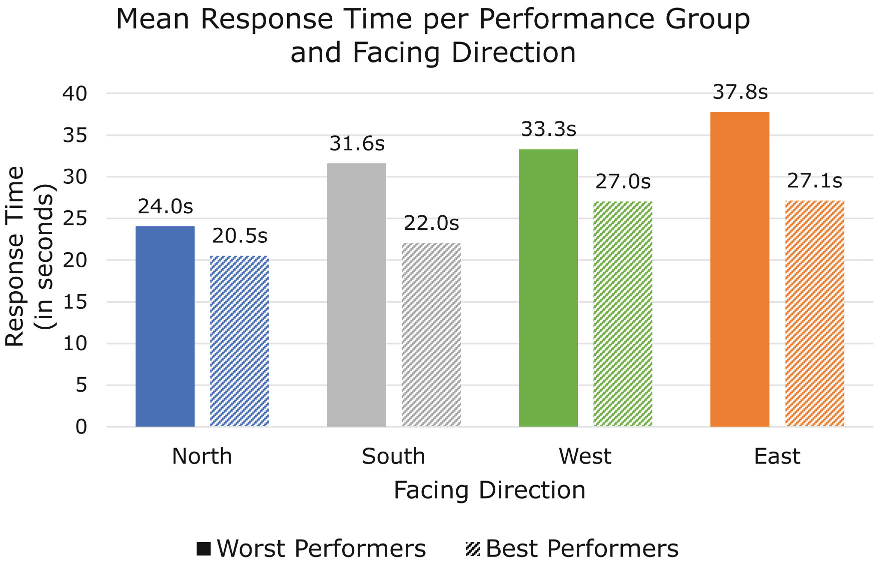

Fig. 5. A comparison of response time from the best or worst performers per facing direction. The bars indicate the standard error. Within each performance group, the North up view performed better than the rest of the views. The mean for the best performers was 24.2 s, while the mean for the worst performers was 31.7 s.

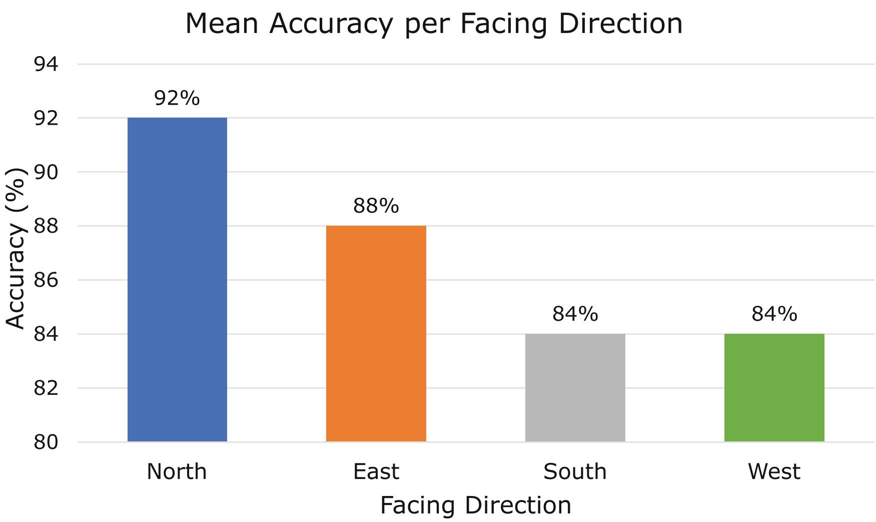

Fig. 6. Mean accuracy per facing direction (higher is better). The bars denote the standard error. The North up direction had the highest accuracy, while the South and West directions had the lowest accuracy.

5 Limitations and Future Work

We expected to see a large improvement in both accuracy and speed when using the ISA display, however, only minor effects emerged for the response timing and no accuracy effects were recorded. We feel that this is in part due to the ease of the task as well as a low sample size, a constraint that was imposed upon us because of the limited time-availability of the outside venue shown in Fig. 1. Because of the group of 9 participants that scored 100% accuracy on both conditions we felt as though we did not fully capture the benefit that the ISA display provides in terms of improving accuracy. And the low sample size was due to COVID restrictions as well as scheduling conflicts with the location. With an increased sample size, the marginal effects shown here should only grow in significance, so we feel as though the 3 s decrease in response time shows the ISA display does provide benefits. Future work could examine a more difficult task, such as identifying real buildings, to obtain a better estimate of the accuracy improvements that the ISA display may provide.

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