U.S. ARMY

DEVCOM C5ISR CENTER

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND C5ISR CENTER

Simulating the Impact of Navigation Waypoint Accuracy on Soldier Performance

19 OCT 2023

Dr. John Graybeal[a], William Heath Sharp[b], Dr. Emily Lasko[c], Kiran Bagalkotkar[a], Dr. Jasmine Dang[a]

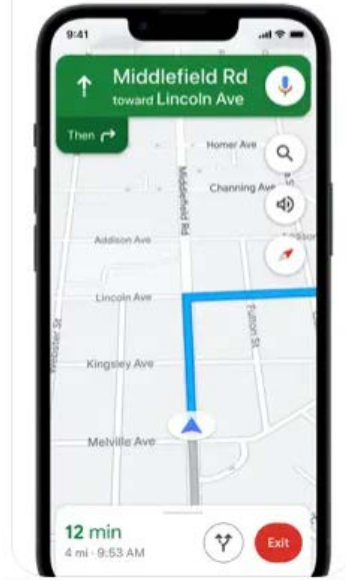
a) DEVCOM C5ISR Center

b) Planned Systems International Inc.

c) CACI International Inc.

INTRODUCTION

STEP BY STEP INSTRUCTIONS THROUGH THE DARK



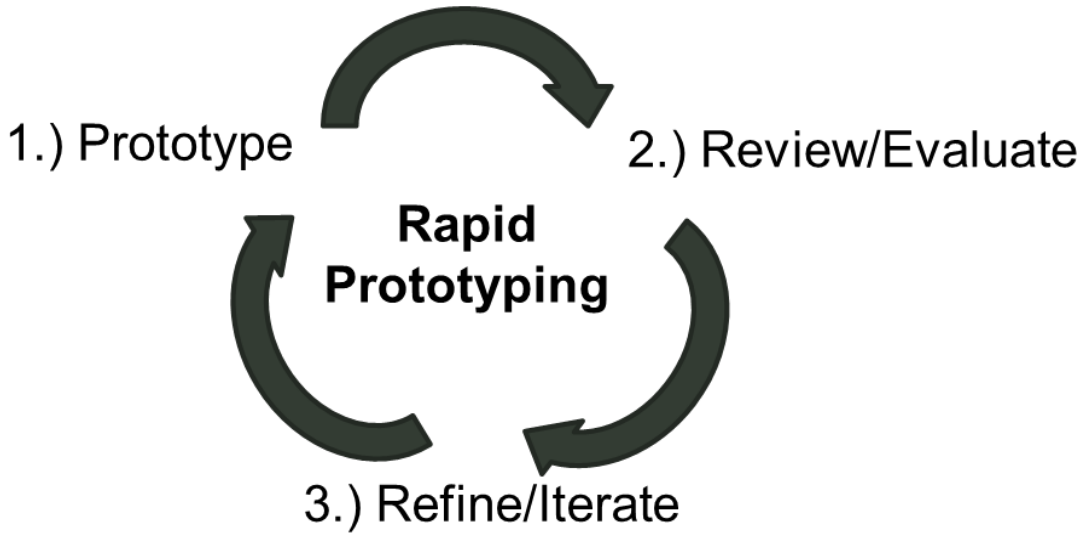
- **The U.S. Army DEVCOM C5ISR Center is exploring how to improve future night vision sensors**
- **Improving a night vision device is about more than simply improving system components to get a better image**
  - **We also want to explore how to make the technology more useful for the Soldier**
- **The maturation of multiple technologies has made it possible to display various types of augmented reality information within night vision sensors**
- **What would happen if we could give Soldier navigation instructions inside their night vision goggles?**

VIRTUAL PROTOTYPING

- **Virtual Prototyping – creation of a computer simulation of a product for presentation and/or evaluation**

- **Rapid, iterative prototyping is best practice for developing technology for human use**
  - Present early, progressive prototypes to users
  - Collect data from users as early in the design process as possible (even before building the first physical prototype)
  - Usability improves faster
  - Shorter development cycle
  - Ultimate cost savings

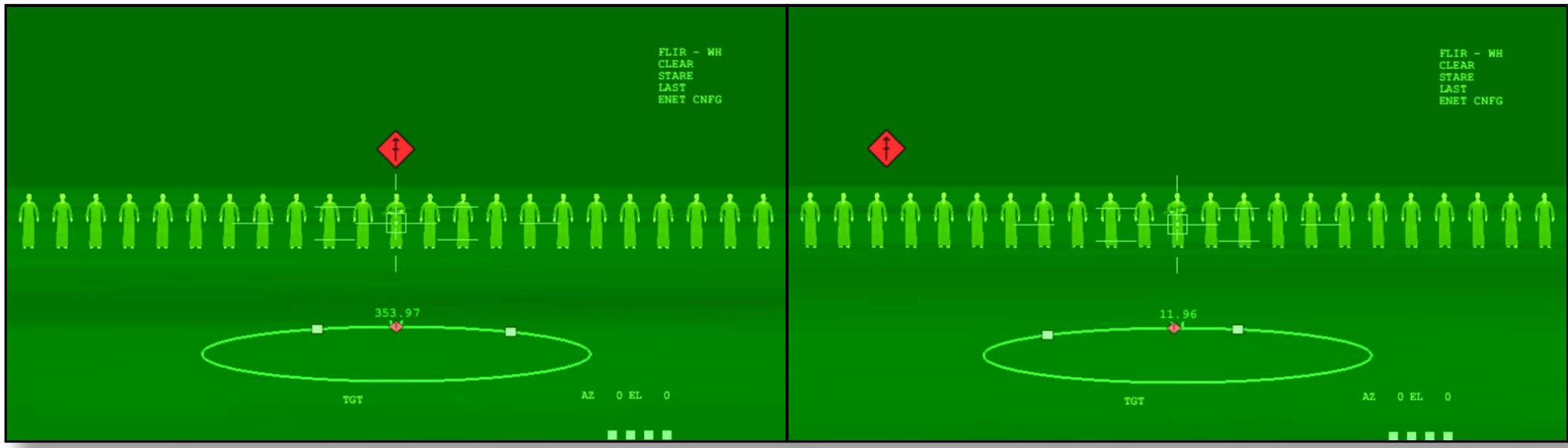
- **Virtual prototyping can allow us to realistically test how adding navigation assistance to night vision devices would affect Soldier navigation**



IMPORTANCE OF QUALITY OF AR INFORMATION

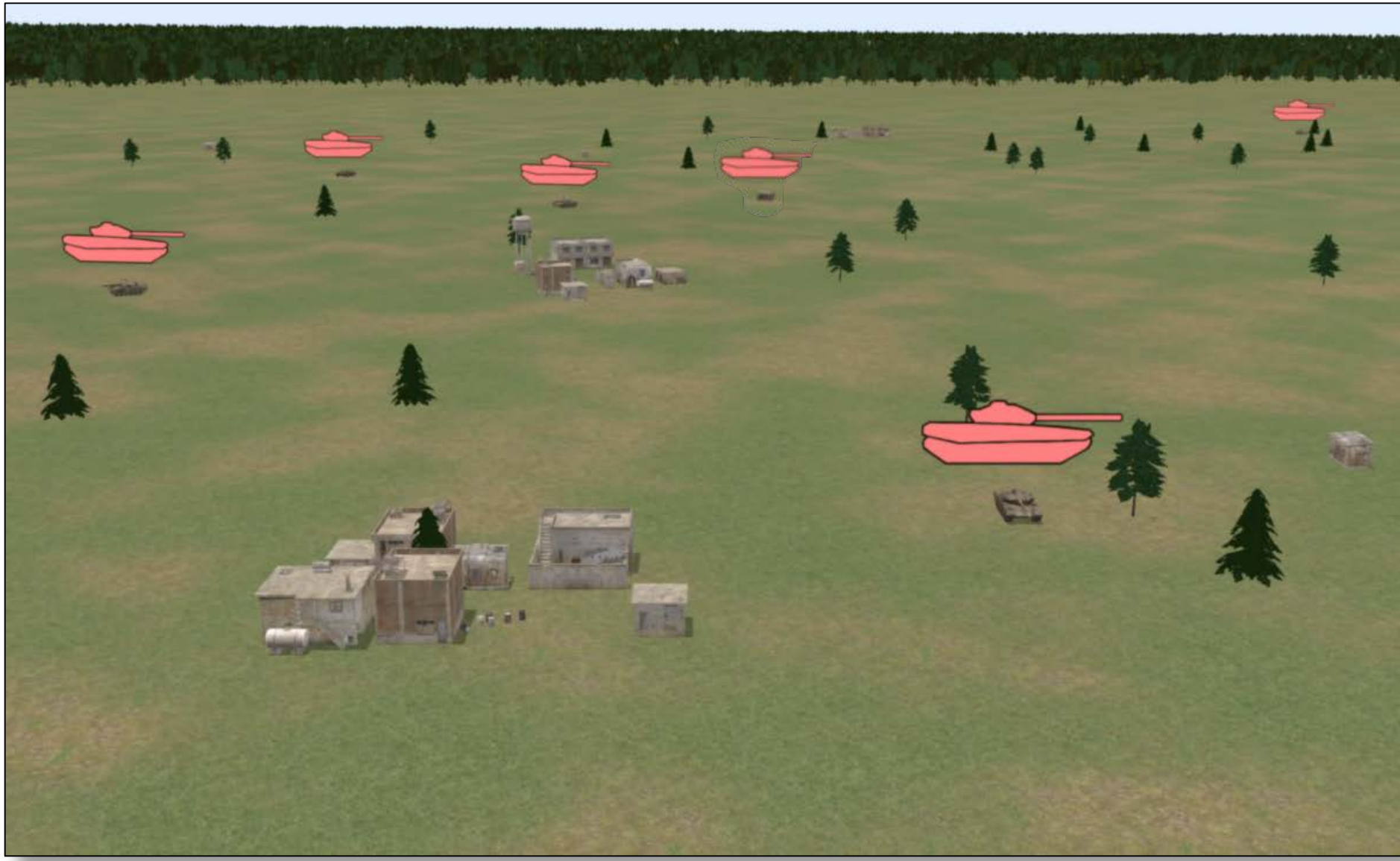
- **Assumption: providing Soldier's with Augmented Reality information will improve their performance**
- **Many factors impact the quality of AR information**
- **For AR information to assist Soldiers, it must be:**
  - Perceivable
  - Interpretable
  - Relevant
  - Timely
  - Accurate

Example: AR designation is perfectly aligned (left) and misaligned (right)



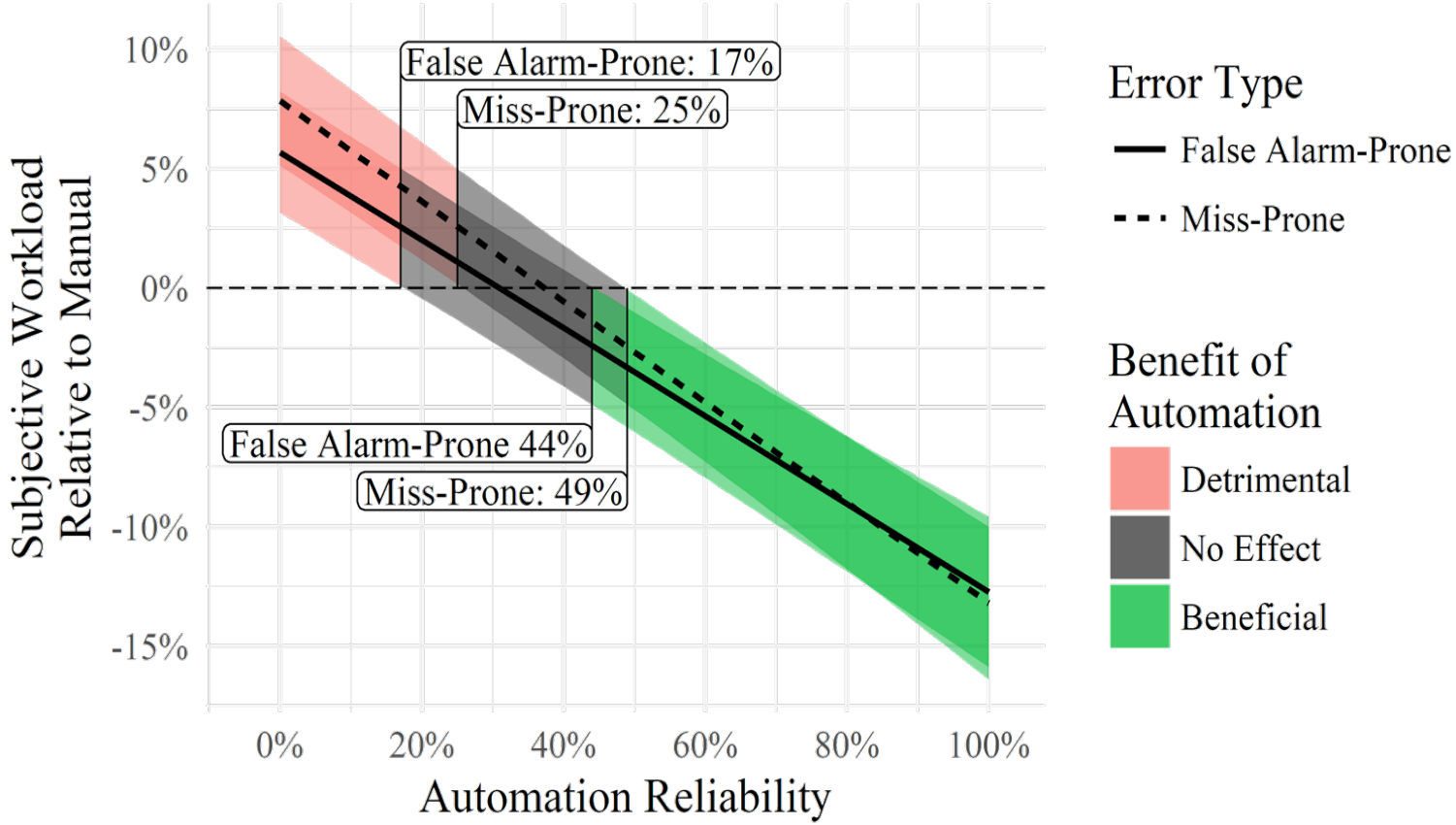
AR SYSTEMS WILL INEVITABLY MAKE MISTAKES

- **Understanding how AR information can be beneficial is essential, but it is important to test what happens with information that is realistically imperfect**



KEY QUESTIONS

- **How "good" does AR information have to be to improve human performance?**
  - This is an empirical question that can be addressed initially through simulation
- **Poor performing AR will not provide benefits**
  - It may even impair human performance!



RESEARCH OBJECTIVES

- **Quantitatively evaluate whether AR waypoints meaningfully improve navigation performance**
  - Compare aided vs. unaided performance
  - Assess the ability of Soldiers to quickly and accurately follow a prescribed route

- **Evaluate how the accuracy of the waypoints impacts Soldier performance**
  - What are the best possible benefits to Soldier performance with perfect guidance?
  - Is AR guidance still beneficial if the waypoints are realistically imperfect?

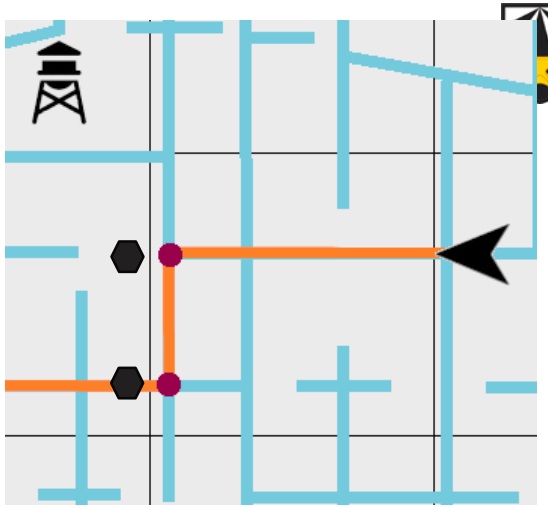
METHODOLOGY

TASK OVERVIEW

- Participants were tasked with navigating prescribed routes through a simulated environment
- They were given a static map of the route to complete with waypoints marked on the map, located at turns and their final destination
- At times, AR waypoints were presented on their display overlay to help guide them to their final destination.
  - These AR Waypoints could be perfect (located at exact same position as on the printed map) or imperfect (waypoints were not located at the exact same position as on the printed map).
- Other times, the AR was off, and they had to navigate routes on their own with just the “printed” map.

EXPERIMENTAL DESIGN

Perfect



Imperfect

- **Four AR conditions:**
  - No AR
  - Perfect Waypoint Accuracy
  - High Waypoint Accuracy
    - Minor geospatial inaccuracies
  - Low Waypoint Accuracy
    - More severe geospatial inaccuracies
- **Five Map Grids:**
  - Five separate 12x12 map grids were created such that each was unique
  - Twelve total routes were created on each map grid varying in length and number of turns.
    - Range of 4-8 turns
- **Four Blocks of Experimental Trials:**
  - Participants completed four blocks of 12 experimental trials
  - Each trial consisted of a single route, ranging from 5 – 9 total waypoints (when AR was on) and 10-19 city blocks travelled to complete the route
  - Within each block of 12 trials, Soldiers experienced routes from an approximately even distribution of all five map grids and encountered an equal amount (3 trials each) of all levels of AR Waypoint Performance and No AR
  - *Consequently, Soldiers could not predict system performance or the underlying map structure on a trial-by-trial basis.*
  - *AR performance did not vary within a single trial*

PARTICIPANTS AND PROCEDURE

- **Participants:**
  - 40 Soldiers
  - Four separate groups of 10 Soldiers at a time

- **Hardware:**
  - Touchscreen monitor (32 inches) to display sensor feed, display overlay, and simulated environment
  - Second monitor to display "Printed Map" and route
  - Commercial gaming controller

- **Procedure:**

Day 1
  - PowerPoint Training and Experimental Overview
  - 12 Training Trials (3 Perfect Waypoint Accuracy, 3 No AR, 3 Low Waypoint Accuracy, 3 High Waypoint Accuracy)
  - First and second blocks of experimental trials
    - 12 Trials per block

Day 2
  - Third and fourth blocks of experimental trials
    - 12 Trials per block

DEPENDENT VARIABLES

- **Route Completion Time**
  - Number of seconds from beginning of a trial until reaching the final destination.

- **Amount of Route Deviation**
  - Describes the distance in meters from the center of the prescribed path. Scenario roads were 10 meters wide, and Soldiers could walk on either side of invisible center line used for scoring.
  - Small deviations (< 5.5 m) indicated the user was on the correct path, larger deviations (> 5.5 m) indicated the Soldier had taken a wrong turn.

- **Percentage of Time Off Route**
  - The percentage of time users were classified as "off route" during a given trial.
  - Soldiers were considered "off route" when their deviance from the prescribed path exceeded the width of the road (5.5 meters from the center of a road 10 meters wide).
  - Soldier position was continuously categorized as either correct or incorrect.

- **Percentage of Waypoints Skipped**
  - Users had the ability to "skip" waypoints by pressing a button on their controller.
  - This DV describes the percentage of waypoints skipped on a given trial (waypoints skipped/total waypoints).
  - Interpretability is limited. If waypoints were too far off road with imperfect AR, users could not reach them and were forced to "skip" them to remove them from the overlay to proceed to the next waypoint. This also does not capture waypoints that users did not skip with their controller, but "skipped" by going on an incorrect route.

ANALYSES CONDUCTED

Linear Mixed-Effects Models were used for all analyses

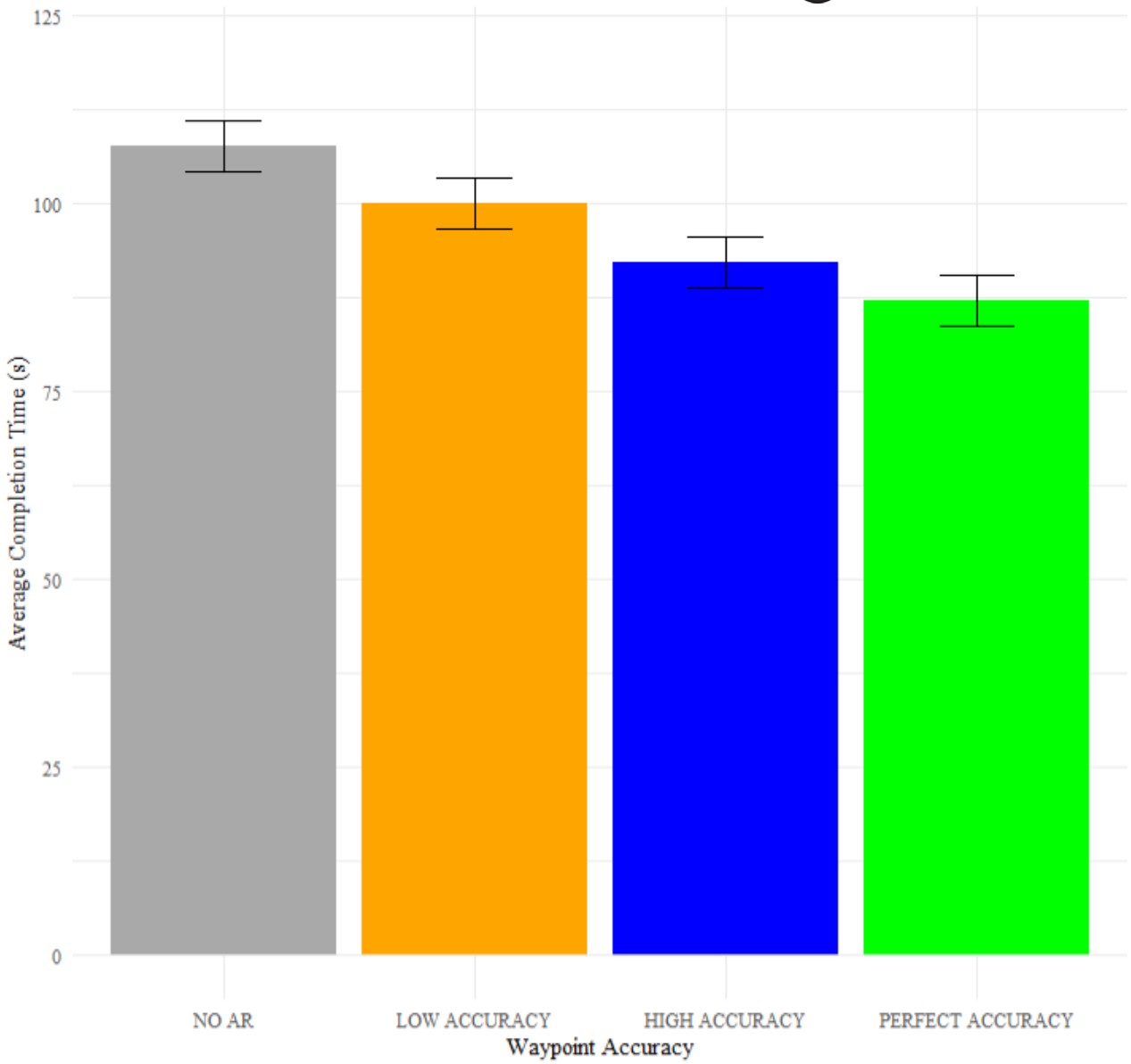
- **Route Completion Time, Amount of Route Deviation, and Percentage of Time Off Route:**
  - Performance in each of the three Waypoint Accuracy Conditions was compared to the No AR Condition
  - The Imperfect Waypoint Accuracy Conditions (High and Low) were compared to the Perfect Accuracy
  - All three Waypoint Accuracy Conditions were pooled together and compared to the No AR Condition

- **Percentage of Waypoints Skipped**
  - As no waypoints were provided in the No AR condition, we only compared performance in the High and Low Waypoint Accuracy to Perfect Accuracy

RESULTS

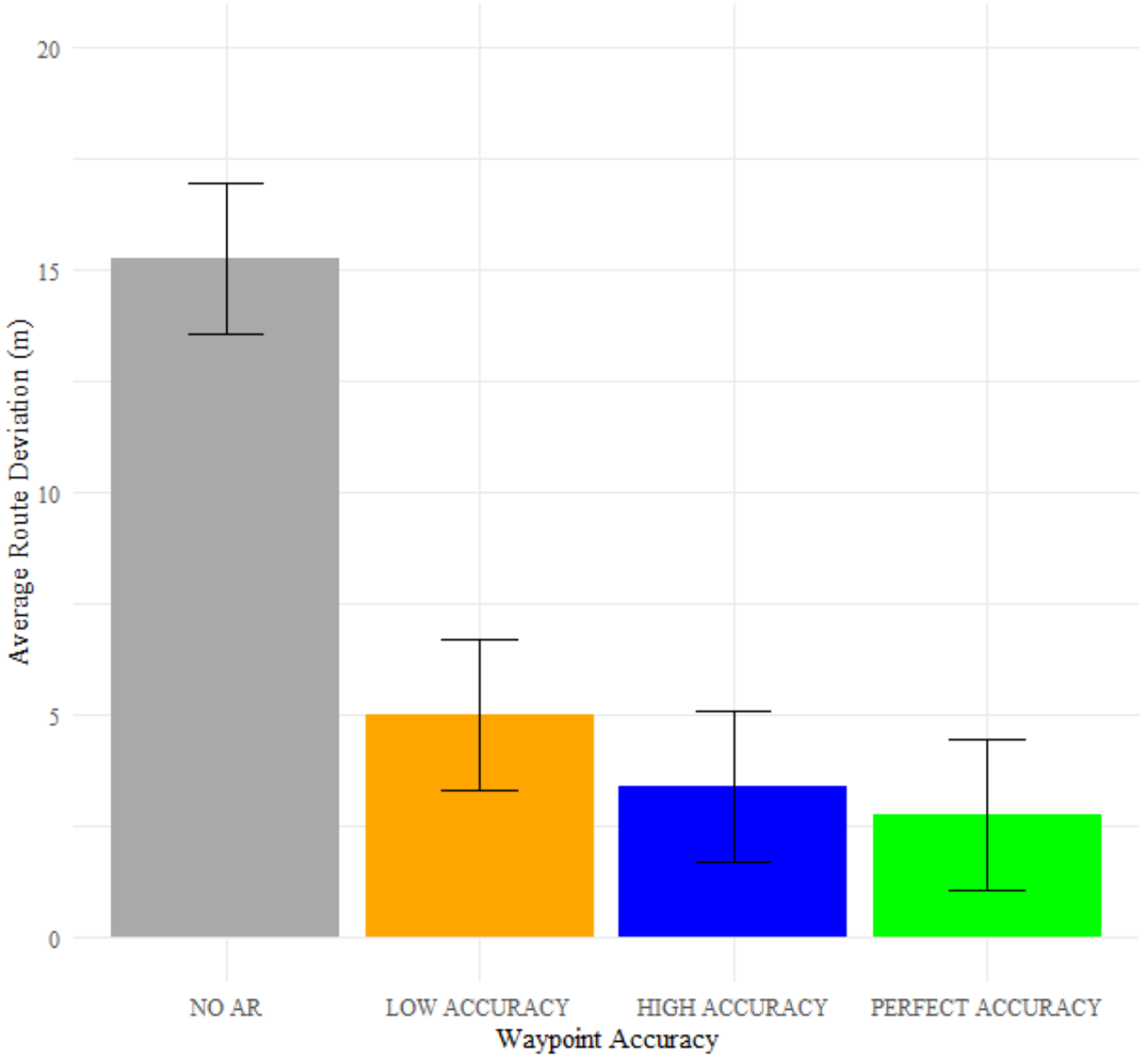
ROUTE COMPLETION TIME

- **Effects by AR condition**
  - Each AR accuracy condition resulted in a significant reduction in route completion time compared to No AR (all *p*-values <.001)
  - Compared to perfect AR, the benefits of imperfect AR were reduced (all *p*-values <.001)
- **No AR compared to all AR**
  - No AR resulted in significantly longer route completion time compared to the three aggregated AR conditions (*p* <.001)



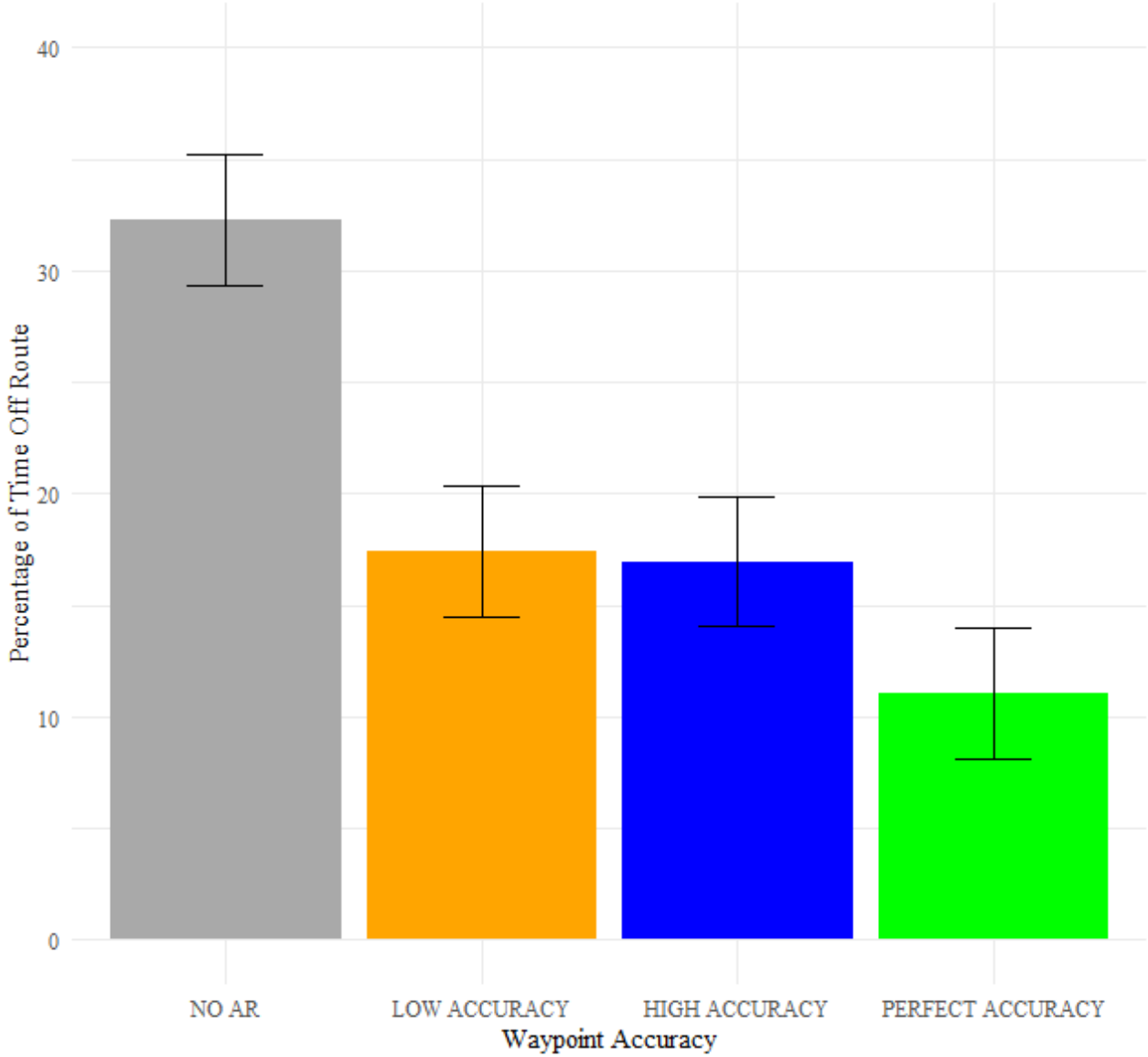
AMOUNT OF ROUTE DEVIATION

- **Effects by AR condition**
  - When the AR overlay was off, Soldiers deviated significantly further from the prescribed route compared to each of the conditions in which they received AR guidance (all *p*-values <.001)
  - Compared to perfect AR, the benefits of imperfect AR were reduced (all *p*-values <.001)
  - The average route deviation for all forms of AR guidance was below the threshold for being considered "off route"
- **No AR compared to all AR**
  - Aggregating performance from the three AR accuracy conditions revealed participants deviated from the prescribed route significantly more in the No AR condition compared to when it was on (*p* <.001)



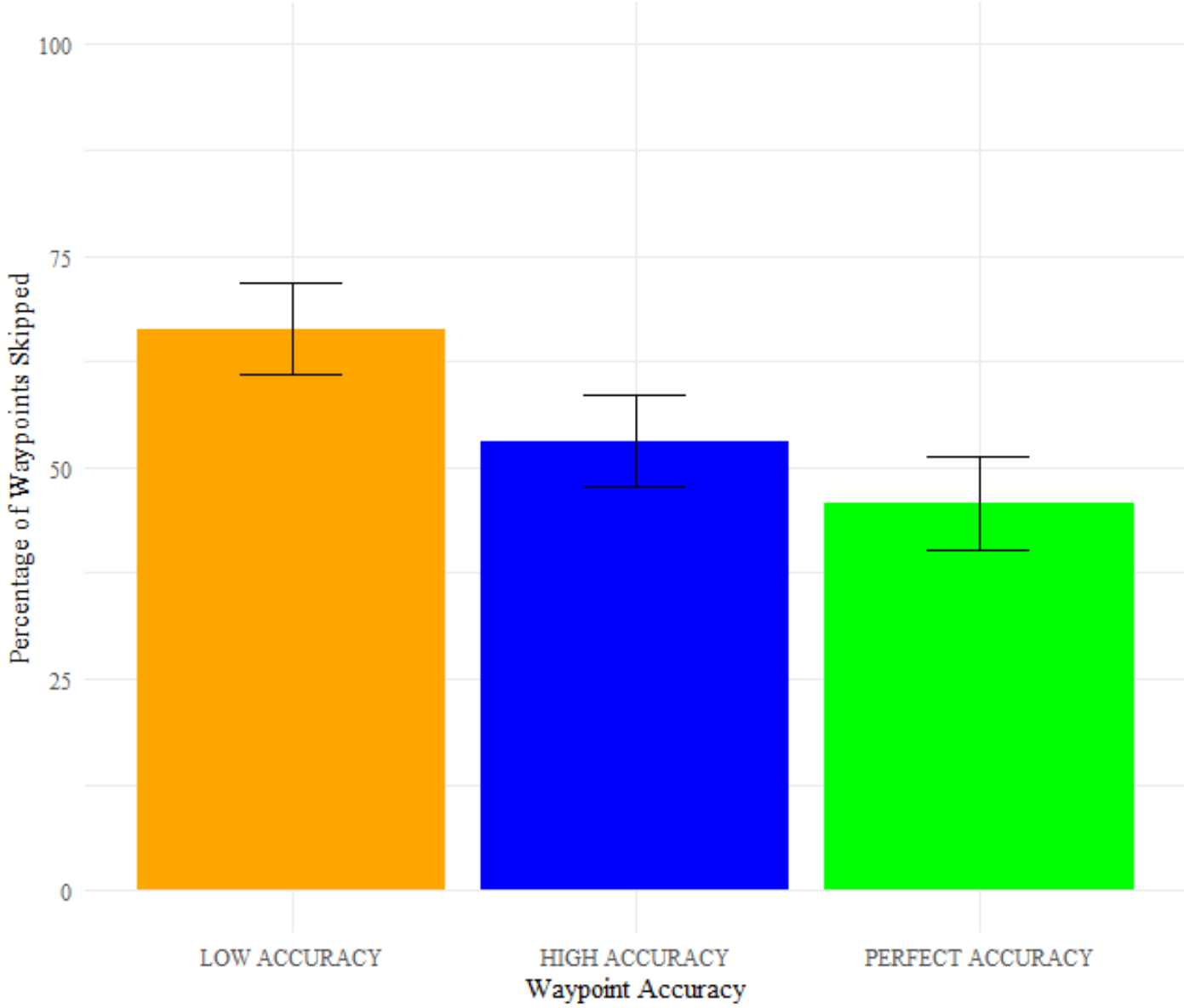
PERCENTAGE OF TIME "OFF ROUTE"

- **Effects by AR condition**
  - Compared to the No AR condition, Soldiers spent significantly less time deviated from the prescribed route during each of the conditions in which they received AR guidance (all *p*-values < .001)
  - Compared to perfect AR, the benefits of imperfect AR were reduced (all *p*-values <.001)
- **No AR compared to all AR**
  - Soldiers spent significantly more time off the prescribed route in the No AR condition compared to the aggregated performance observed in all three AR conditions



WAYPOINTS SKIPPED

- **Effects by AR condition**
  - Compared to the Perfect Accuracy condition, Soldiers skipped significantly more waypoints in the Low Accuracy ($p < .001$) but not the High Accuracy conditions ($p = .164$)
  - Soldiers also skipped significantly more waypoints in the Low Waypoint Accuracy condition compared to the High Waypoint Accuracy condition ($p < .001$)



DISCUSSION

LIMITATIONS

- **Differences exist between navigation skills in virtual versus real environment**

- **Simulation Limitations**
  - Lacked perceptual feedback, such as proprioception, tactile cues
  - Soldiers were forced to stay on roads (unrealistic)
  - Soldier were tested in isolation with only a map, without any other navigational assistance they might have from teammates
  - A more immersive simulation, perhaps using virtual reality and a 360˚ treadmill, might better simulate navigation

- **The task was long and repetitive**
  - Differences in stress or motivation may have affected how Soldiers used the system

- **These limitations may affect the generalizability of our findings, specifically the quantitative estimates of changes in performance**

STRENGTHS: BEYOND THE LIMITATIONS OF THE REAL WORLD

- **Experimental control and consistency**
  - All Soldiers completed a variety of unique routes
  - Ability to use a counterbalanced design with the quality of information displayed rotated across unique routes
  - Ability to easily display the desired levels of system performance
    - It would be difficult to get this combination of diversity (of scenarios) and consistency (across people) in the field
- **Easy and precise data logging**
  - It would be difficult to continuously and precisely log the position Soldiers throughout the navigation attempts in the field
- **Access to a large volume of Data**
  - 40 Soldiers x 48 simulated scenarios = 1,920 navigation paths
  - Rarely feasible to get this volume of data during nighttime experimentation due to a variety of factors
- **Virtual prototyping allows faster data collection**
  - No need to wait for physical hardware/software prototype to be finished
- **Summary:** *This simulation provided a feasible and cost-effective alternative to a nighttime field collection with a physical prototype*

CONCLUSION

- **It is critical to understand how AR errors affect cognitive performance for specific tasks**
  - We will continue to develop simulations to examine the effects of providing realistically imperfect information to Soldiers in their sensor imagery
- **All metrics of Soldier performance improved with AR waypoint guidance**
  - Even imperfect guidance was always beneficial in this simulation
- **System benefits were reduced substantially by realistic errors in waypoint registration accuracy**
- **Metrics of Soldier performance were differentially sensitive to waypoint accuracy errors**
- **This simulation revealed fundamental principles that designers of future night vision systems should consider**
  - This methodology can inform system requirements

THANK YOU.

APPROVED FOR PUBLIC RELEASE