An Analysis OF Extended Reality Mockups for Use In Verification: Phase 1

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2025 Human Research Program
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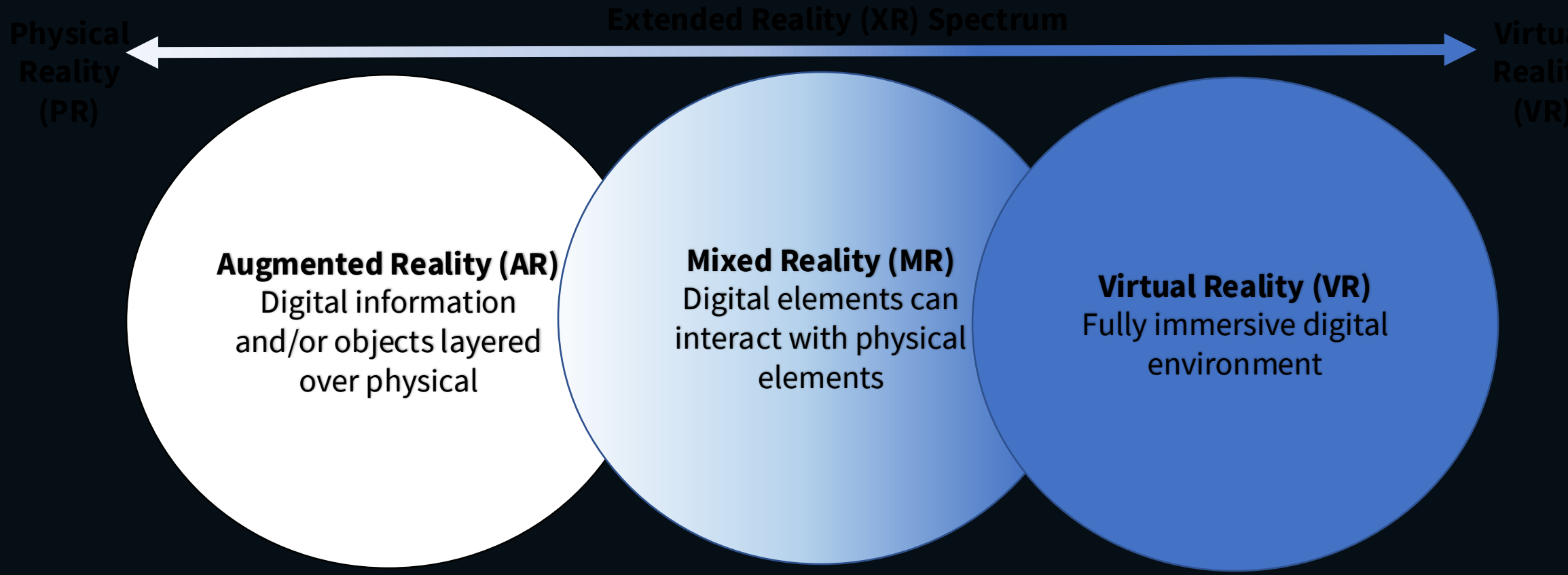
Background

- Before being approved for flight-readiness, spacecraft hardware must pass verification.
- Verification is required for human rating and is important to ensure that a system meets NASA's minimum specifications.
- Verification activities can be costly, as developers must often build high-fidelity physical mockups for specific verification evaluations.
- XR technologies may provide significant cost savings.

Extended Reality (XR) Technologies



Problem Statement

- Cost savings is not sufficient justification for the adoption of new approaches.
- There is little evidence concerning the validity of XR mockups for verification.
  - Verifications need only be passed once.
- XR technologies introduce new testing considerations and ill-defined terms, making evaluation and discourse difficult.
  - Immersion, fidelity, presence, nausea, training to use tech etc.

SWOT Analysis

	Enhancer Encourages Adoptions	**Inhibitor** Discourages Adoption
Internal Factors Attributes of the XR technology	**Strengths** What advantages do XR technologies have for conducting verifications?	**Weaknesses** What disadvantages do XR technologies have for conducting verifications?
External Factors Testing considerations, NASA culture etc.	**Opportunities** What additional benefits can encourage the adoption of XR technologies?	**Threats** What are the hurdles to adoption of XR technologies for verifications?

Virtual Reality SWOT Analysis

Strengths	Weaknesses
• Simulate microgravity • Full control over scenario and elements • Safely simulate dangerous situations • High affective validity • High internal validity • Fast reconfiguration • Assets are shareable • Crewmate simulation	• Nausea • Limited interaction fidelity • Limited sensory fidelity • Limited integration of supporting products • Hardware variability • Headset limitations • New sources of testing discrepancies
Opportunities	**Threats**
• Lower development costs • Reduced time for Test Readiness Review • Remote testing • Training mockups • Validation research • New practices to maximize XR technologies • Evolving technology	• Difficult to validate • Ill-defined terminology • Ill-defined levels of fidelity • High face validity ≠ valid verification mockup • Additional training required • New measures to consider: Presence, nausea etc. • Requires dedicated testing space • Limited support of multi-system verifications

PR vs. VR Study: Habitable Airlock

	Physical Reality	Virtual Reality
Port View		
Forward View		

Tasks and Procedures

VR

PR

Tasks Performed in Each Environment

1. Exercise volume
2. Maintenance access
3. Glare test
4. Overhead stowage
5. Trash access
6. Maintenance accommodation
7. Privacy
8. Hatch door open/close

Switch Mockups

Participants

- 13 participants (7 female, 6 male)
- 12 crew-like, 1 Subject Matter Expert
  - 25 to 60 years
  - 20/20 or corrected vision
  - Minimum STEM Bachelor's degree in a STEM discipline or equivalent years of experience
- Average age was 32.69 years old (SD = 3.90)
- 7 wore no corrective lenses, 6 wore glasses or contacts
- Overall, reported low use of AR/VR headsets

Results

Physical Reality

Virtual Reality

Hardware Related Factors

- Low levels of nausea
  - Motion Illness Symptoms Classification scale (MISC; Reuten et al., 2020)
  - 11 reported *No problems* and 2 reported *Some discomfort*
- Overall headset usability was high
  - NASA Modified System Usability Scale
  - *M* = 86.30, SD = 11.94
- Participants reported feeling immersed
  - *To what extent did you feel present in the environment, as if you were really there?* (Bouchard et al., 2004)
  - *M* = 76.69, SD = 19.09, Median = 77

Privacy

PR

VR

Do you feel the curtain affords enough privacy for tasks like personal hygiene and changing clothes?

	Physical Reality	Virtual Reality
Yes	100%	100%
No	0%	0%
Unsure	0%	0%

Do you feel that there is enough volume to perform tasks like personal hygiene and changing clothes?

	Physical Reality	Virtual Reality
Yes	85%	100%
No	0%	0%
Unsure	15%	0%

Note. Difference was not significant $p = .48$.

Stowage Operation

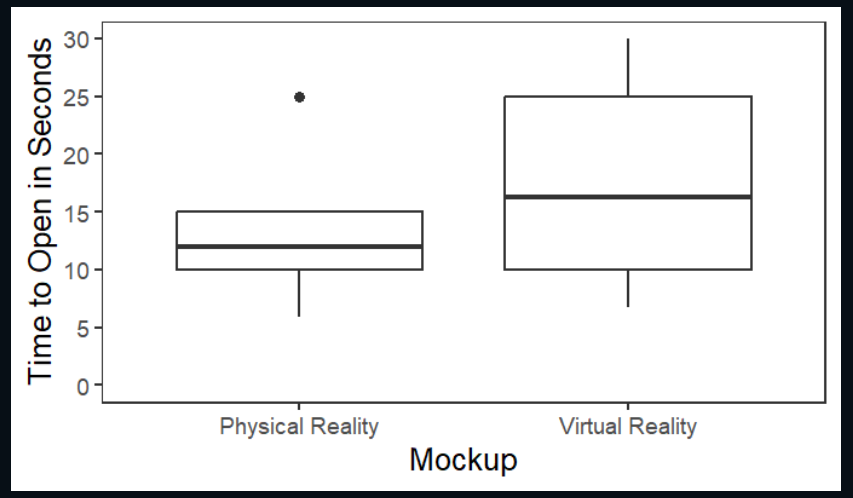
Physical Reality

Virtual Reality

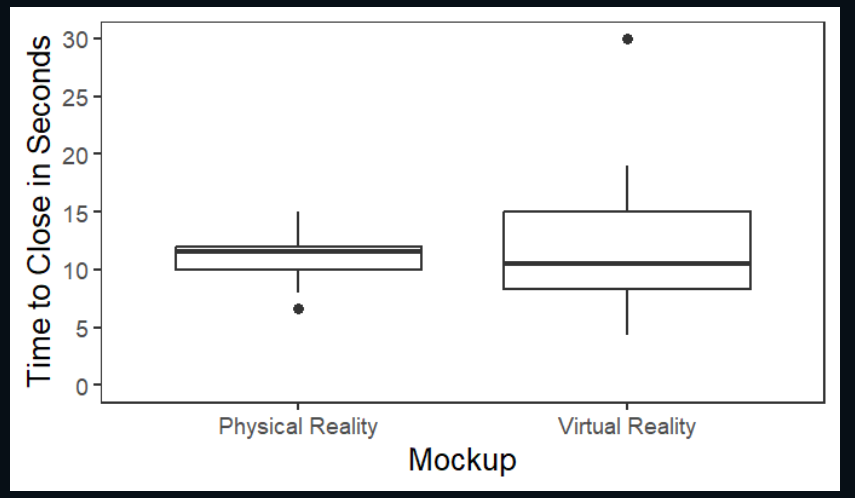
Are you able to reach the stowage?
-100% yes response in VR and PR

Are you able to successfully open the stowage?
-100% yes response in VR and PR

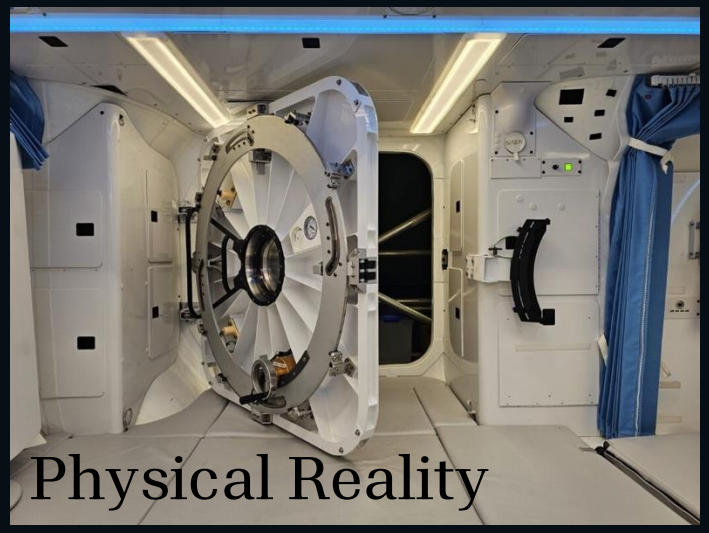
Hatch Door Open/Close



$t(12) = 2.41$, $p = .03$, $MD = 4.5$ secs, Cohen's d = 0.67

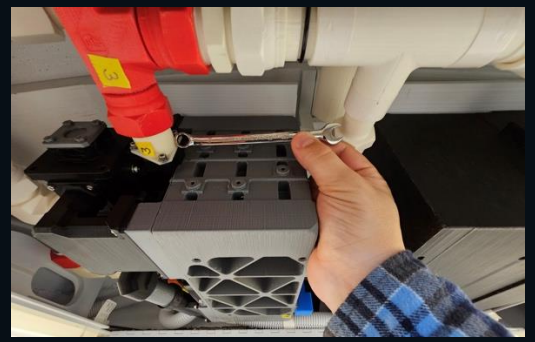


$t(12) = 0.92$, $p = .38$, $MD = 1.4$ secs, Cohen's d = 0.26



Maintenance Accommodation

PR

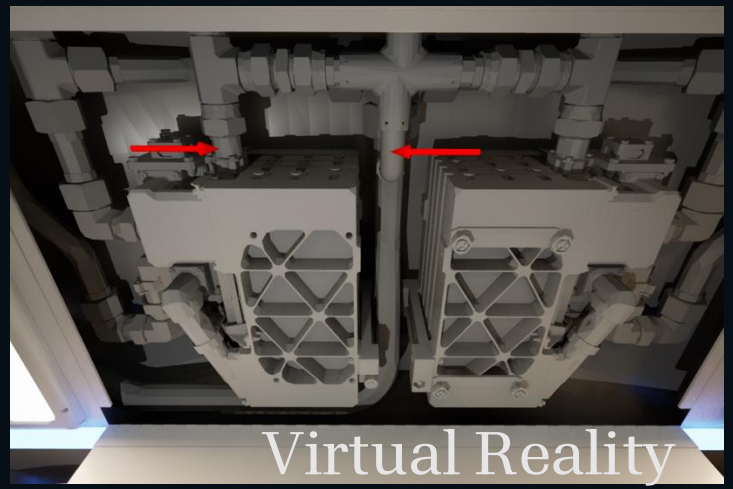


8 mm

9 mm

18 mm

VR



Are you able to pass the wrench, lengthwise, through the designated space?

Mockup	8 mm		9mm		18 mm	
	Yes	No	Yes	No	Yes	No
Physical Reality	46%	54%	0%	100%	8%	92%
Virtual Reality	62%	38%	8%	92%	8%	92%

Ground truth: 8 mm can pass through, 9 and 18 mm cannot.
8 mm comparison is not statistically significant $p = .70$.

Mockup Similarity

Comparing the physical and virtual mockup, how similar were the two mockups?

- 0-Not Similar at all to 7-Very Similar

Similarity Ratings by Task

Comparison	M	SD	Median
Exercise volume	6.23	1.48	7
Overhead stowage	6.23	1.01	7
Privacy	6.31	0.63	6
Trash access	5.46	1.13	6
Hatch door open/close	5.31	2.06	6
Maintenance accommodation	5.38	1.45	5
Maintenance access*	3.69	2.36	5
Glare test*	3.08	1.93	3
Overall	**6.08**	**1.19**	**6**

Glare test and Maintenance accommodation were rated as less similar compared to many of the other tasks.

Study 1 Summary

- There are issues for using VR for verification.
  - High similarity ratings did not always predict similar outcomes.
  - A more systematic approach might be warranted.
- Best use case may be single component verifications.
  - Simple interactions (e.g., opening/closing stowage)
  - Volume inspections, if embodiment is supported well
  - Caution is still recommended
- Demonstrations with Yes/No outcomes appear more viable than outcomes requiring precise measurement (e.g., time).

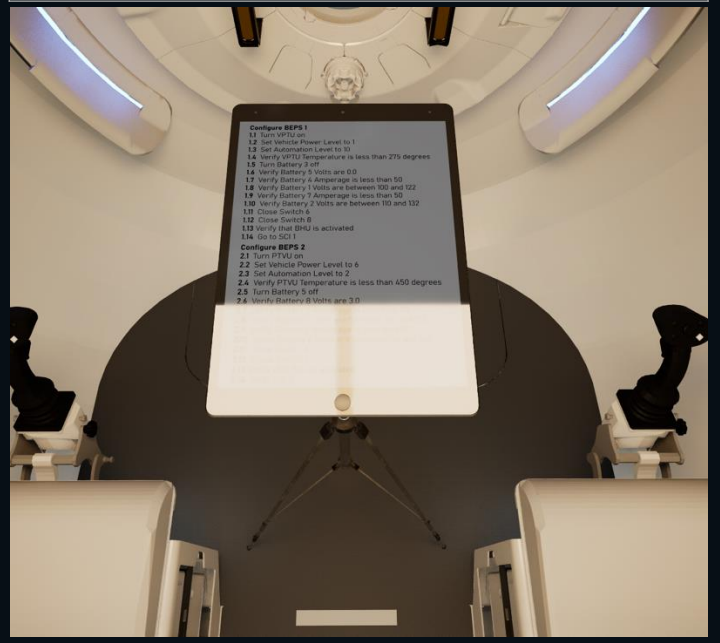
Preliminary XR Framework Elements

- **Requirement**
  - What requirement(s) is to be verified?
- **Method Type**
  - What verification methods are to be used?
- **Fidelity**
  - Does the XR tech support the essential task characteristics?
- **Outcome Validity**
  - Can we trust the results we gather with the XR mockup?
- **Test type**
  - Is it a single component, rolled up, or integrated test?
- **Supporting Equipment**
  - Can the XR mockup properly integrate supporting products?
- **Hardware**
  - Is the proper hardware being used?

Technical Requirement

V2 8058 Glare Prevention

Does lighting impact your ability to read on the screen?



Taxonomy of Extended Reality Verification Mockups

XR Mockup Type	Physical Reality	Augmented Reality	Mixed Reality	Augmented Virtuality	Virtual Reality
Description	• Mockup and scenario are completely physical	• Elements are primarily physical • Digital elements are superimposed on physical • Low integration between digital and physical elements	• Elements are a blend of physical and digital • Digital and physical elements are highly integrated	• Elements are primarily digital • Physical elements are supplementary to digital • Low integration between digital and physical elements	• Mockup and scenario are completely digital
Example		PR mockup + AR overlays to act as interface mockups	Low fidelity PR mockup + VR overlay to add visual details	VR mockup for reach assessment + Brassboard for hardware operation	VR mockup for volume evaluation

Future Work: Phase 2

- Build upon the results of Phase I, with an emphasis on the use of Mixed Reality.
- Develop guidelines for development and approval of XR mockups for verification
  - What lessons can we transfer from other fields?
  - Are there useful and valid measures for XR outcomes such as presence, nausea, and fidelity?
  - What role can they play in validating XR mockups?
- Continue to mature XR Framework
  - Better define fidelity
  - Identify fidelity dimensions among requirements such as sensory, task, interaction etc.
  - Identify what XR Mockups best suit particular requirements
  - What outcomes do we need to consider and how can we best validate them?

Thank you!
Questions?