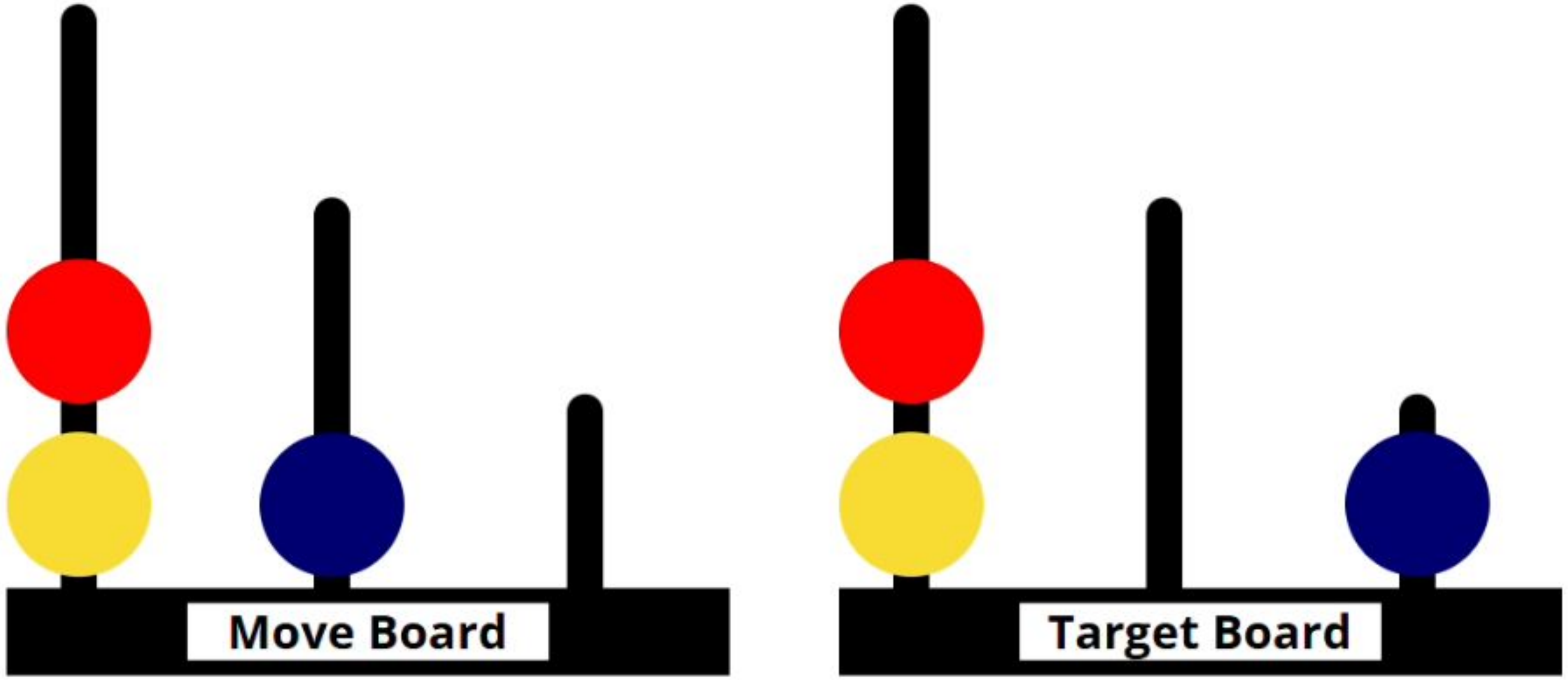
Toward Standardized VR Neuropsychological Testing: Lessons from the Tower of London

This presentation explores how different interfaces (physical, digital (2D), and virtual reality (VR)) affect performance on the TOL task.



Executive Functioning and Assessment

Mental Processes

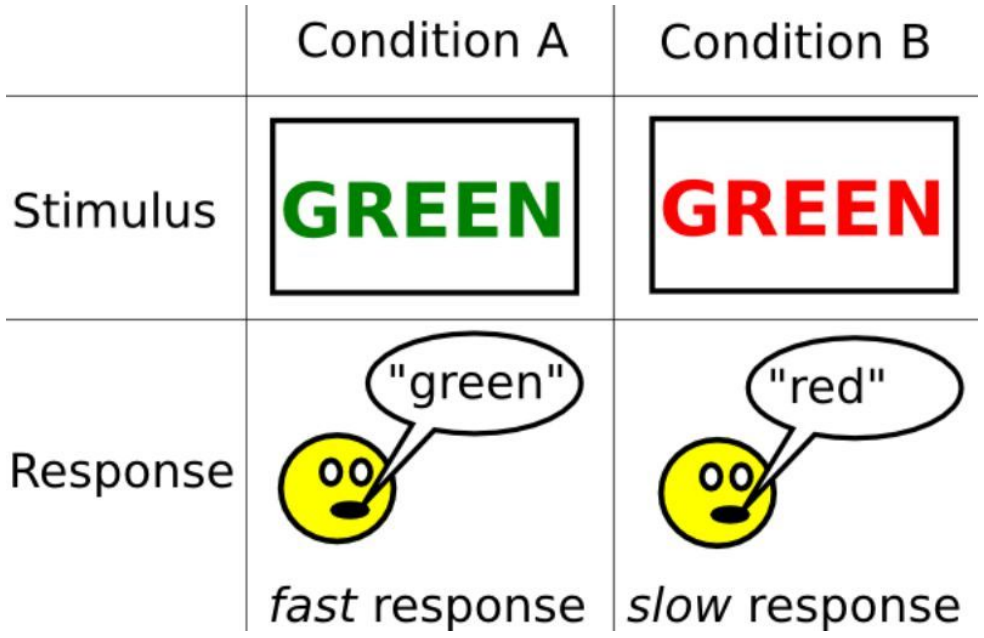
Executive functioning includes inhibition, working memory, cognitive flexibility, and problem-solving abilities that override automatic operations.

Brain Injury Impact

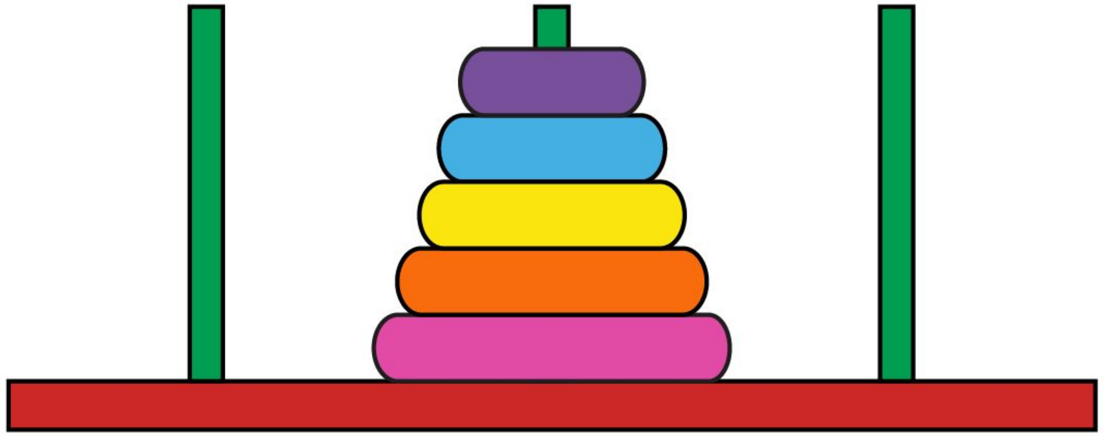
The frontal lobe, which controls executive functions, is the most commonly damaged brain region in traumatic injuries.

Assessment Methods

Tasks like the Stroop Test and Tower of London help quantify executive function, with VR versions showing potential for higher ecological application.



Example: Overriding impulsivity in Stroop Task



Example: Planning in Tower of Hanoi

Tower of London Task Steps

- **Goal:** Match configuration of move board to target board in fewest number of moves. Depending on the interface, this might look different...

Interface Conditions

Digital Task

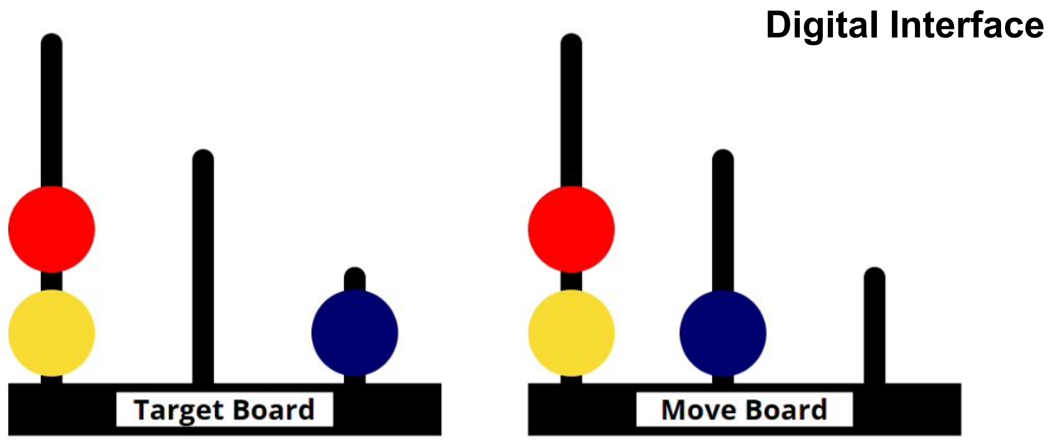
- HTML file run on gaming laptop with colors matching physical version.
- Standardized instructions with automatic data recording.

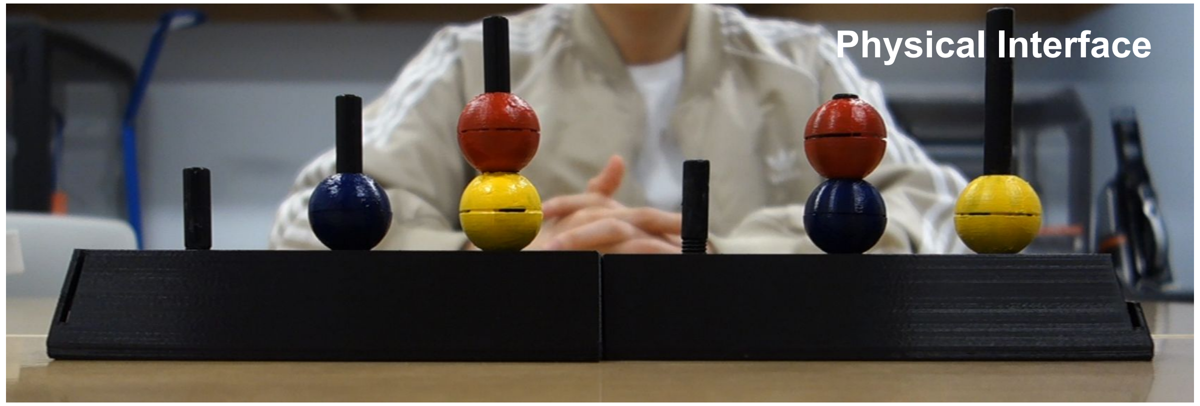
Virtual Reality Task

- Built in Unity3D.
- Virtual room resembling experiment space with participant seated at virtual table.
- Interface similar to digital condition but in immersive 3D environment.

Physical Task

- Traditional 3D-printed version of Shallice's original task (1982).
- Experimenter arranged target configuration behind foam board.
- All problem-solving recorded via camera for later scoring.





So Why Do We Need a VR Task?

Distinct Brain Activation

Milla et al. (2019) observed increased oxygenated hemoglobin levels with 3D Tower of Hanoi, likely due to physical and spatial components.

Enhanced Cognitive Metrics

Campbell et al. (2009) found overlapping brain activation patterns with VR task about finding an alternative driving route, suggesting simulation of real-world planning.

More Precise Measurement

VR enables tracking of fine-grained and automatic recording of responses beyond traditional metrics while not compromising the spatial element of real world tasks. Also, consistent administration between participants for increased reliability.

Experimental Design

Participants

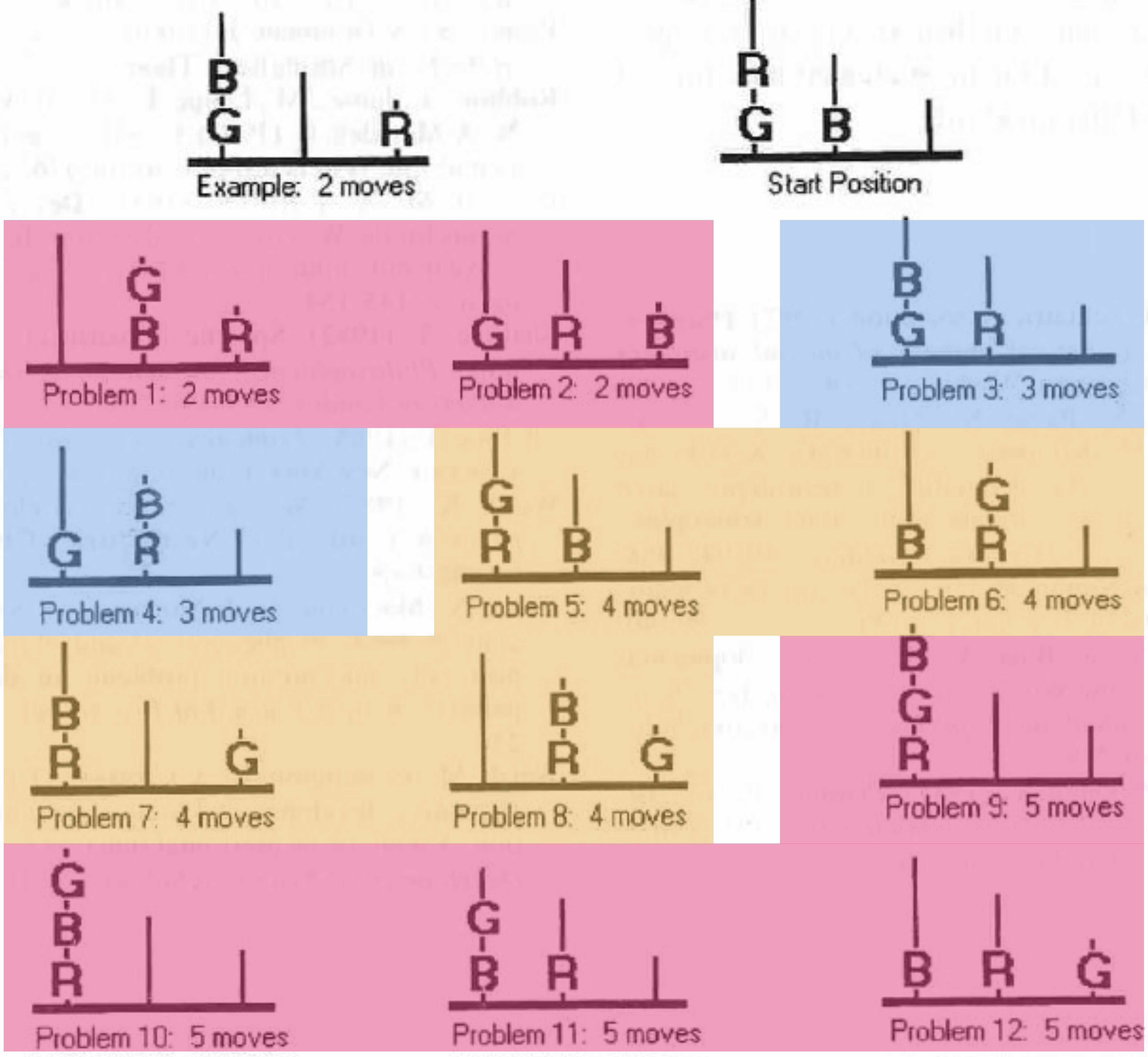
33 University of Richmond students with normal/corrected vision and no colorblindness. (n=11 digital, n=11 VR, n=11 physical).

Random Assignment

Participants randomly assigned to physical, digital, or VR condition.

Task Completion

12 trials (up to 120 seconds each) requiring matching target configurations with minimum moves. 1 practice trial.


B
G
R
Example: 2 moves
R
G
B
Start Position
G
B
R
Problem 1: 2 moves
G
R
B
Problem 2: 2 moves
B
G
R
Problem 3: 3 moves
G
B
R
Problem 4: 3 moves
G
R
B
Problem 5: 4 moves
B
G
R
Problem 6: 4 moves
B
R
G
Problem 7: 4 moves
B
R
G
Problem 8: 4 moves
B
G
R
Problem 9: 5 moves
G
B
R
Problem 10: 5 moves
G
B
R
Problem 11: 5 moves
B
R
G
Problem 12: 5 moves

Research Questions:

RQ1:

RQ2:

RQ3:

RQ4:

RQ1: How does the **number of extra moves** vary across trials of **differing difficulty** for the three interfaces?

Extra Moves: Moves taken to reach solution - minimum moves required

Trial Difficulty: Assessed via minimum moves and trial number

RQ2: How does **planning time** vary across trials of **differing difficulty** for the three interfaces?

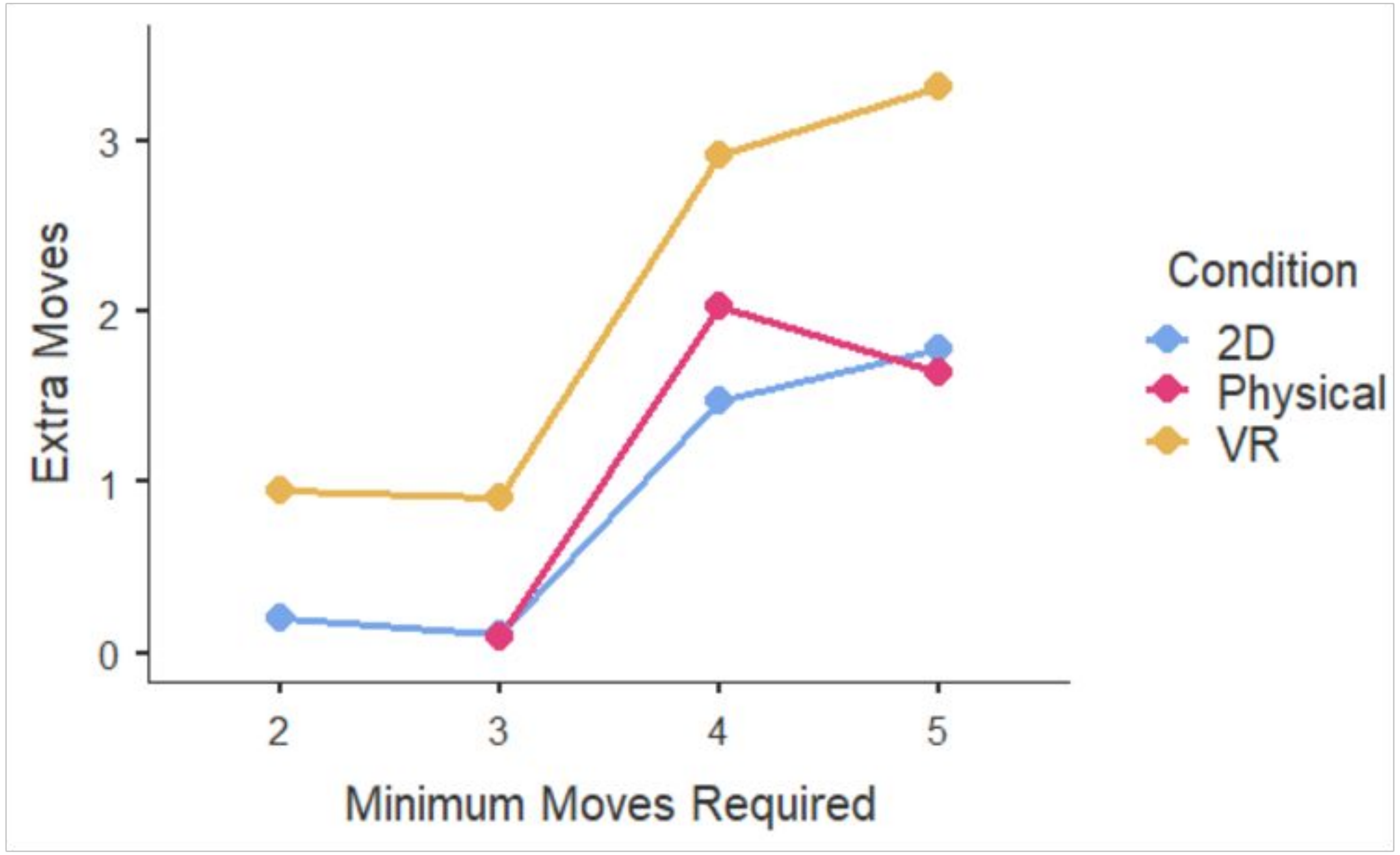
Planning time: Amount of time before make first move.

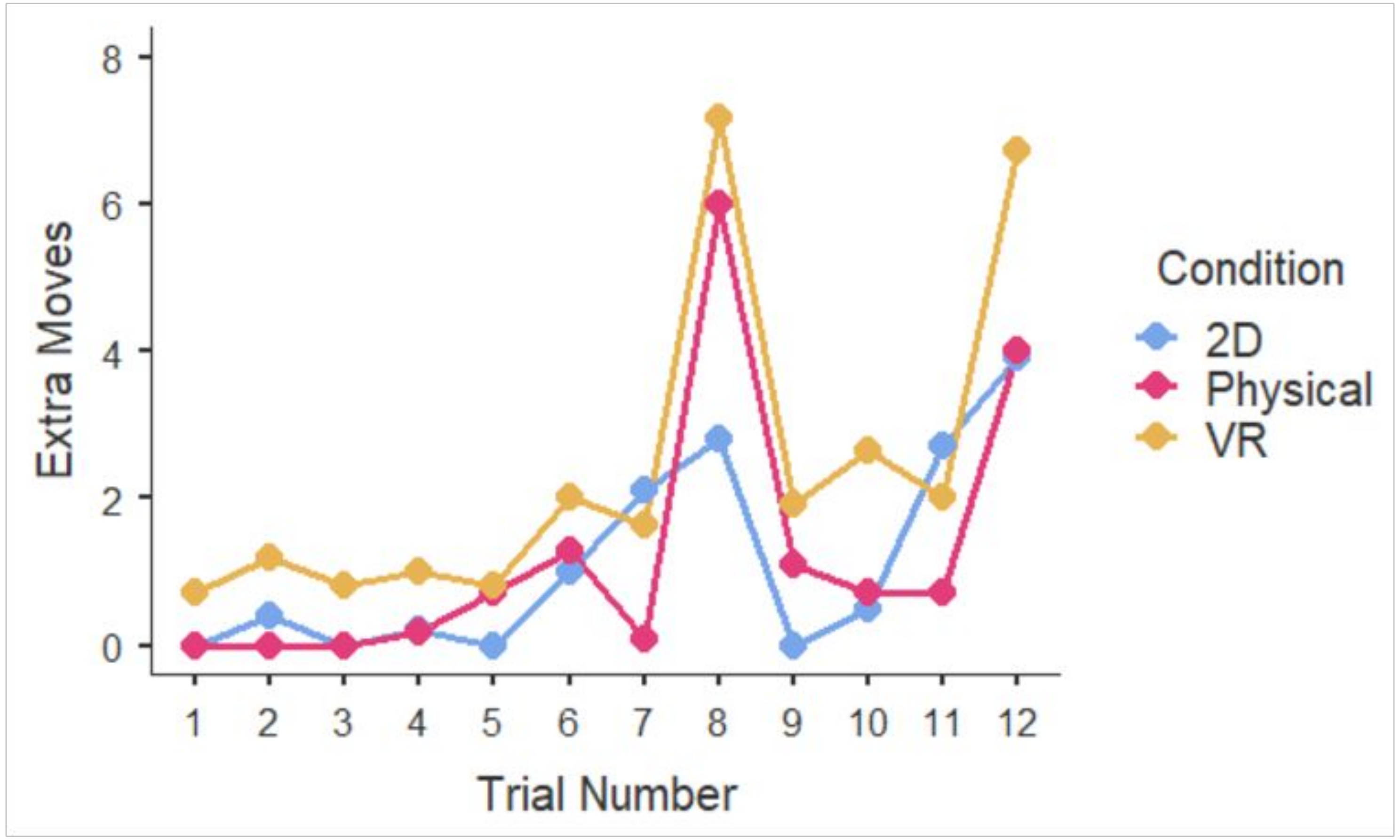
Trial Difficulty: Assessed via minimum moves and trial number

RQ3: What is the relationship between **planning time** and **extra moves** across interfaces while controlling for **trial difficulty**?

RQ4: How does **interface** influence **probability** of solving a trial in the minimum number of moves?

RQ1 — Extra Moves Vary Across Interfaces





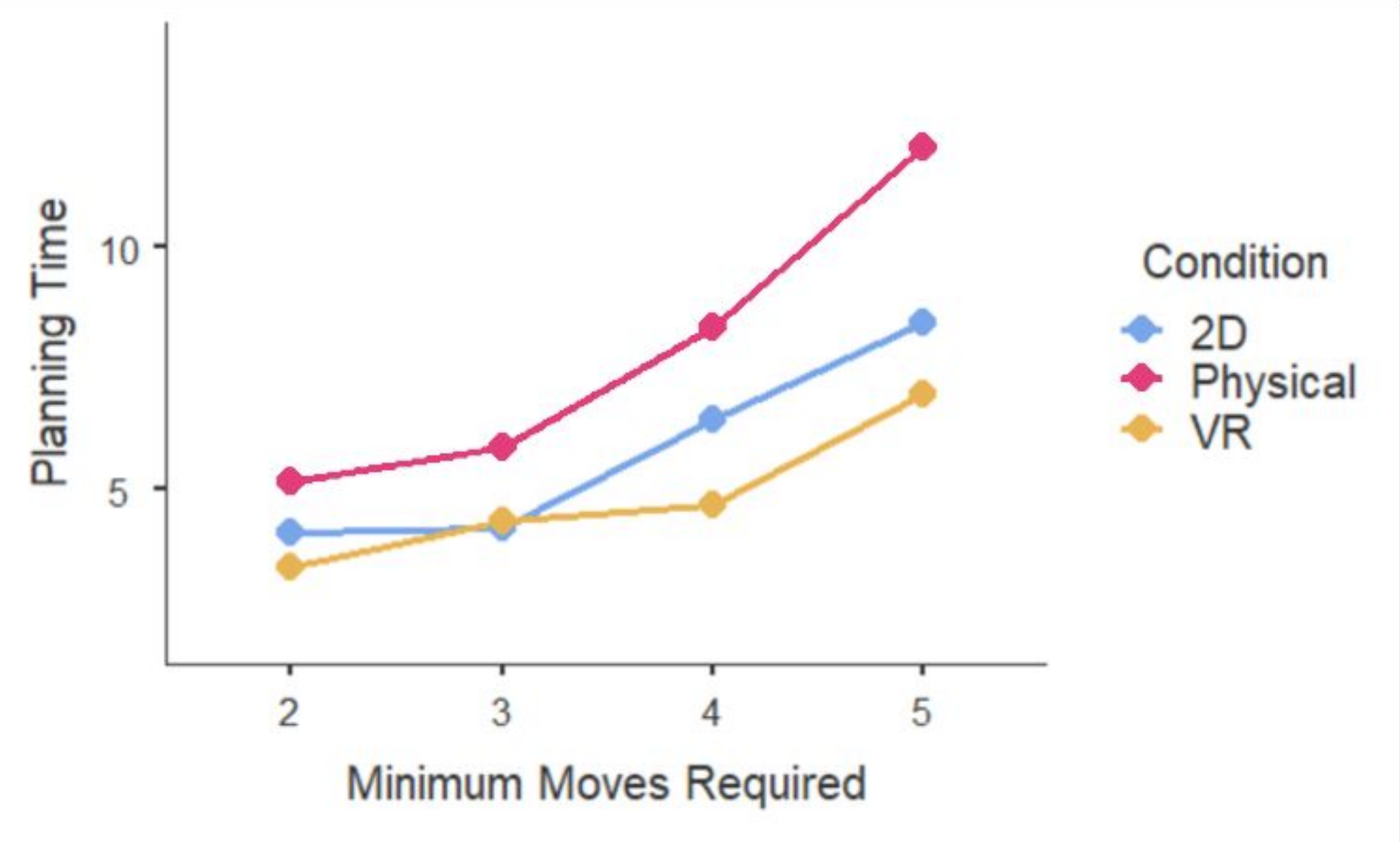
Condition effect: F(2, 33.8) = 3.467, p = .043 (Post hoc: VR vs. 2D p = .084; VR vs. Physical p = .095)

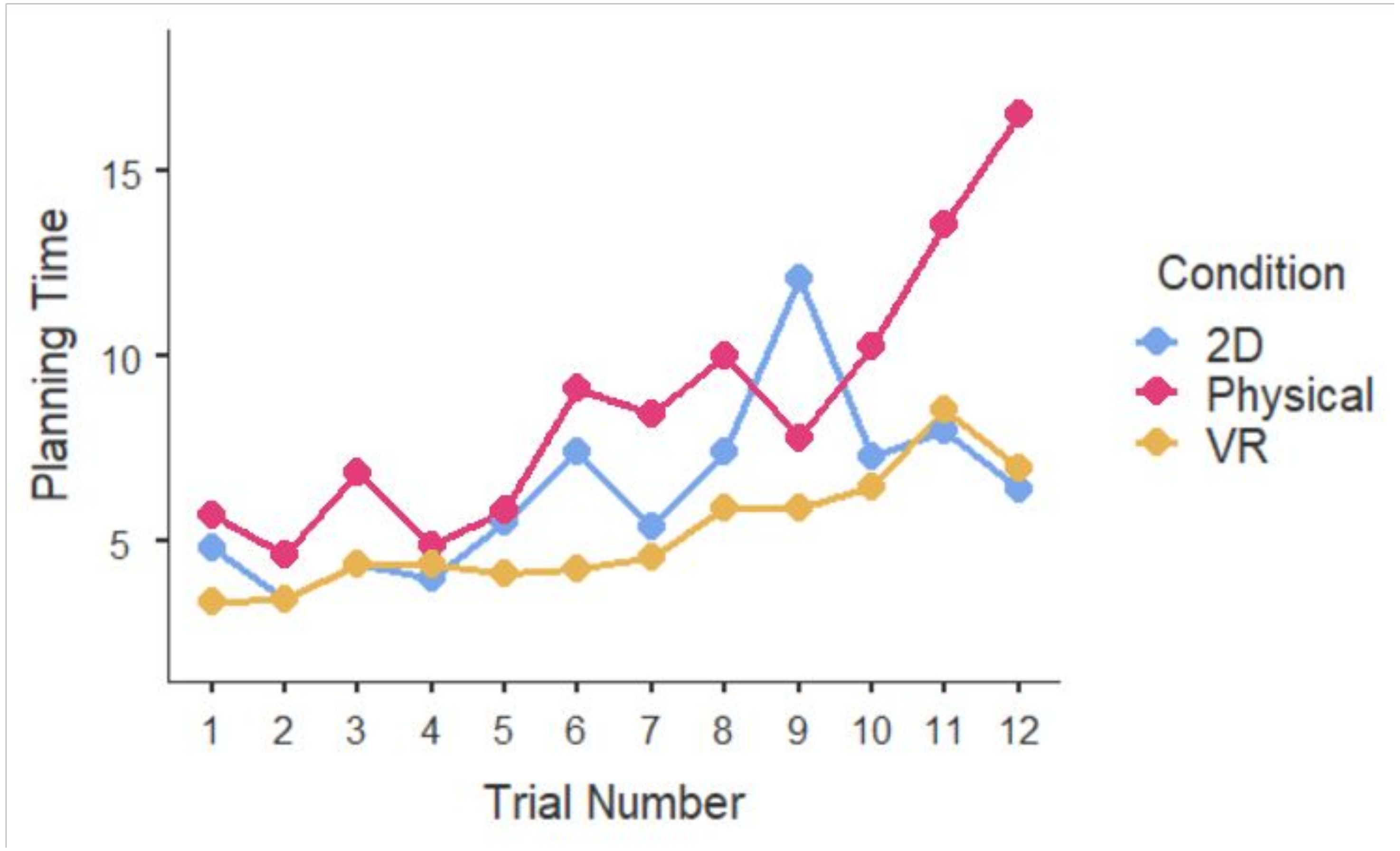
Trial effect (min. moves): F(3, 341.9) = 9.940, p < .001

Condition effect: F(2, 28.9) = 4.44, p = .021 (Post hoc: VR > 2D p = .039; VR vs. Physical p = .056)

Trial effect (number): F(11, 318.0) = 13.01, p < .001

RQ2 — Planning Time Moderated By Difficulty





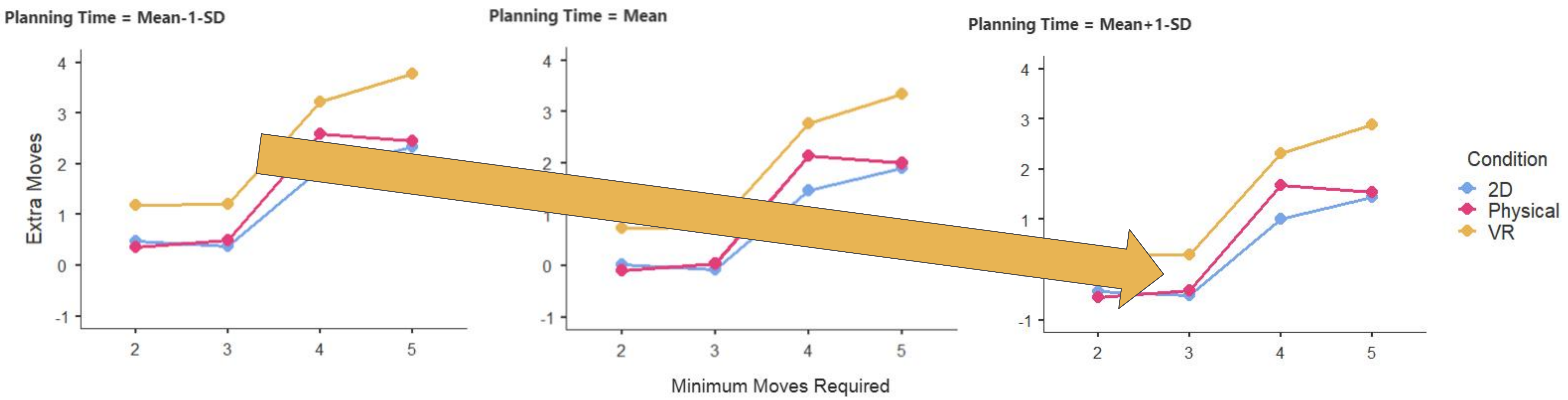
Condition effect: F(2, 31.2) = 2.60, p = .09

Trial effect (min. moves): F(2, 342.1) = 13.513, p < .001

Condition effect: F(2, 22.7) = 3.26, p = .042 (Post hoc: Physical > VR p = .042)

Trial effect (number): F(11, 318.1) = 4.35, p < .001

RQ3 — Planning Time Predicts Total Moves

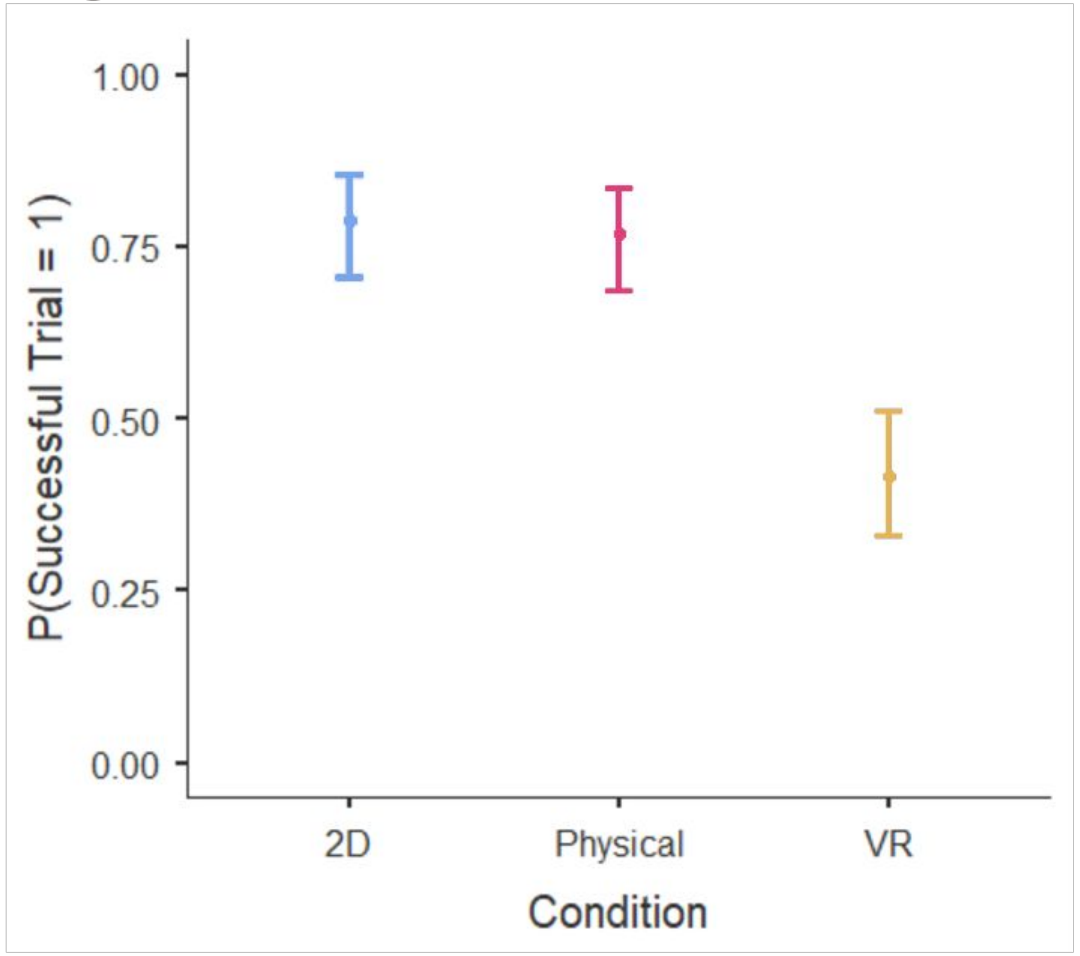


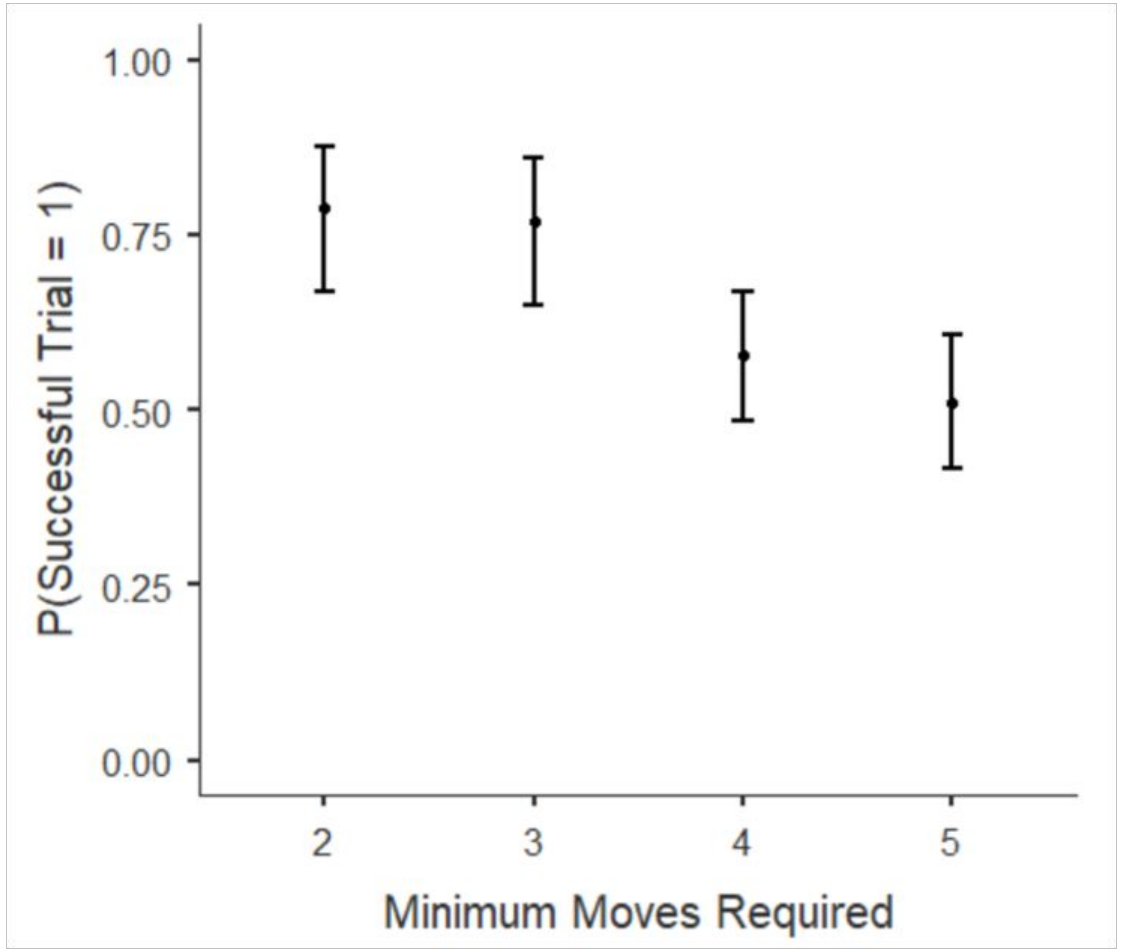
Condition effect: $F(2, 34.5) = 2.335$, $p = .112$

Planning time effect: $F(1, 319.9) = 6.864$, $p = .009$

Trial effect (min. moves): $F(3, 343.6) = 11.813$, $p < .001$

RQ4 — Interface and Task Difficulty Predict Likelihood of Successful Problem Solving

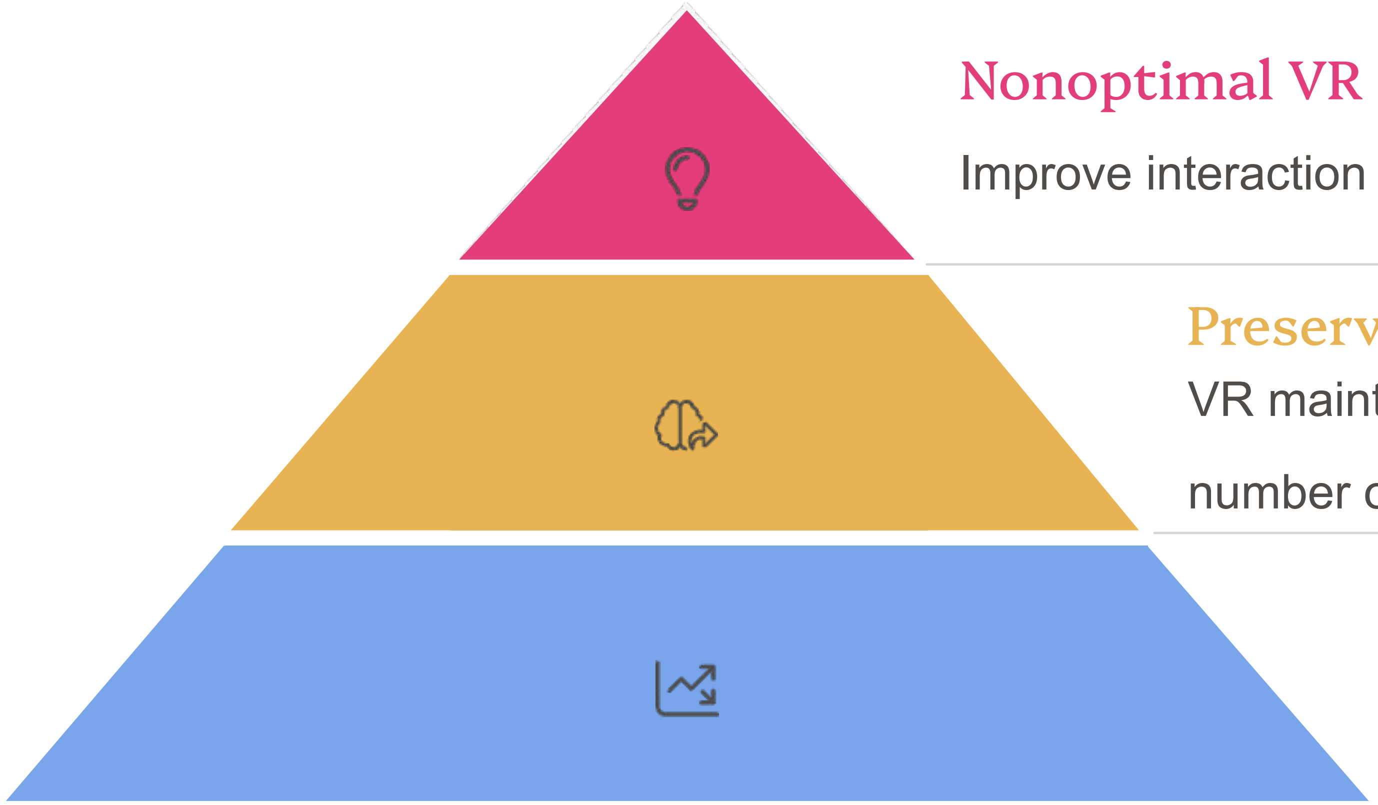




Condition effect: VR:2D $p < 0.001$; OR = 0.194

Trial effect: 4-move trials ($p = 0.006$; OR = 0.366), 5-move trials ($p < 0.001$; OR = 0.279)

Conclusions



Nonoptimal VR Design

Improve interaction design and reduce unnecessary cognitive load

Preserved Gameplay Structure

VR maintains critical TOL structure though evidently more difficult with number of extra moves and planning time

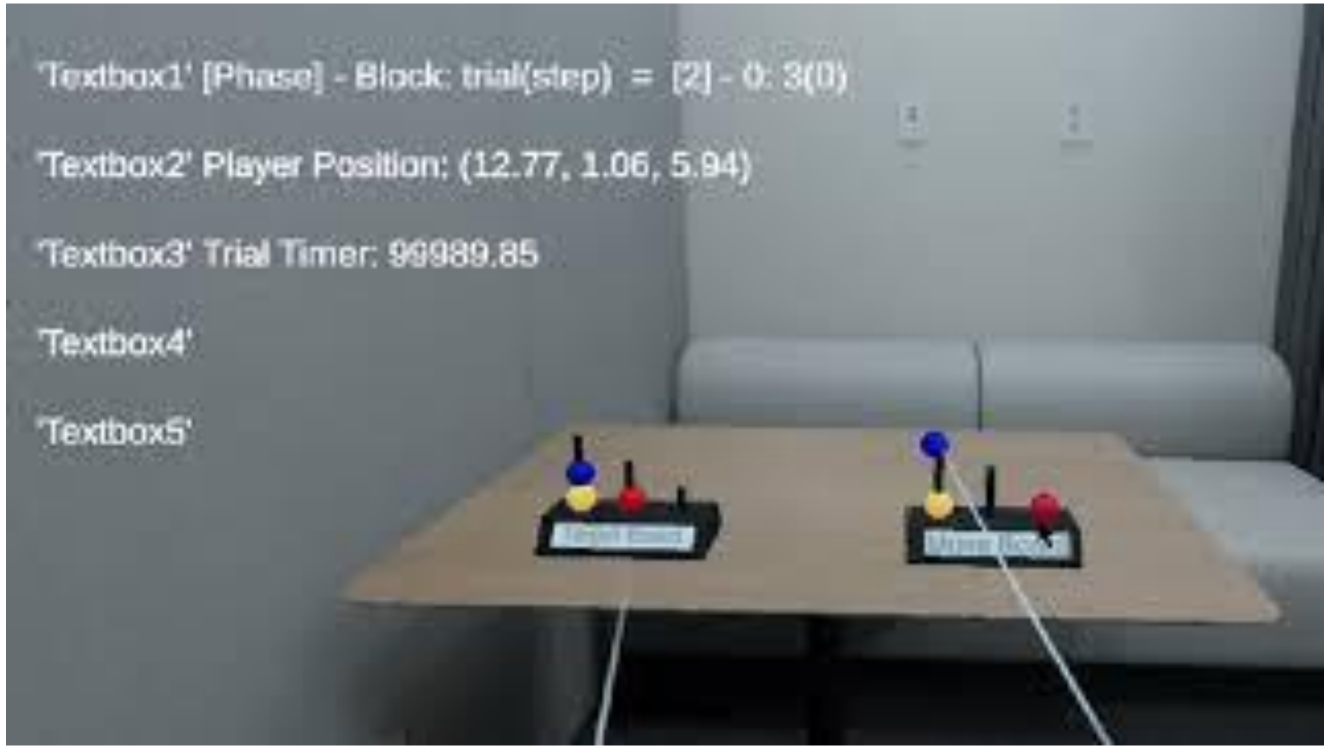
Performance Differences

VR interface initially more demanding but successful pilot

Future Directions

Direction 1: Adjust player position following instruction presentation.

Direction 2: Change ball-board physics to account for gravity effects.



Thank you for your attention.

Any questions?