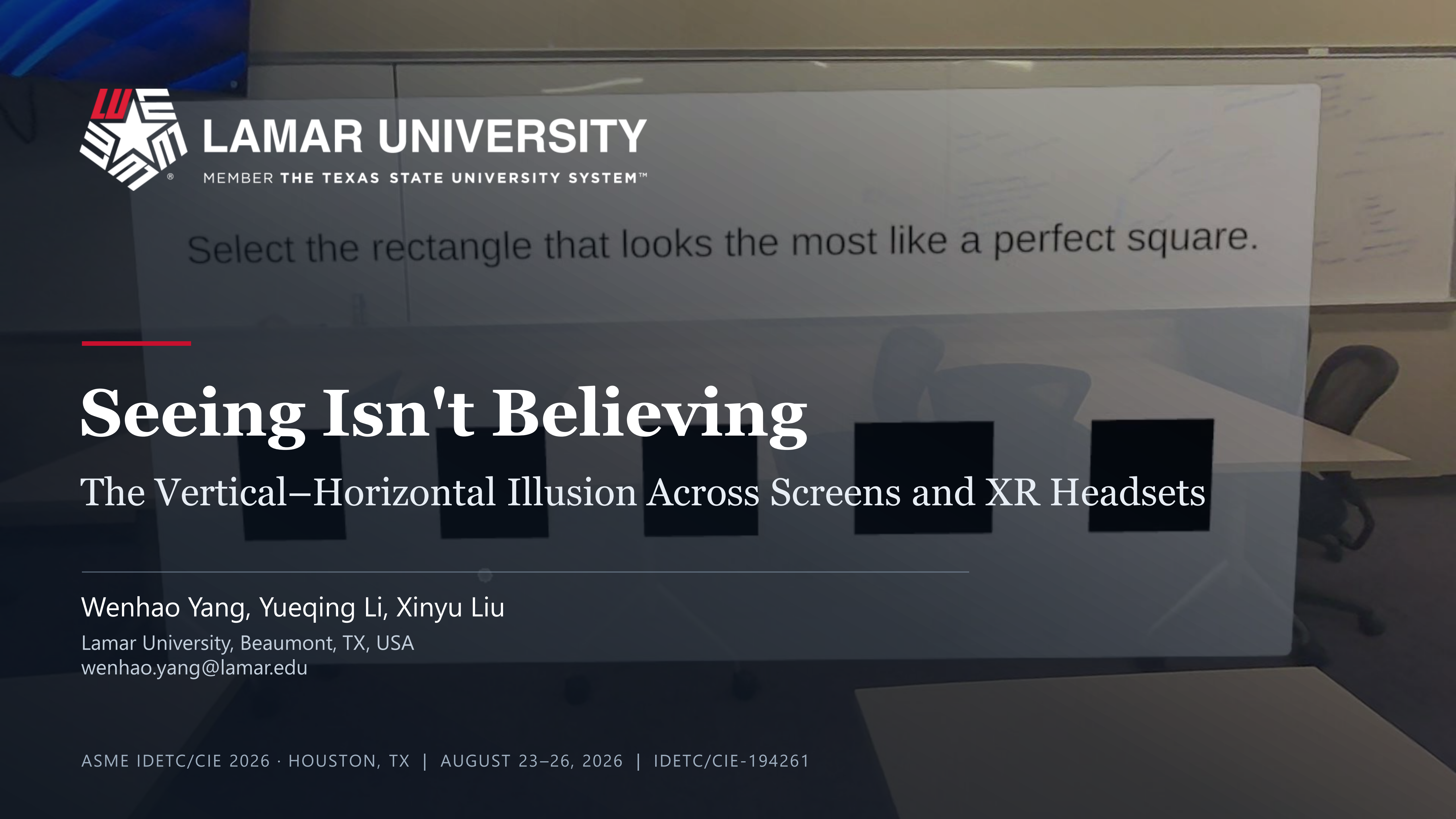

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Seeing Isn't Believing

The Vertical–Horizontal Illusion Across Screens and XR Headsets

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ASME IDETC/CIE 2026 · HOUSTON, TX | AUGUST 23–26, 2026 | IDETC/CIE-194261

Is it a rectangle? Is it a square?

It’s a square.

Squares are the fundamental building blocks.

- Material Design cards
- Facebook posts
- Instagram Posts
- Pinterest pins

A 1:1 post card, as a feed renders it. [1]

[1] B. Chana, "11 optical illusions found in visual design," Prototypr, May 7, 2018. [Online]. Available: https://blog.prototypr.io/11-optical-illusions-found-in-visual-design-295e7ae211b9. [Accessed: Aug. 21, 2026].

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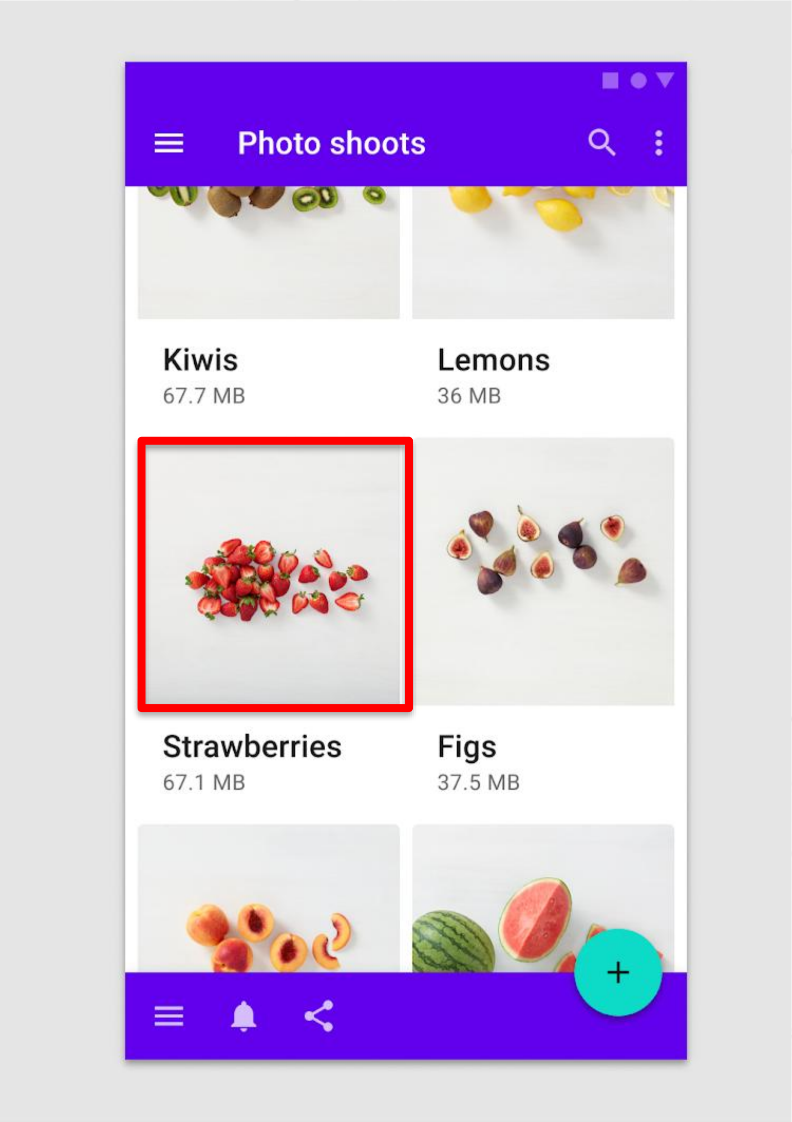

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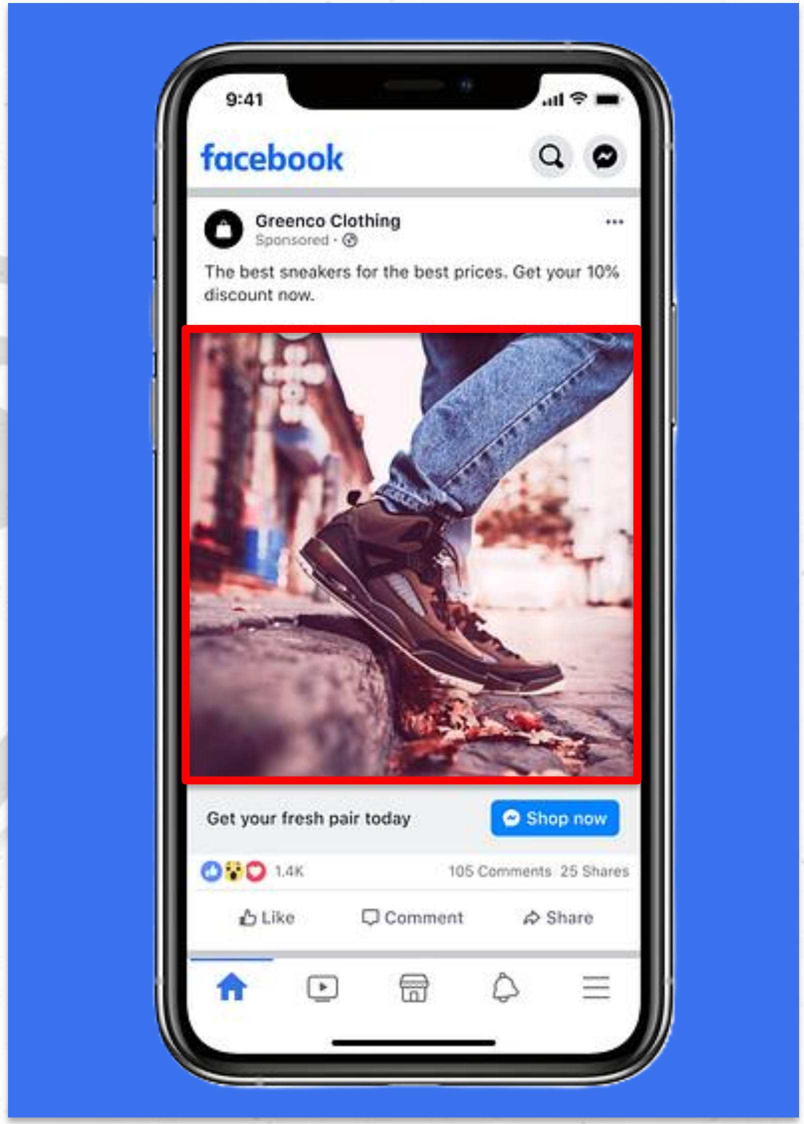

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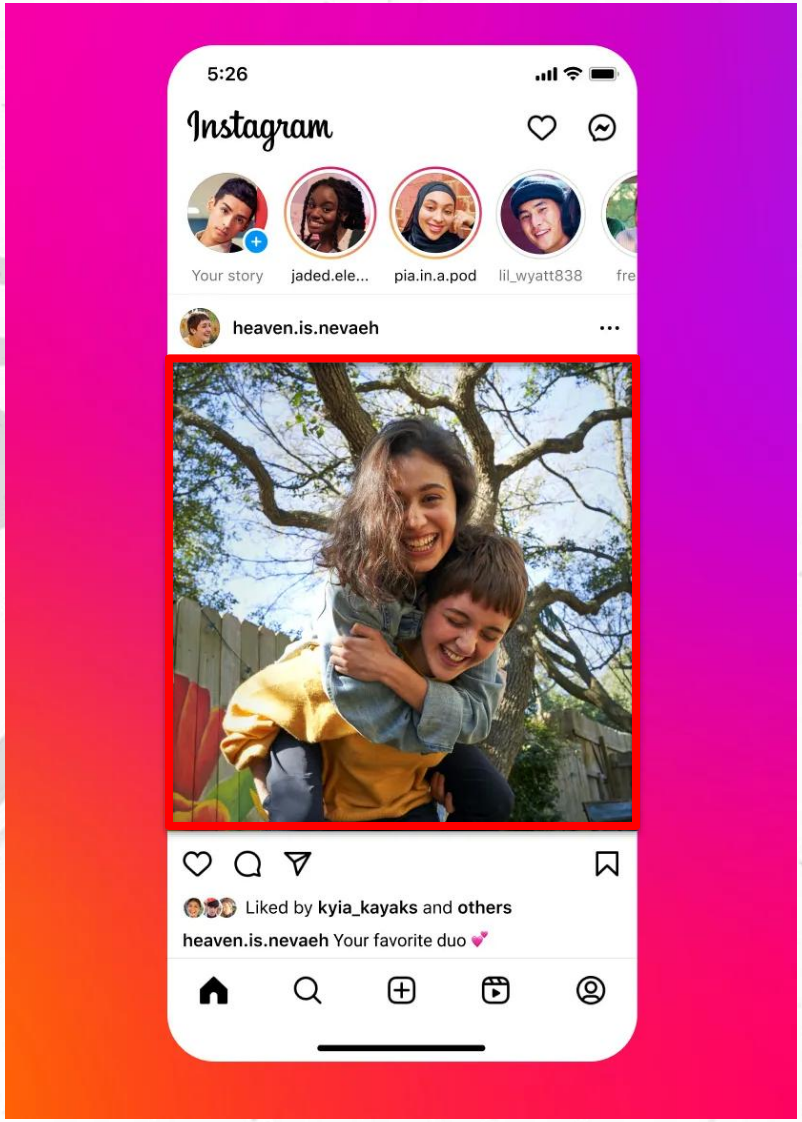

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OPENING

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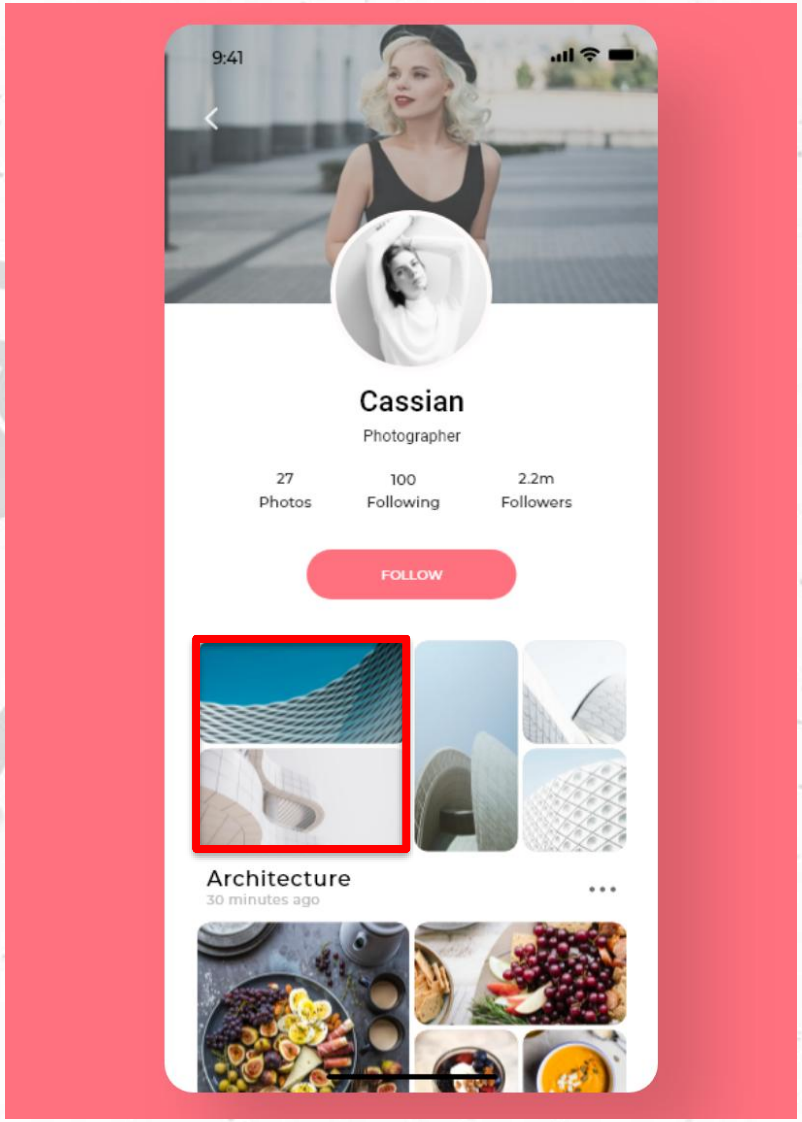
- Pinterest pins



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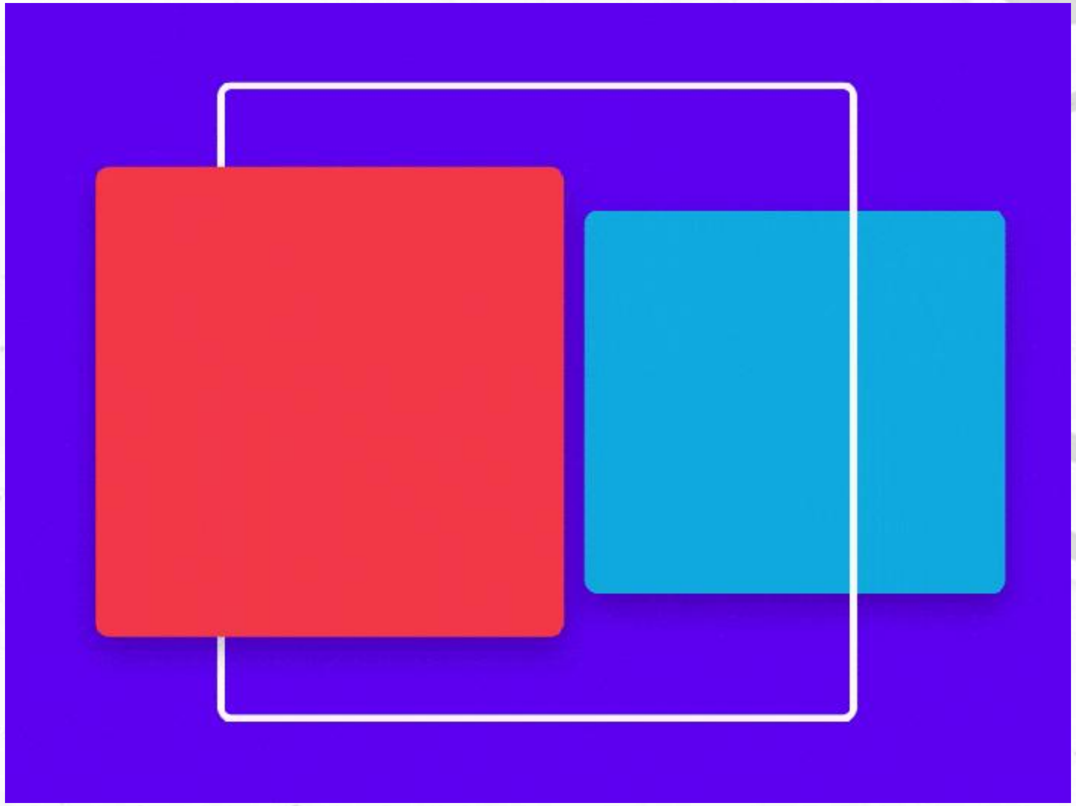
Vertical Horizontal Illusion

The vertical sides appear longer than the horizontal sides.



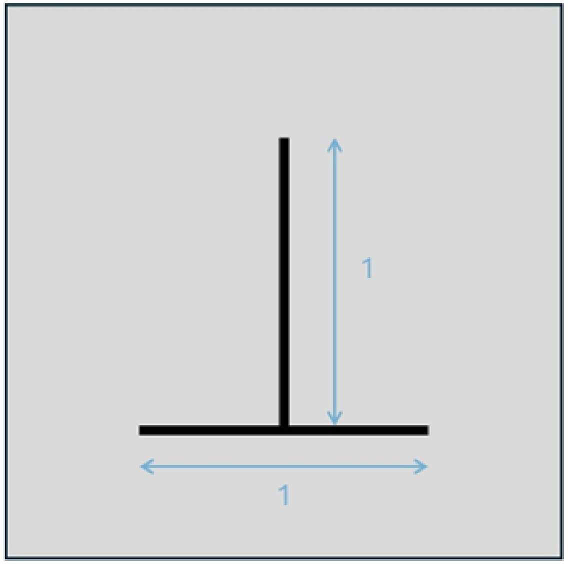
The same square, in a different interface — a 1:1 feed post. [1]

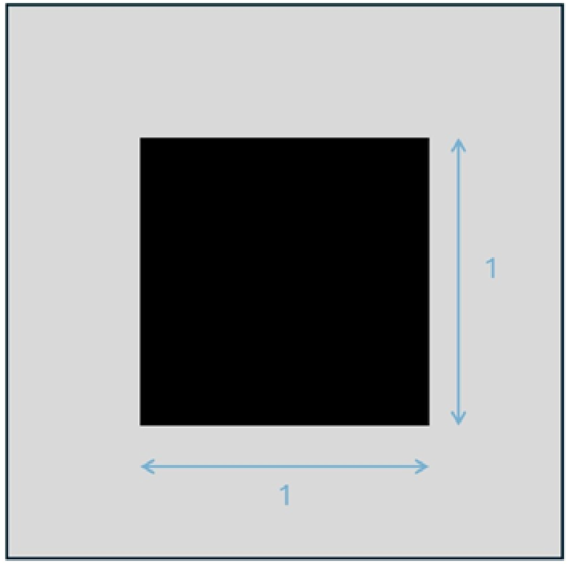
[1] B. Chana, "11 optical illusions found in visual design," Prototypr, May 7, 2018. [Online]. Available: https://blog.prototypr.io/11-optical-illusions-found-in-visual-design-295e7ae211b9. [Accessed: Aug. 21, 2026].

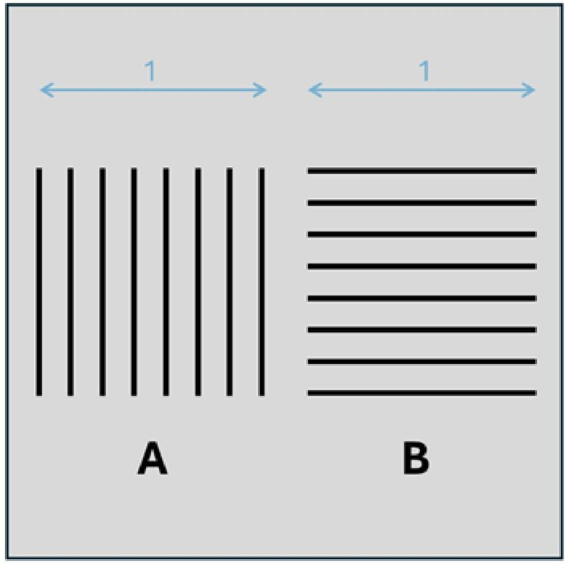
SITUATION

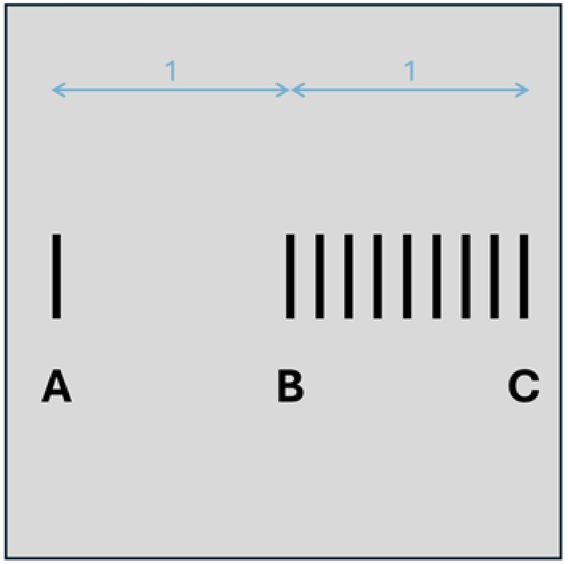
Four ways the eye reliably gets a line wrong

A vertical extent is consistently judged longer than an identical horizontal extent.









1 T and L figures: the vertical segment appears elongated. [2]

2 Squares look taller and narrower than their true proportions.

3 Helmholtz illusion [3]: horizontal elements make a square look taller.

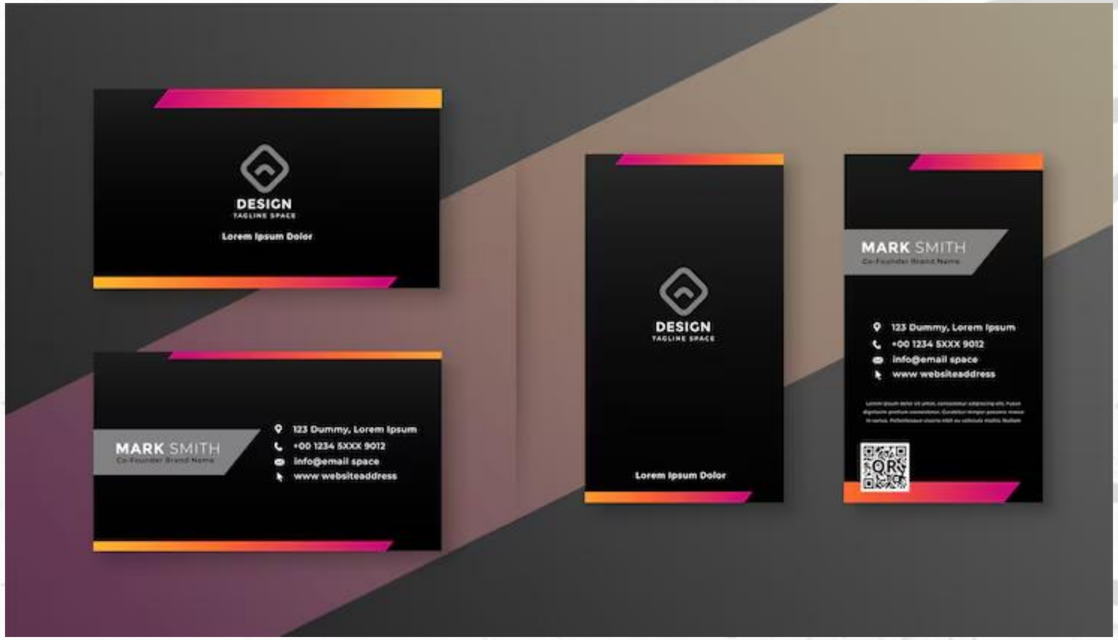
4 Oppel–Kundt [4]: a filled interval is overestimated against an empty one.

[2] Taylor, Crystal Marie. “Visual and haptic perception of the horizontal-vertical illusion.” Perceptual and motor skills Vol. 92 No. 1 (2001): pp. 167–170.
[3] Helmholtz, H von et al. Handbuch der physiologischen Optik. Vol. 3. Leipzig Voss (1867).
[4] Wackermann, Jiří. “The Oppel-Kundt illusion.” Oxford compendium of visual illusion (2017): pp. 303–307.

EVERYDAY EVIDENCE

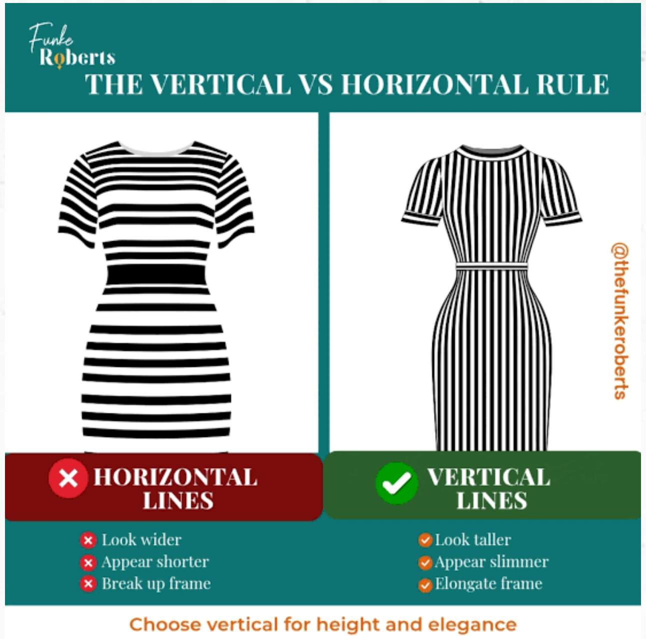
VHI in Everyday Life

Object & Space Perception



Horizontal–Vertical Anisotropy [5]: Vertical orientation makes the same object look larger. *

Fashion & Silhouette Design



A designer's application of the same effect exploited in UI attention cues. *

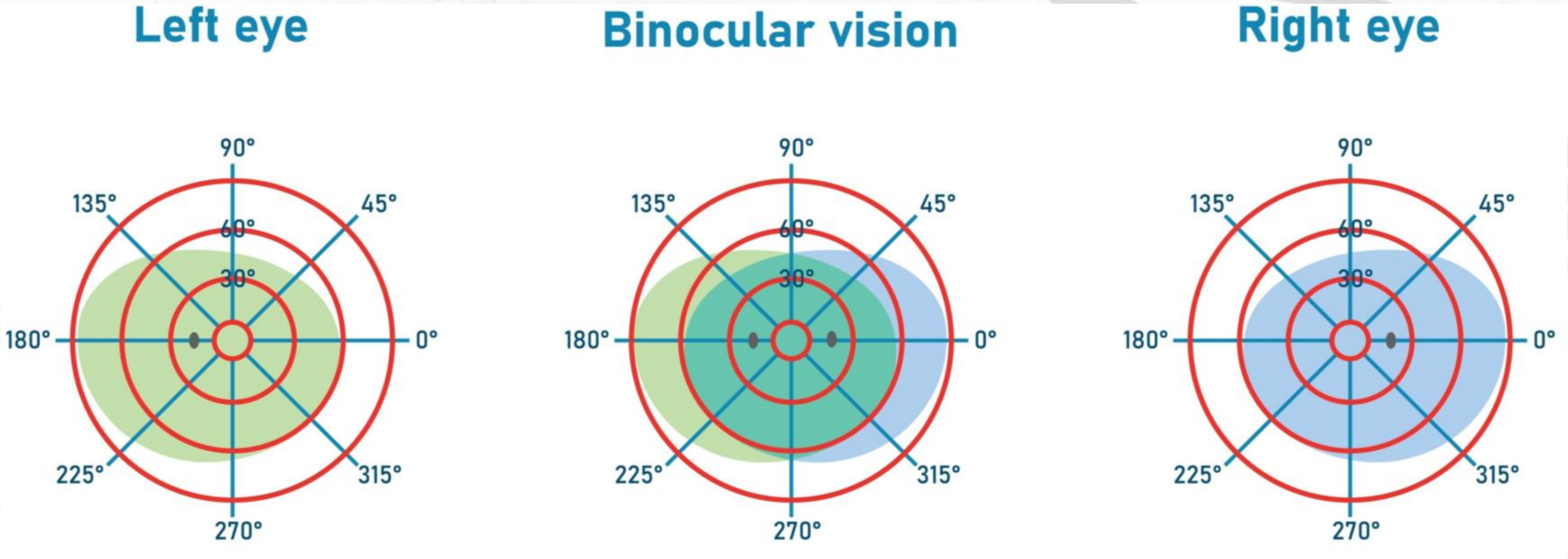
VHI quietly governs how we judge size, distance, and attention

[5] Dopkins, Stephen and Galyer, Darin. “Horizontal–vertical anisotropy with respect to bias and sensitivity.” Journal of Vision Vol. 20 No. 7 (2020): pp. 1–1.

* Images are from Internet.

Why the illusion happens

Classic psychophysics attributes VHI to anisotropies in the binocular visual field.



A framing effect

- Horizontal asymmetry creates a physical frame.
- Reducing asymmetry attenuates the illusion. [6]

Gaze and Context

- Fixation stability modulates VHI. [7]
- Greater retinal-image stability = larger effect.
- Contextual cues amplify the bias.

Altering visual-field boundaries, surrounding frames, or gaze stability systematically amplifies or attenuates VHI [6, 7, 8].

[6] Prinzmetal, William and Gettleman, Laurie. "Vertical-horizontal illusion: One eye is better than two." Perception & Psychophysics Vol. 53 (1993): pp. 81–88.
[7] Chouinard, Philippe A., Peel, Hayden J. and Landry, Oriane. "Eye-Tracking Reveals that the Strength of the Vertical-Horizontal Illusion Increases as the Retinal Image Becomes More Stable with Fixation." Frontiers in Human Neuroscience Vol. 11 (2017): p. 143.
[8] Mikellidou, Kyriaki and Thompson, Peter. "The vertical-horizontal illusion: Assessing the contributions of anisotropy, abutting, and crossing to the misperception of simple line stimuli." Journal of Vision Vol. 13 No. 8 (2013): p. 7.

COMPLICATION

From 2D to Spatial XR: Perceptual Challenges

Desktop monitors

Fixed viewing distance, negligible optical distortion.

Smartphones

Short viewing distance, hand-held framing.

XR head-mounted displays

Immersive, near-eye spatial environments with fully configurable rendering geometry.

Hardware-Induced Perceptual Variable

Near-eye optics introduce a cocktail of distortions: [9]

- Asymmetric Horizontal/Vertical FOV
- Lens-induced geometric warping (distortion)
- Vergence-accommodation conflicts (VAC)

Measured consequences

Recent VR studies show that optical distortion, FOV limits and rendering characteristics systematically bias perceived geometry [10, 11].

The Critical Knowledge Gap How the classical VHI behaves across different modern XR devices remains completely unknown.

[9] Feld, Nico and Pointecker, Fabian. “Perceptual Issues in Mixed Reality: A Developer-oriented Perspective on Video See-Through Head-Mounted Displays.” (2025)
[10] Tong, Jonathan, Allison, Robert S and Wilcox, Laurie M. “Optical distortions in VR bias the perceived slant of moving surfaces.” (2020): pp. 73–79.
[11] Guan, Phillip, Mercier, Olivier, Shvartsman, Michael and Lanman, Douglas. “Perceptual Requirements for Eye-Tracked Distortion Correction in VR.” SIGGRAPH’22 (2022)

RESEARCH QUESTION

Does VHI survive XR — and can design attenuate it?

1 Does the Vertical–Horizontal Illusion persist within modern XR head-mounted displays that use stereoscopic 3D rendering, and if so, to what extent?

2 Can UI design interventions reduce the magnitude of VHI in XR interfaces?

THREE CONTRIBUTIONS

A unified framework

A perceptual square-matching task applied across mobile, monitor and HMD displays in a within-subject study with 24 participants.

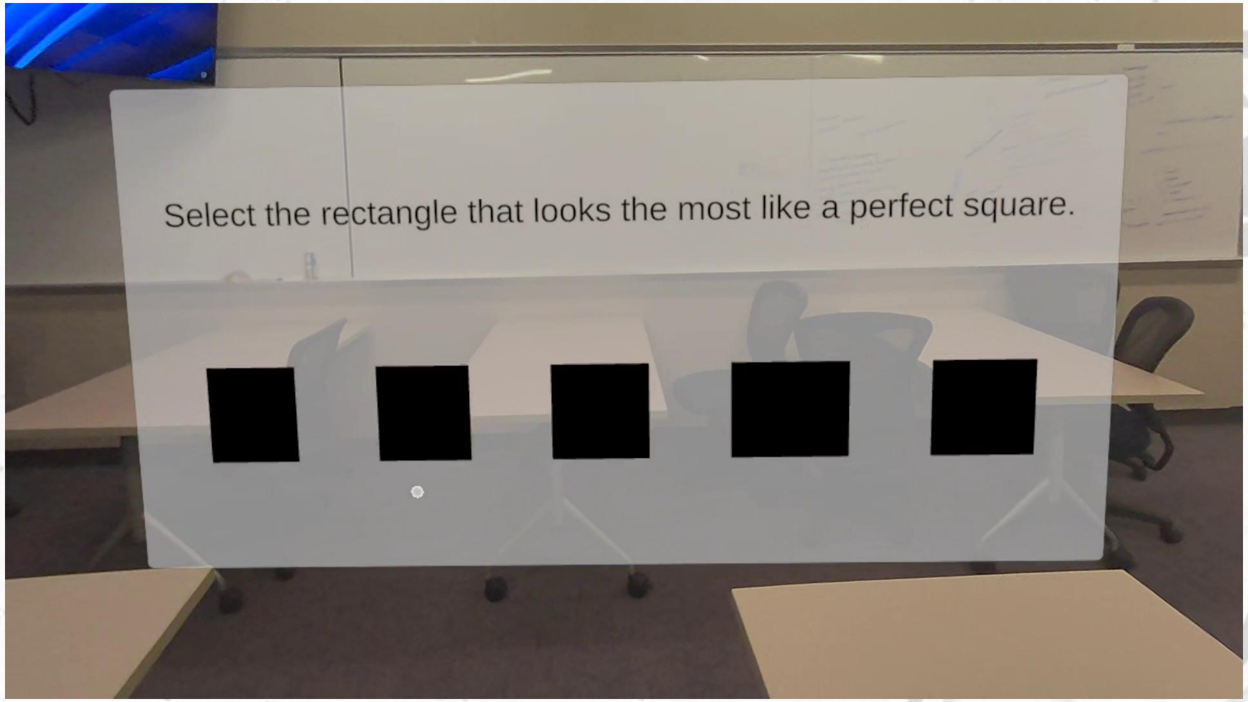
AR interface variants

A set of AR interface variations designed and evaluated to test whether specific UI strategies attenuate VHI in XR environments.

Design implications

Empirical evidence supporting the mitigation of perceptual anisotropies in future XR interface development.

Square Recognition Test (SRT) system

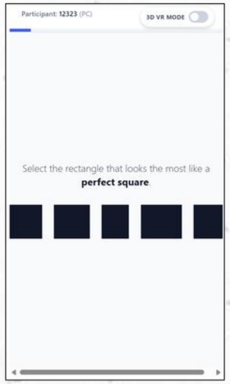


THE CANDIDATE SET R, DRAWN AT TRUE ASPECT RATIO

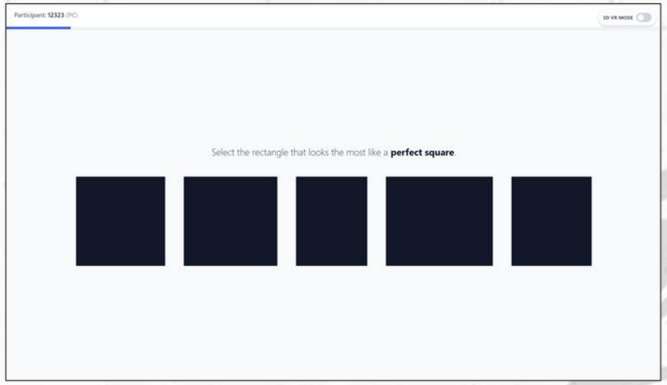
1. Five black-filled rectangles are displayed horizontally on the screen.
2. Their aspect ratios are drawn without replacement from *R* and shown in randomized order （a trial need not contain a square）.
3. The instruction is fixed: select the rectangle that “looks most like a perfect square.”
4. Ten trials per session, with no correctness feedback, to limit learning effects.
5. Rectangle height is held constant; aspect ratio is manipulated by width alone.
6. Each device uses its native modality: mouse on PC, touch on mobile, hand gesture in AR.

Square Recognition Test — live trial captured through the AR pass-through view.

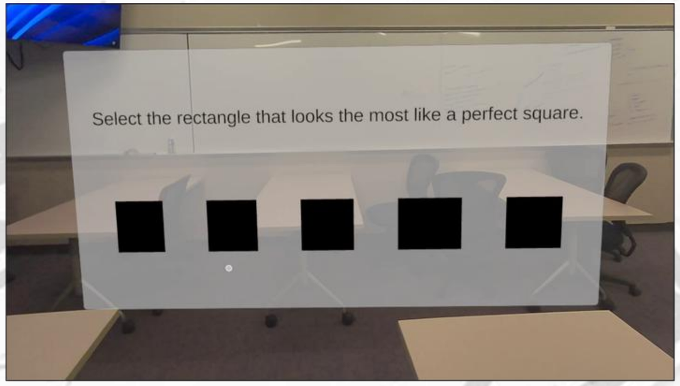
Devices and Participants



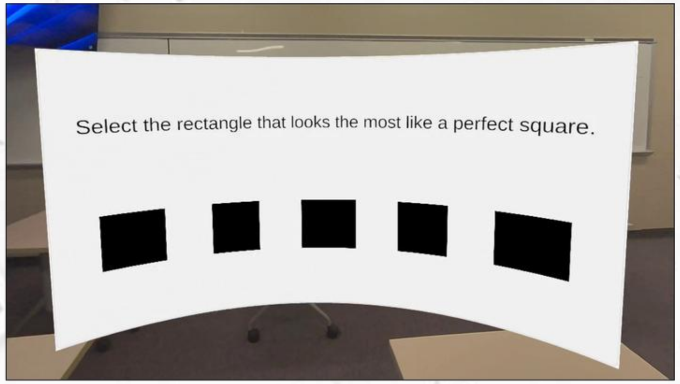
(1) Mobile



(2) PC Monitor



(3) AR HMD with flat canvas



(4) AR HMD with curved canvas

Mobile phone

6.1-inch OLED touchscreen, held at roughly 35 cm.

PC

27-inch monitor, viewed at approximately 60 cm.

AR — flat canvas

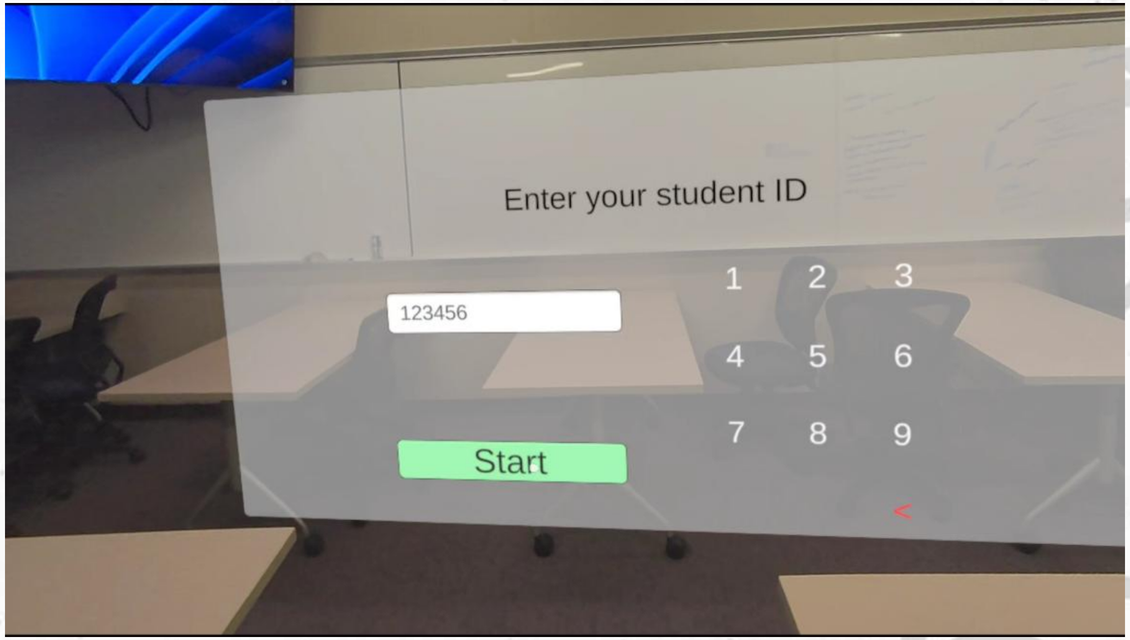
Meta Quest 3S pass-through, horizontal field of view ≈ 97°, virtual focal distance ≈ 2 m.

AR — curved canvas

Same headset and settings; rendering canvas curved at radius 2 m.

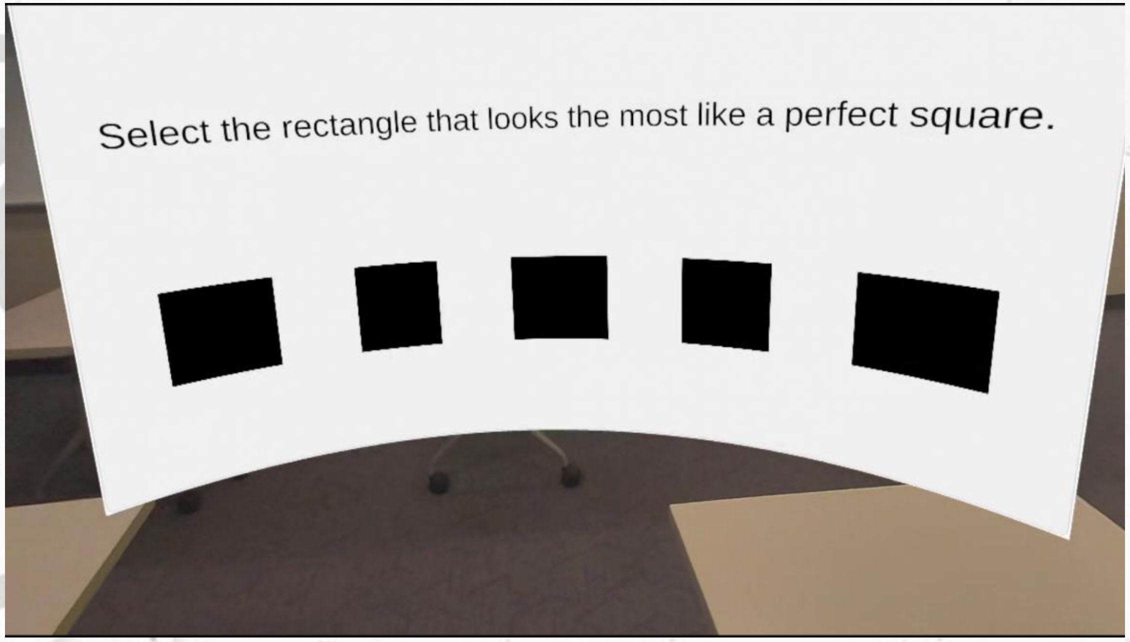
Within-subject design: every participant completed all four conditions; condition order randomized and counterbalanced.
24 participants and 240 trials per condition. Informed consent obtained; protocol approved under Lamar IRB-FY26-141.

Two AR canvases



AR — flat canvas

Meta Quest 3S pass-through, horizontal field of view ≈ 97°, virtual focal distance ≈ 2 m.



AR — curved canvas

Same headset and settings; rendering canvas curved at radius 2 m.

Same headset, same settings, same task, same content — only the rendering surface changes.

* Screen capture of the SRT running in the Quest 3s headset on both rendering canvases.

Five measures, and a non-parametric analysis

PSE

The participant-level median chosen aspect ratio — the point where “too tall” and “too wide” become indistinguishable.

Bias

PSE − 1. Positive values mean a wider-than-tall preference.

Accuracy

Share of valid trials in which the true square was chosen.

$$\text{Accuracy} = \frac{N_{\text{correct}}}{N_t - N_{\text{void}}}$$

Response time

Participant-level median per-trial duration, in milliseconds.

Variability

Within-participant SD of the chosen aspect ratios.

ANALYSIS PATH

Shapiro-Wilk showed non-normal PSE on at least one device (all $p < 0.05$) — so every inference below is non-parametric.

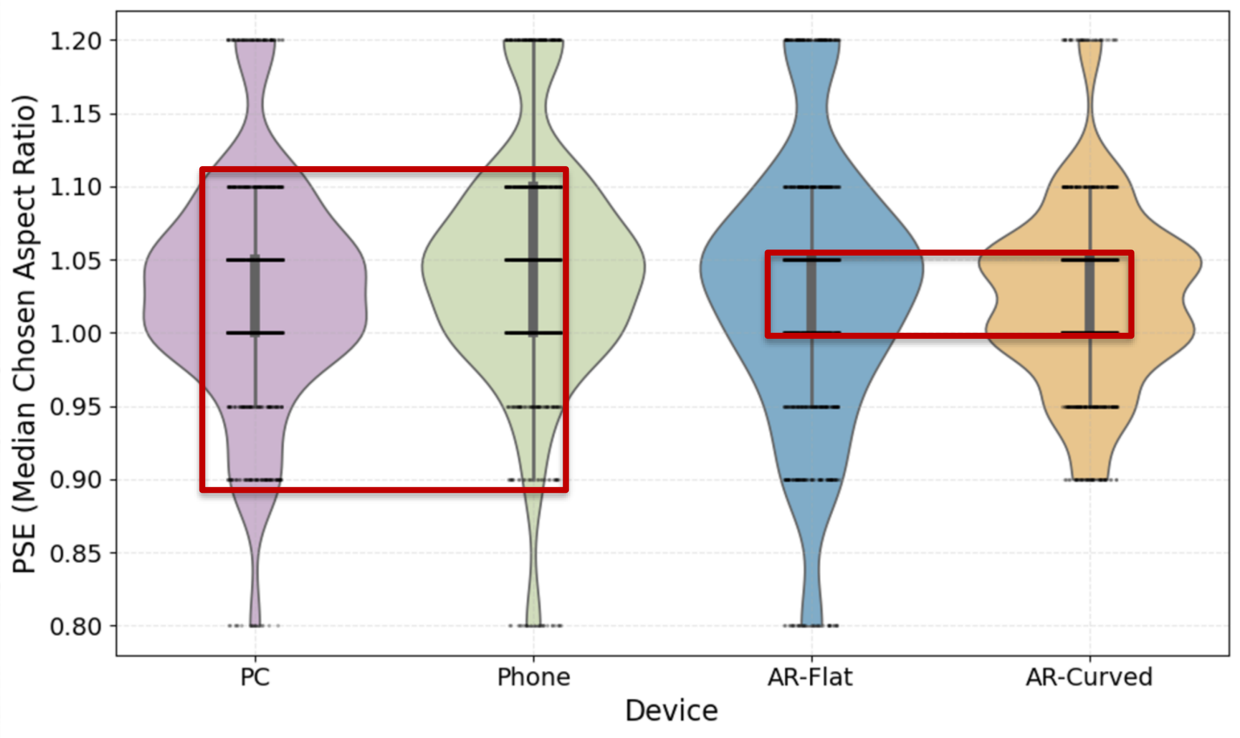
Across-device PSE: Kruskal-Wallis. Pairwise contrasts: Mann-Whitney U with effect size

$$r = \frac{Z}{\sqrt{N}}$$

Accuracy and response time: Friedman, with Holm-Bonferroni corrected Wilcoxon follow-ups. Uncertainty: mean ±1.96 SE; Wilson intervals.

```
no true-square option → excluded from accuracy
RT < 0.2 s → excluded, under 1% of responses
RT > Q3 + 3 × IQR → excluded per participant
```

Across-Device Point of Subjective Equality (PSE)



Participant-level PSE by device. All four distributions sit above unity. N = 24 per condition.

+2–4%

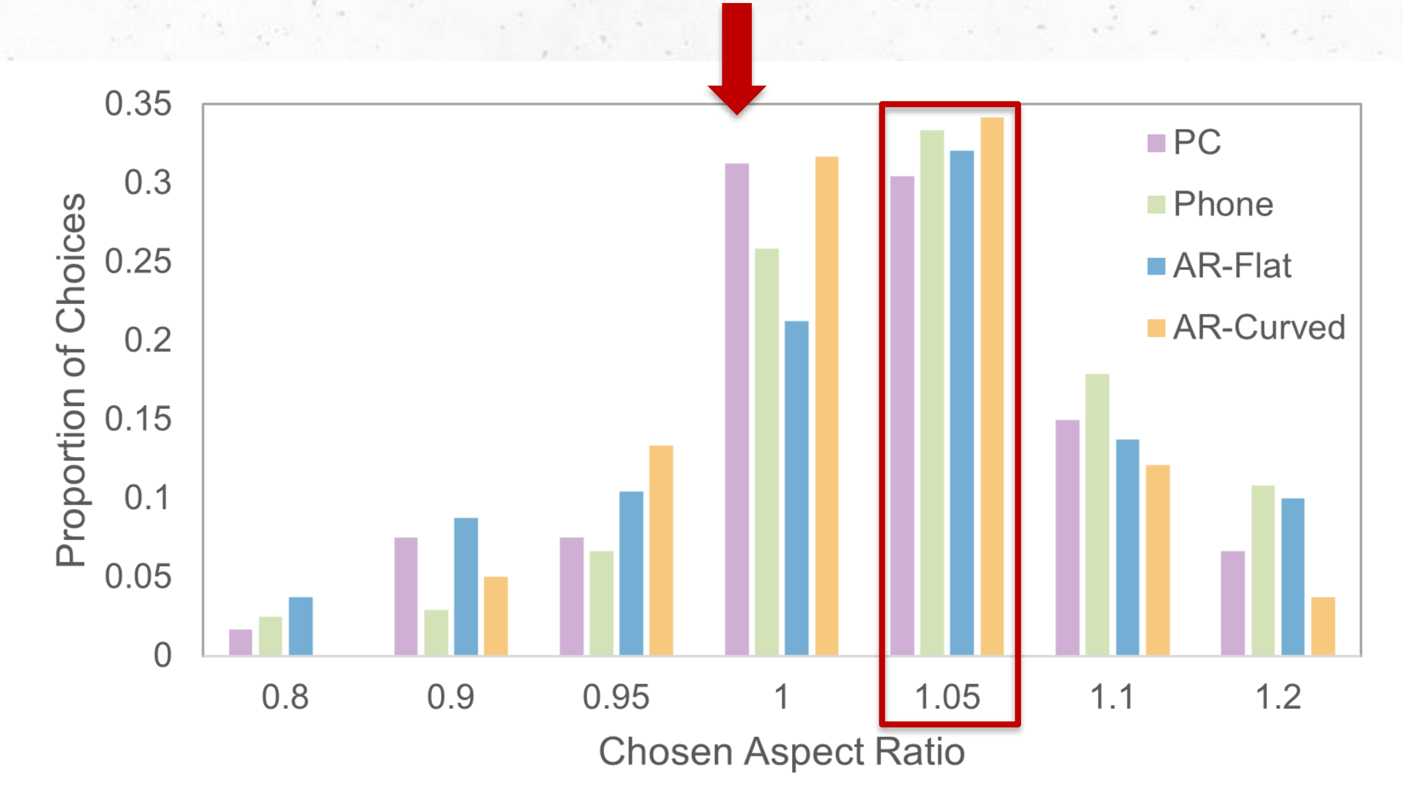
PSE 1.019–1.044 across all four device conditions

A rectangle must be slightly wider than tall before it looks square — on every display. The AR distributions are the more compact pair; PC and Phone spread wider.

Measure	PC	Phone	AR-Flat	AR-Curved
Participants	24	24	24	24
Sample size	240	240	240	240
PSE	**1.0353**	**1.0438**	**1.0263**	**1.0188**
Accuracy (mean)	0.412	0.323	0.252	0.406

Kruskal-Wallis: no significant device effect on PSE.

The most-chosen rectangle is 5% wider than square



Distribution of chosen aspect ratios, by device.

`1.05`

dominates every condition except PC — peaking at 0.33 in AR-Curved and 0.30 on Phone.

`1.00`

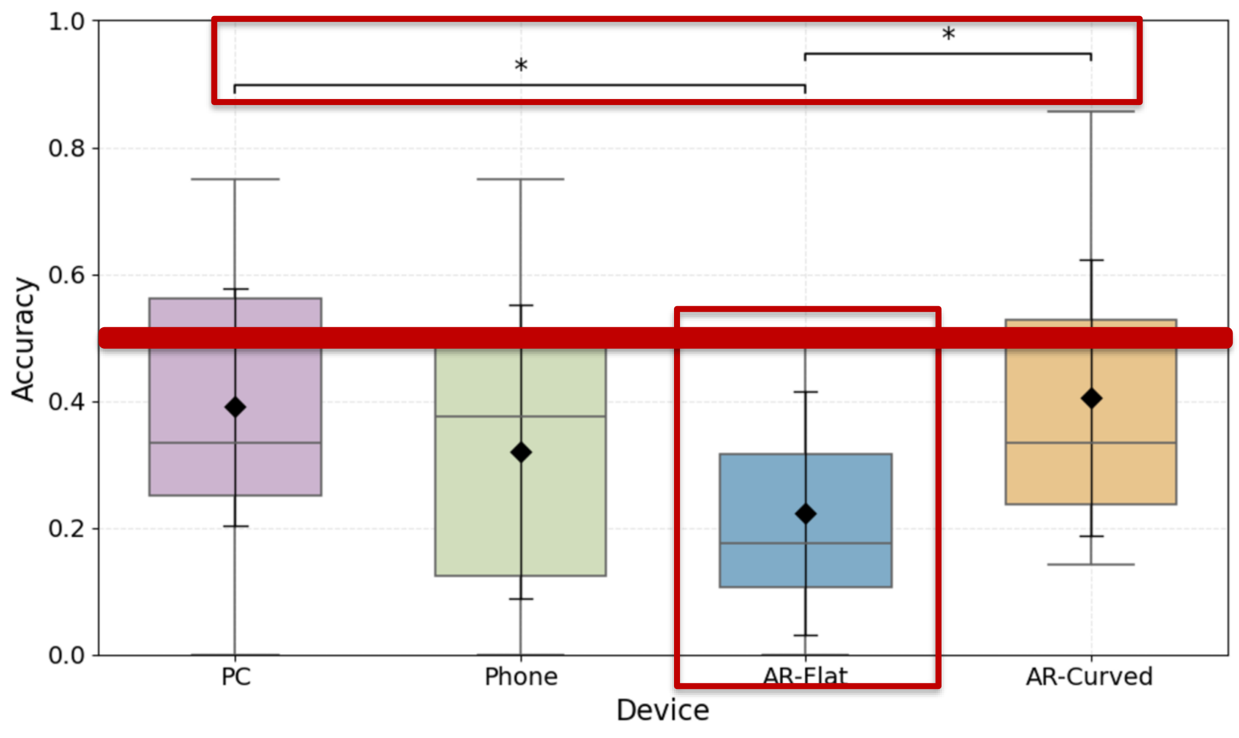
is the PC exception: its peak sits at the objective ratio, at 0.31.

`0.80–0.90`

are rarely chosen anywhere — each under 8% of responses.

AR-Curved also declines most steeply toward the extremes, with notably fewer selections at 1.20 than Phone or AR-Flat.

Accuracy is not uniform — AR-Flat is the trough



True-square hit rate by device, computed on valid trials only.

0.252

AR-Flat hit rate — vs 0.412 on PC and 0.406 on AR-Curved

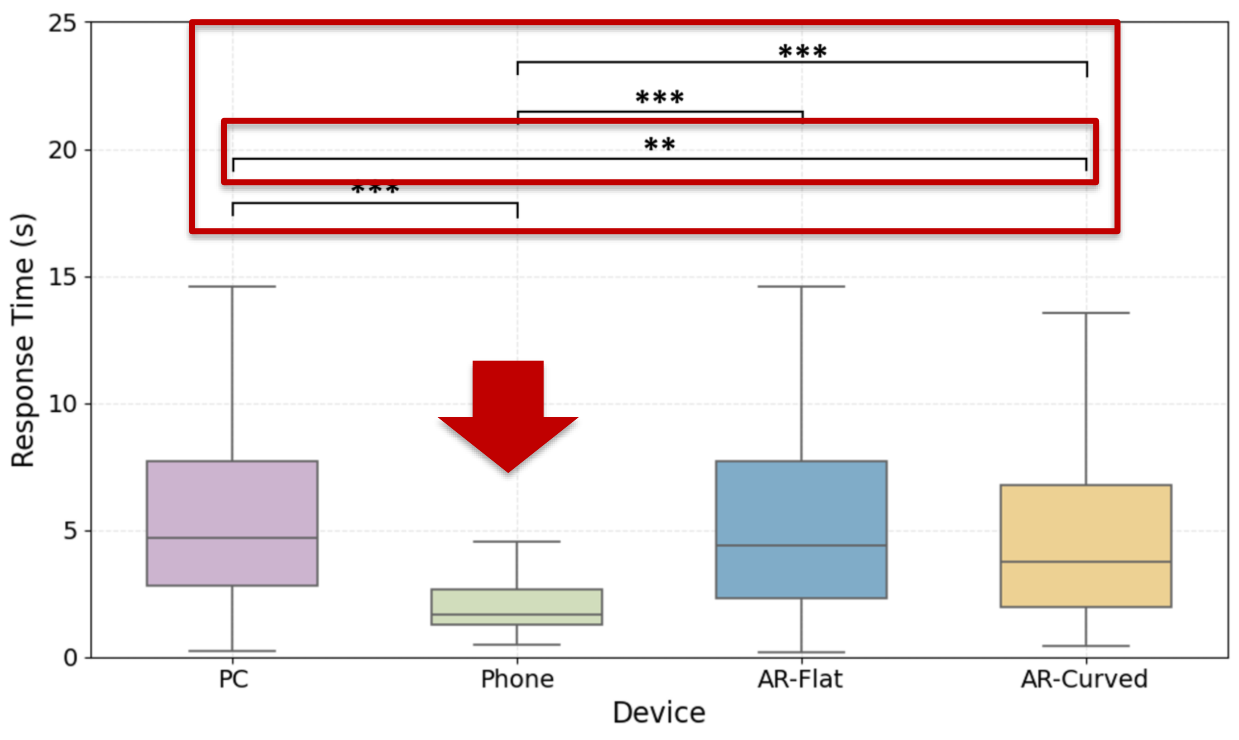
```
Friedman χ²(3) = 8.216, p = 0.0418
Kendall's W = 0.119 (small-to-moderate)

PC vs AR-Flat p = 0.018 large
AR-Flat vs AR-Curved p = 0.0336 large
all other pairs: p ≥ 0.26 (Holm-corrected)
```

- Hit rate is low everywhere
- even the best condition is under half
- the flat AR canvas is significantly worse than PC and than curved.

RESULT 3 · RESPONSE TIME

Phone is fastest, PC slowest, curved beats flat



Cleaned response-time distributions by device, N = 186 paired.

MEDIAN RESPONSE TIME, CLEANED

Phone	1.68 s
AR — curved canvas	3.73 s
AR — flat canvas	4.40 s
PC	4.67 s

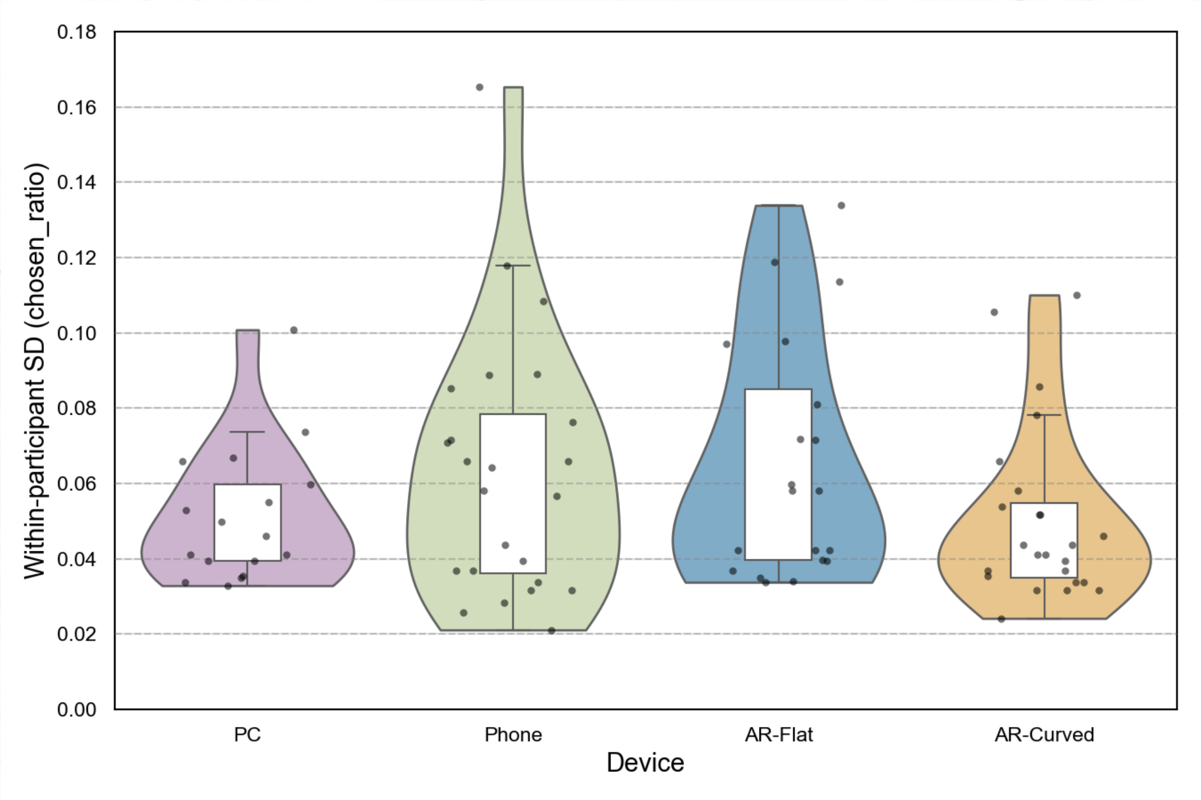
Friedman $\chi^2(3) = 134.79$, $p < 10^{-28}$
Kendall's $W = 0.242$ (moderate)

Phone vs PC $p \approx 2.85\text{e-}21$ $r \approx .708$
Phone vs AR-Flat $p \approx 6.63\text{e-}17$ $r \approx .626$
Phone vs AR-Curved $p \approx 1.30\text{e-}16$ $r \approx .619$
AR-Curved vs PC $p = 0.0027$ $r \approx .243$

AR-Flat vs AR-Curved $p = 0.0595$ – not significant

Phone clusters tightly at low response times;
PC and both AR conditions are right-skewed.

Responding is consistent — slightly less so in AR



Within-participant SD of chosen aspect ratios, by device.

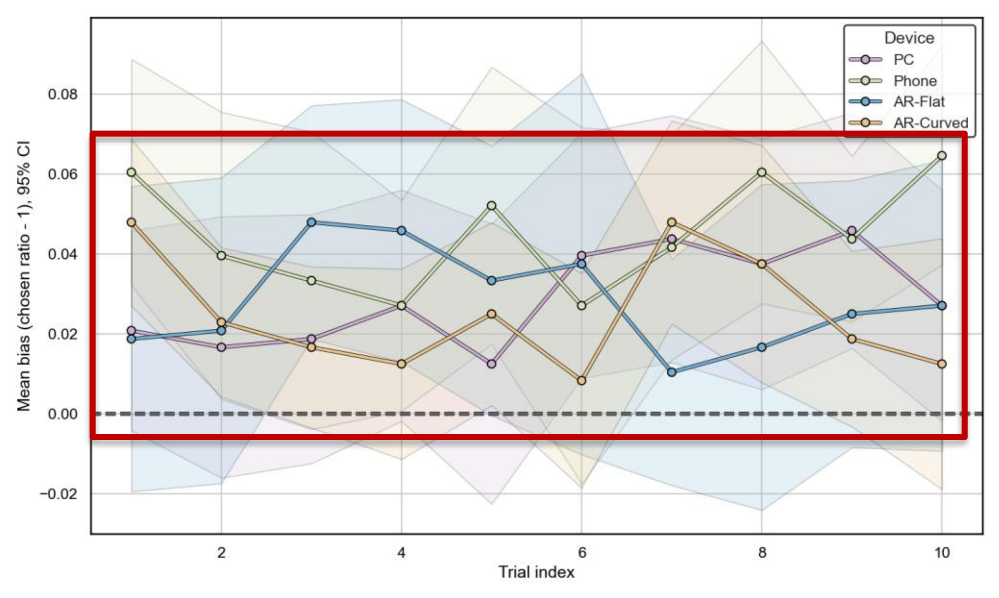
Across all conditions participants responded consistently trial to trial — SD values are low everywhere.

Both AR conditions show slightly broader dispersion than PC and Phone.

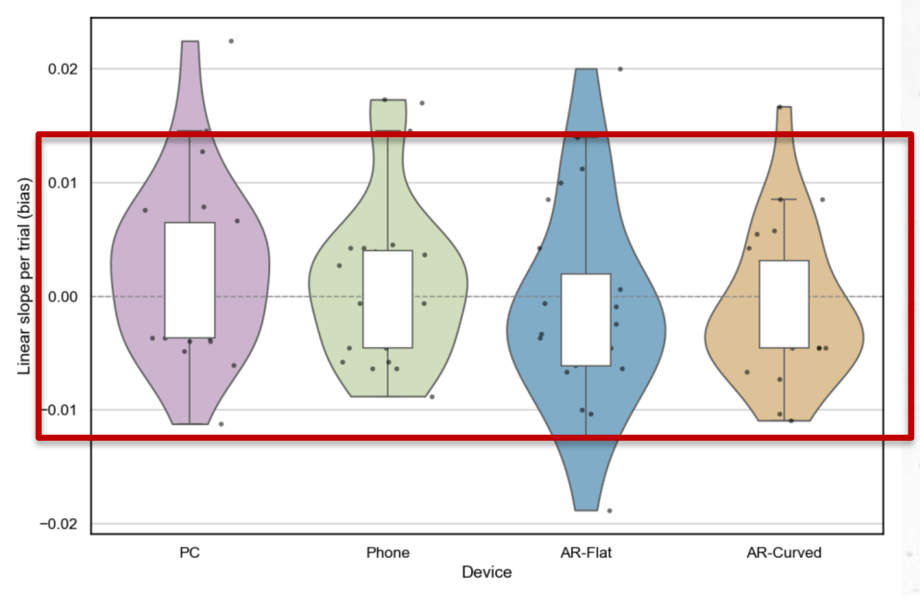
HOW TO READ THE FIGURE

The violin contours show the full variability distribution for each device. The overlaid boxes give median and interquartile range. Individual points are participant-level SD values — they expose the between-participant heterogeneity.

No learning, no fatigue, no short-term recalibration



- Mean bias across trial index 1–10 with 95% confidence
- Intervals trajectories are flat and strongly overlapping across devices.



- Participant-level linear slopes of bias against centered trial index
- Clustered around zero for every device, none approaching significance.

The SRT gives a stable measure of subjective squareness within a short session — which is what makes it plausible to embed in UI evaluation workflows or automated calibration pipelines.

INTERPRETATION

“No significant device effect” ≠ device-invariant

Numerical differences were observed — Phone > PC > AR — but none reached significance.

1

Genuinely device-invariant

VHI would then be a deeply internalized spatial prior rather than a context-dependent artifact — consistent with its appearing even in this minimal, cue-free task.

2

Underpowered

The study may be unable to detect small-to-moderate device effects at 24 participants and 10 trials per session.

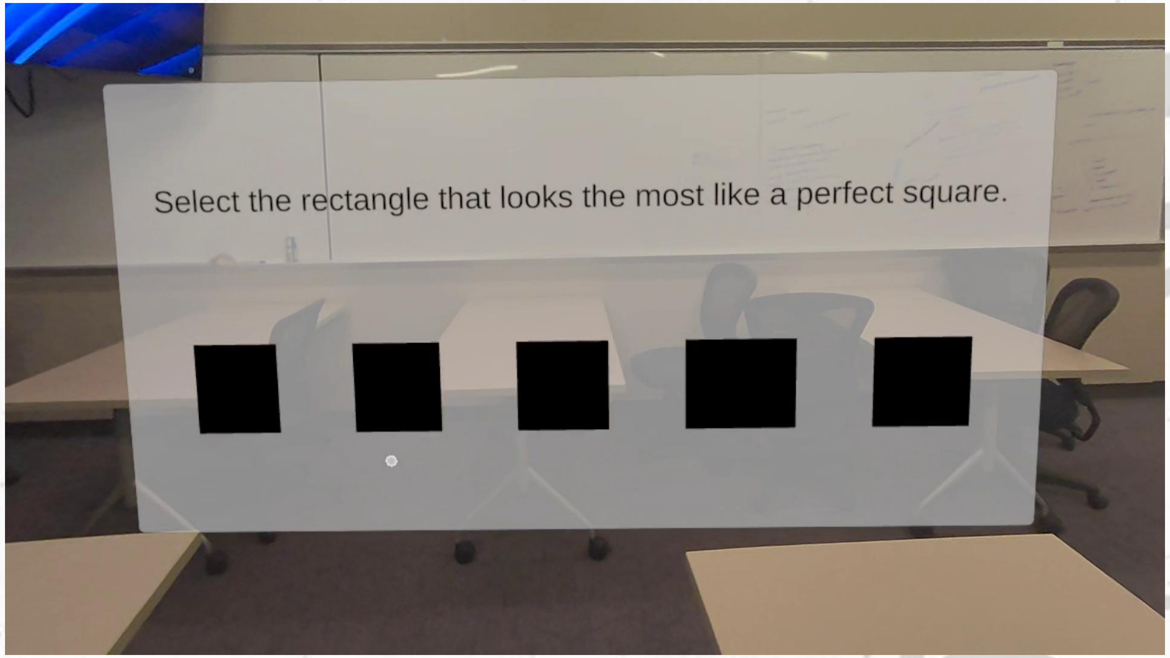
3

Masked by variability

Device-dependent distortions may be hidden by substantial individual variability — which the SD figure shows is real.

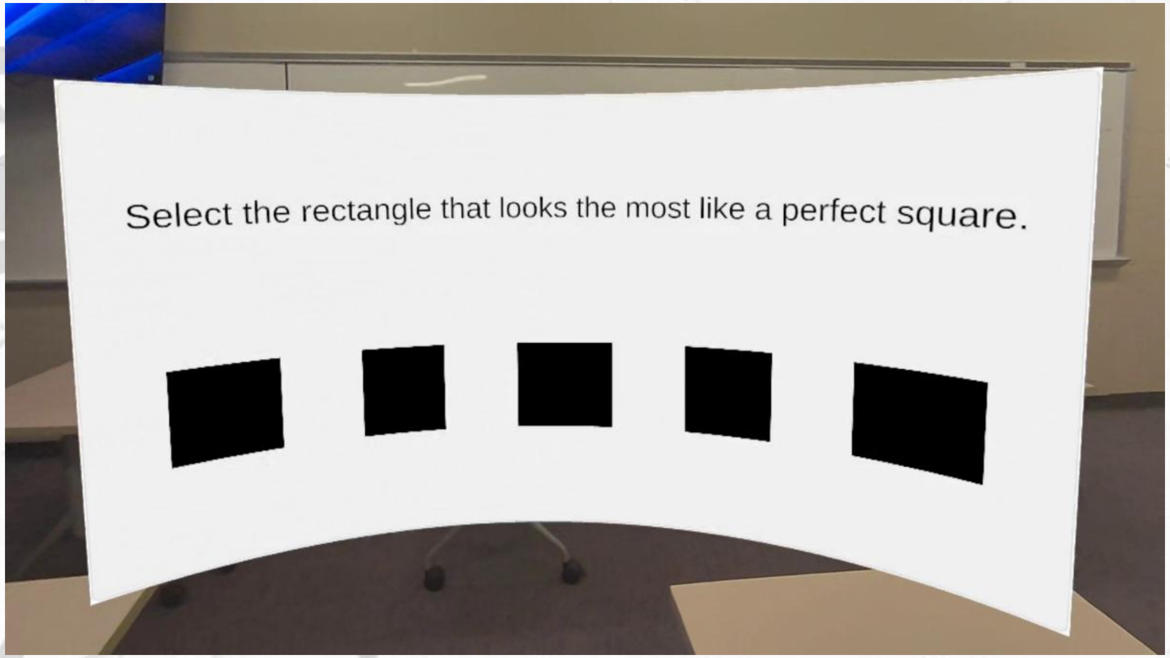
Given the established influence of field-of-view asymmetry, binocular disparity and rendering characteristics, it is unlikely that devices have no influence at all. What this dataset supports is a call for higher-precision methods and larger samples.

Curving the canvas moves PSE toward veridical



AR — flat canvas

PSE 1.0263 · Accuracy 0.252



AR — curved canvas, radius 2 m

PSE 1.0188 · Accuracy 0.406

Same headset, same settings, same task, same content — only the rendering surface changed.
The curved canvas gave the lowest bias of any condition tested and recovered accuracy to monitor level.
A software-level adjustment: perceptual improvement in XR does not have to wait for new optics.

Takeaways

1

Treat nominal squares as perceptually wrong

- Users perceive 2–4% wider rectangles as true squares.
- Optimize UI elements for perception, not geometric equality.

2

Curve the surface before changing hardware

- Curved rendering lowers bias without changing underlying content.
- A highly actionable, software-level lever for XR interface design

- Optical distortions make manual eye-verification unreliable.
- Use the **SRT** as a stable, automated verification tool.

CONCLUSION

A square is not what it measures

Key Takeaway:

The Vertical-Horizontal Illusion generalizes across all displays, but curved rendering offers an immediate software-level fix.

REPRODUCE THE SRT

10 trials, 1 instruction
Cross-platform: mobile, desktop and HMDs.
Contact for the task specification:
wenhao.yang@lamar.edu

AUTHORS AND APPROVALS

Wenhao Yang · Yueqing Li · Xinyu Liu
Lamar University, Beaumont, TX, USA
Study protocol approved under Lamar IRB-FY26-141.
Thanks to all of our participants.

Reference

[1] B. Chana, "11 optical illusions found in visual design," Prototypr, May 7, 2018. [Online]. Available: https://blog.prototypr.io/11-optical-illusions-found-in-visual-design-295e7ae211b9. [Accessed: Aug. 21, 2026].
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Thank You !

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