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ACTIVA

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Mapping pupil-based gaze vectors into three-dimensional world coordinate system for evaluating eye-hand coordination during naturalistic object manipulation.

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Purpose

Accurate assessment of eye-hand coordination in natural settings is essential for understanding the complexities of human visuomotor behavior.

Gap: Current research is hindered by a lack of robust methods for effectively mapping gaze data into three-dimensional world space[1].

Eye-tracking and **motion capture** are powerful tools but typically used independently. Combining them requires solving two synchronization challenges[2]:

⏱ Temporal
Shared timing references to align data streams without temporal offset

📐 Spatial
Mapping both datasets into the same 3D world coordinate system

This study evaluates a dual-stage synchronization framework[3] for eye-tracking and motion capture to support the investigation of eye-hand coordination during object manipulation.

Methods

Study Population

Sample Size	7 (3 Females / 4 Males)
Age	29.0±3.8 years
Spherical equivalent refraction	Right eye (OD): -1.25±0.77 D Left eye (OS): -1.25±0.79 D

Experimental Setup

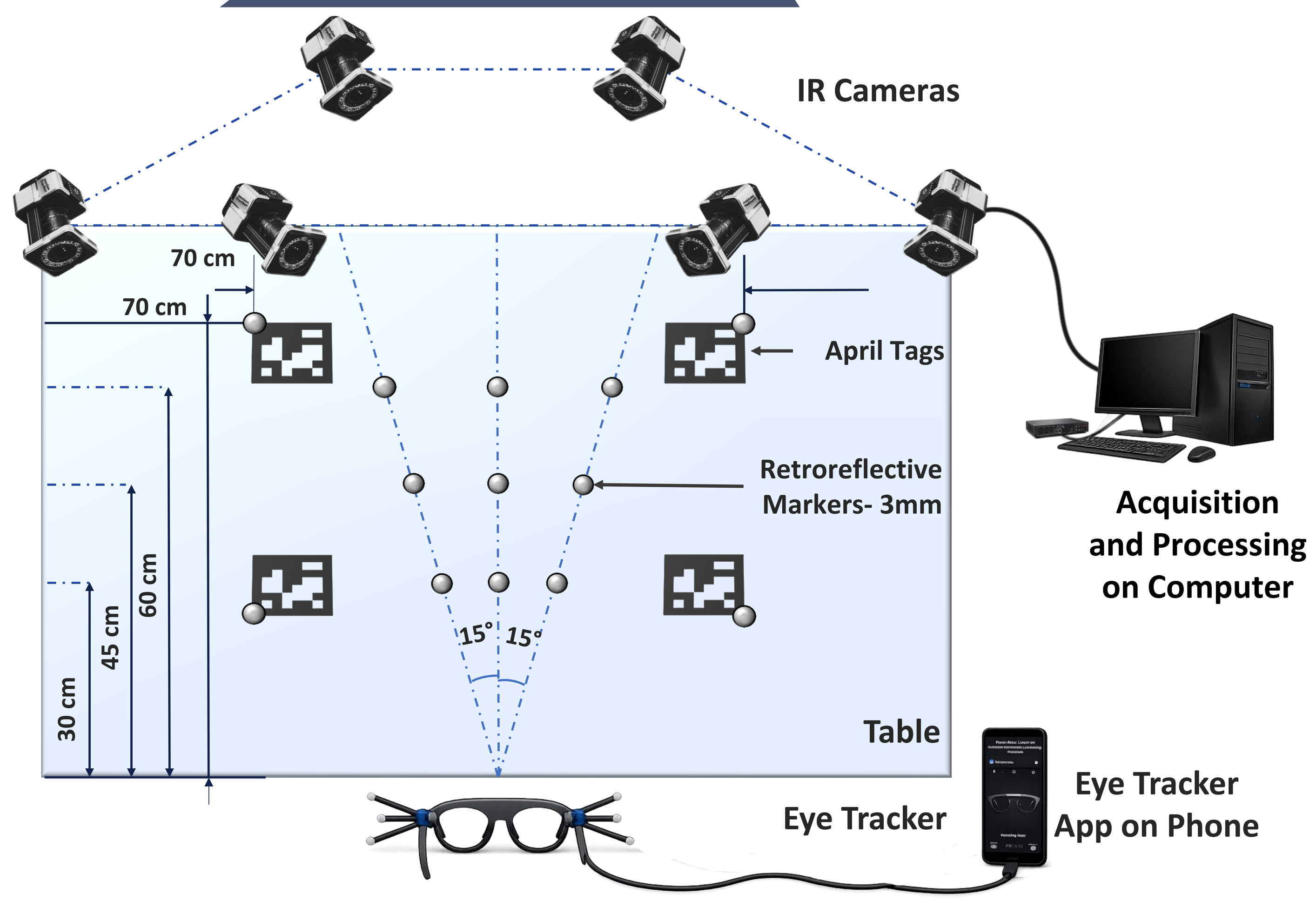


Figure 1: Schematic representation of experimental setup

Methods

Experimental Paradigm

Task Type →	Static Fixation	Depth Saccades	Lateral Saccades	Multi-line fixation	Smooth Pursuit	Head Roll
Task No. →	T1	T2	T3	T4	T5	T6

Temporal Synchronization — Aligning internal clocks between systems

Lock Lab box — **Trigger Source** (Start/Stop) → TTL pulse → **Arduino** — **Sends TTL** (reads serial data) → Serial USB → **Python Script** — Reads serial, Detects state changes, Sends events to Neon → Wi-Fi → **Neon Cloud** — **Storage**: Video, Gaze, Events (events.csv)

Spatial Synchronization — Gaze coordinates → 3D world coordinates

Raw gaze Local 2D pupil coordinates → **Temporal Alignment** Timestamp offset correction → **April Tag Detection** Scene camera best-frame search → **Neon Pose Estimation** PnP solve World camera → **Mocap Ground Truth** Vicon 3D marker positions

Rigid Body Transformation
compute_rigid_body_transform() → R·t matrices → gaze_world = R · gaze_local + t

Data Analysis

3D Representation of Output

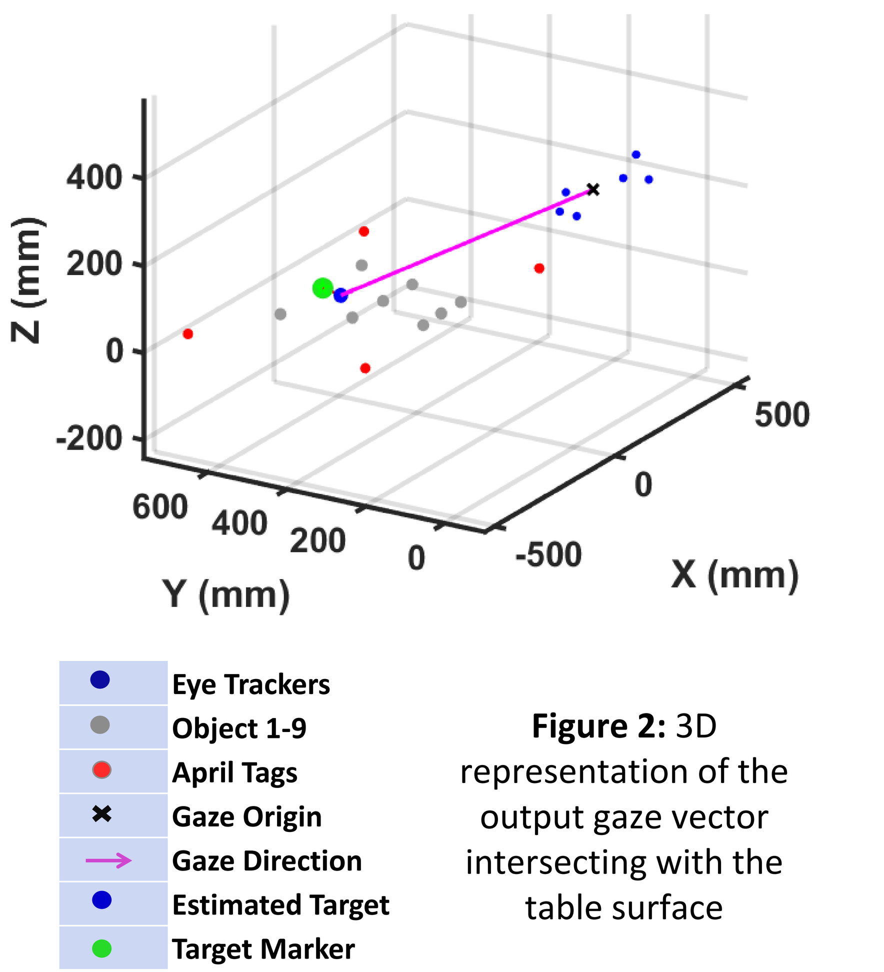


Figure 2: 3D representation of the output gaze vector intersecting with the table surface

Angular Distance Error:

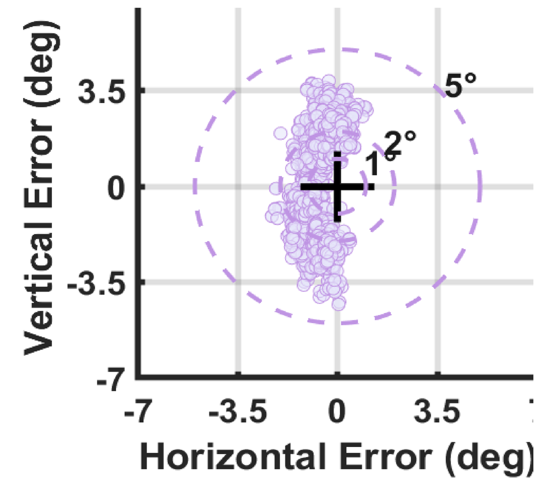


Figure 3: Angular discrepancy between predicted gaze vector and true marker direction

Linear Distance Error

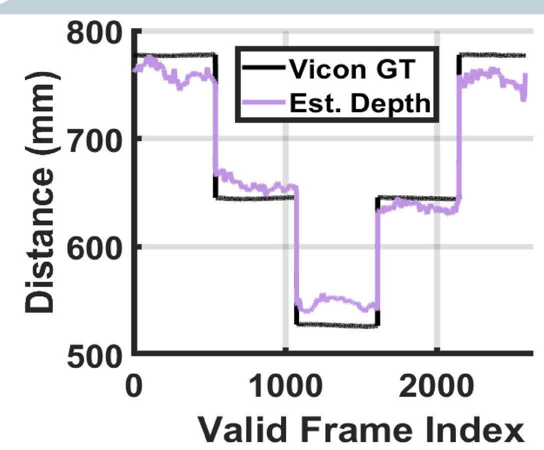
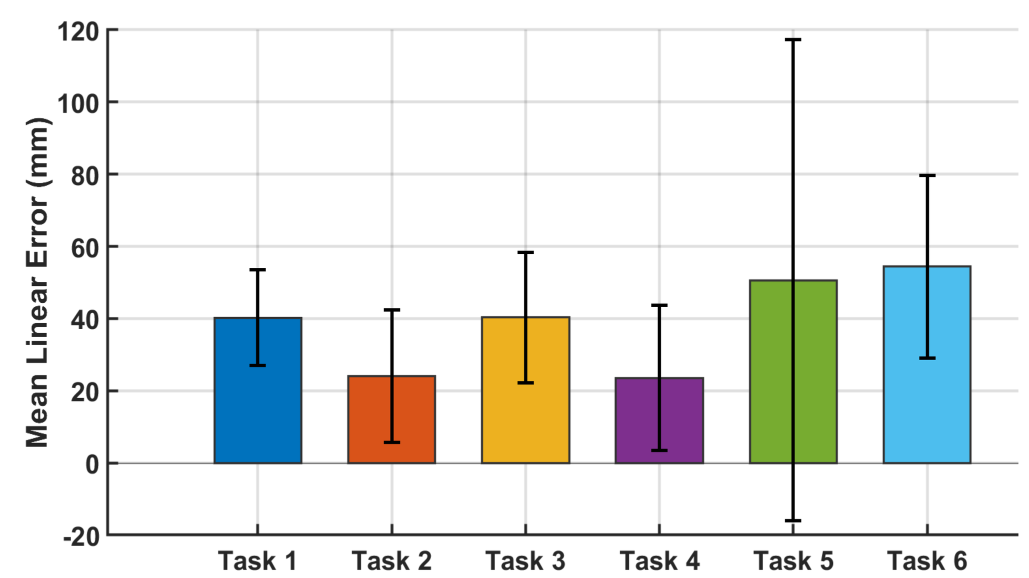


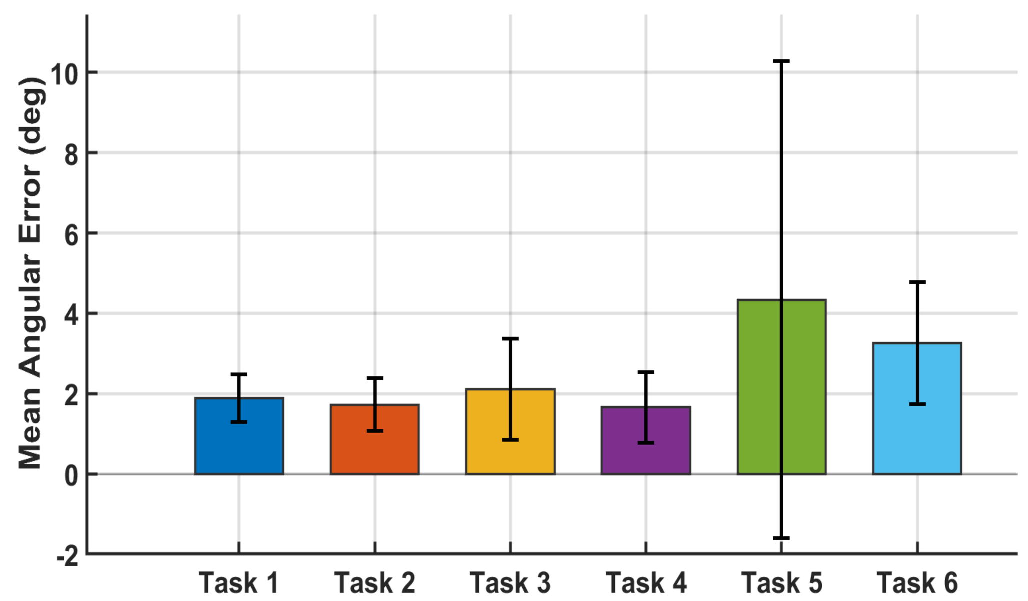
Figure 4: Difference between the length of obtained gaze vector and ground truth from the origin

Results



Linear Error Across Tasks

Task	Linear (mm)
Task 1	40.3 ± 12.7 mm
Task 2	24.0 ± 18.4 mm
Task 3	40.3 ± 18.1 mm
Task 4	23.5 ± 19.9 mm
Task 5	50.6 ± 66.6 mm
Task 6	54.4 ± 25.4 mm



Angular Error Across Tasks

Task	Angular (deg)
Task 1	1.8 ± 0.6°
Task 2	1.7 ± 0.7°
Task 3	2.1 ± 1.3°
Task 4	1.6 ± 0.9°
Task 5	4.3 ± 5.9°
Task 6	3.2 ± 1.5°

Figure 5: The 2 graphs In the top and bottom represent Linear and Angular error respectively across all tasks for all participants.

Conclusion

Our findings validate the integration of eye-tracking and motion-capture data for precise spatial localization. The consistency of results across various tasks confirms that this methodology effectively bridges the gap between raw gaze vectors and meaningful 3D behavioural metrics, for advanced studies in naturalistic eye-hand coordination.

References

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(2) Stone, S. A., Boser, Q. A., Dawson, T. R., Vette, A. H., Hebert, J. S., Pilarski, P. M., & Chapman, C. S. (2022). Generating accurate 3D gaze vectors using synchronized eye tracking and motion capture. Behavior Research Methods, 56, 18–31. https://doi.org/10.3758/s13428-022-01958-6

(3) Pupil Labs. (2026). neon_mocap_localization: Localize Neon in Motion Capture coordinate systems [Computer software]. GitHub. https://github.com/pupil-labs/neon_mocap_localization

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Disclosure: D. Narasappa, P. Sanz Diez, Y. Sauer, and S. Wahl (Employment: Carl Zeiss Vision International GmbH); R. Agarwala (none).