Pupillary Response to Surface Protrusion Intensity across Visual, Tactile, and Visuo-tactile Modalities

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INTRODUCTION

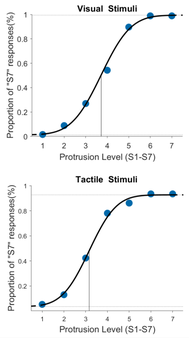
Pupillary response is known to vary parametrically with sensory intensity across modalities, reflecting automatic physiological tracking of stimulus magnitude(Wang & Munoz, 2015). While this relationship is well established in vision and audition (Binda & Murray, 2015; Zekveld et al., 2018), evidence in the tactile domain remains limited and inconsistent (Gusso et al., 2021). This study examined how pupil dynamics change as a function of protrusion degree from a surface across visual, tactile, and visuo-tactile modalities.

METHODS

STIMULI

Six protrusion levels (S1-S6; heights: 0.5-3.0 mm, 0.5 mm intervals) created in Blender 4.4.3

- Visual: 3D-rendered images, 15° visual angle, 50 cm viewing distance
- Tactile: 3D-printed objects (SLA-printed, ABS-like resin)

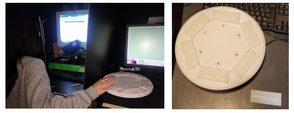


Manipulation check

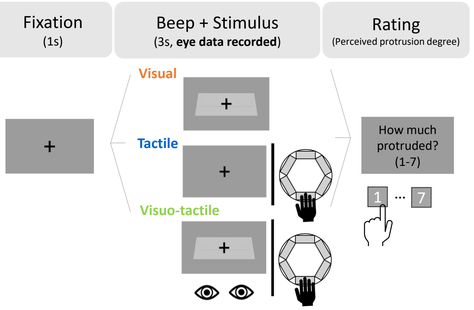
: Verified that they are perceived as intended in both visual and tactile modalities in a preliminary experiment (13 participants)

EXPERIMENTAL DESIGN

- **Participants** : 17 (6 males)
- **Conditions**
  - **Modalities:** Visual, Tactile, Visuo-tactile
  - **Protrusion degree:** S1(0.5mm) ~ S6(3.0mm)
- **Task**
  - Participants viewed/touched protrusion stimuli for 3 seconds, then rated perceived protrusion magnitude on a 1-7 scale (1=not protruded at all, 7=very protruded)
  - Tactile stimuli were presented via rotating wheel; participants stroked the surface from left to right for 3 seconds using three fingers of their right hand.

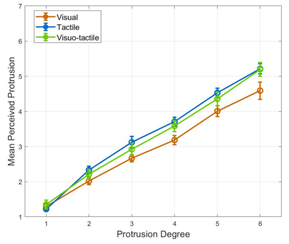


- Eye-tracking 1000 Hz (EyeLink 1000, SR Research)
- Central fixation (0.4°)
- **Procedure**



RESULTS

BEHAVIORAL RESULTS

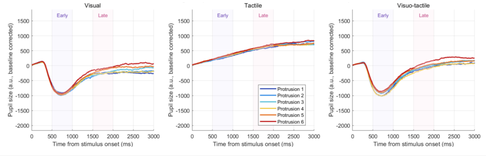


- Protrusion effect
  - Perceived protrusion magnitude increased linearly with physical protrusion level across all modalities
- Modality differences
  - Tactile-related conditions showed higher perceived magnitude than the visual-only condition
  - General pattern across protrusion levels
  : Tactile, Visuo-tactile > Visual

ANALYSES

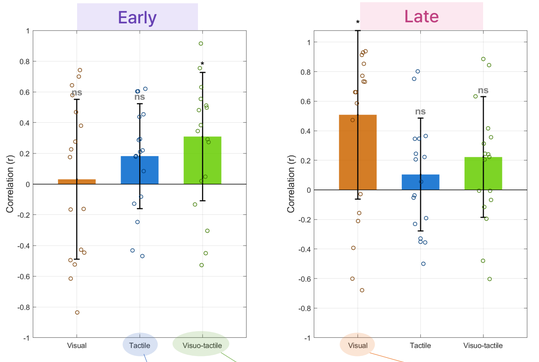
Two pupil data analysis windows:

- Early (500–1000 ms)
  : selected to capture early stimulus-driven pupillary responses (Mathôt & Vilotijević, 2023)
- Late (1500–2000 ms)
  : selected to capture post-perceptual pupillary responses
- Both windows were defined based on pilot data



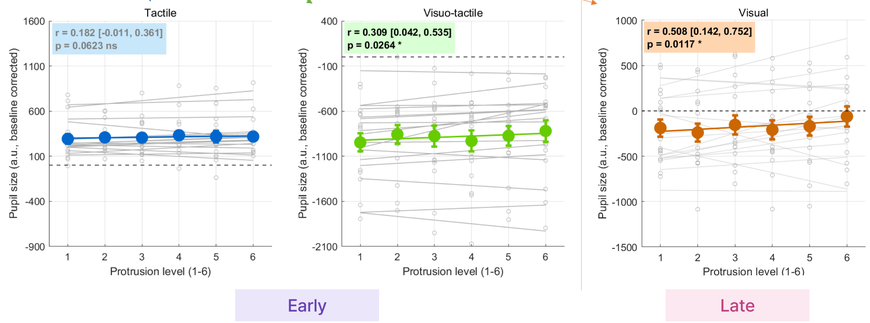
PUPILLOMETRY RESULTS

Protrusion-Pupil Correlations Vary by Modality and Time Window



- Baseline-corrected pupil size increased significantly with protrusion level in the Visuo-tactile condition during the Early window (r = 0.309, p = .026) and in the Visual condition during the Late window (r = 0.508, p = .012).
- The Tactile condition showed a positive trend in the Early window that approached but did not reach significance (r = 0.182, p = .062), with no significant correlation in either window.

(r: Fisher z-transformed group-mean Pearson correlation)



CONCLUSION

- Pupillary responses to surface protrusion degree were modality- and time-dependent. A significant positive correlation between protrusion level and pupil size was observed in the Visuo-tactile condition during the Early window and in the Visual condition during the Late window.
- These findings suggest that pupil dilation reflects stimulus intensity depending on both sensory modality and time window.

References

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