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Perceived Incongruence of Visual and Haptic Roughness is Asymmetric

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I. Introduction

Multisensory integration is essential for creating a unified percept of the environment. Of particular interest is visuo-haptic perception—the merging of visual and tactile cues—due to its crucial role in texture recognition. While previous research has confirmed that the integration of these modalities enhances perceptual accuracy, the conditions under which sensory incongruence becomes perceptually noticeable remain unclear[1]. This study examines whether the brain exhibits a modality bias (i.e., whether visual or haptic input dominates perception) and whether the threshold is stable across texture roughness levels.

A. Visuo-haptic roughness perception

Visual perception of roughness is driven by cues like shading and spatial frequency, while haptic roughness perception depends on mechanoreceptors sensing vibration, pressure, and friction. Despite differences in encoding, these modalities often yield coherent percepts. However, when visual and tactile inputs differ substantially, sensory conflict can arise, necessitating resolution through integration or perceptual segregation. [2, 3]. Existing literature suggests the brain exhibits some tolerance to sensory discrepancies, overlooking minor differences while differentiating larger ones. [4]. Moreover, sensory dominance can occur in situations where one modality disproportionately influences the resulting percept. For example, visual dominance is often observed in spatial tasks. The extent of modality dominance in visuo-haptic texture judgments, however, remains debated, with conflicting findings across studies.

B. Research objectives

This study aims to determine the roughness incongruence detection threshold in visuo-haptic perception, assess the generalizability of this threshold across varying roughness levels, and explore modality dominance in the detection of incongruent visuo-haptic textures. By addressing these objectives, the research contributes both to theoretical models of multisensory integration and to practical applications in human-computer interaction.

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II. Method

A. Participants

Twenty-two participants (16 male, 6 female; mean age 24.5 years) with normal or corrected-to-normal vision and no touch-related conditions were recruited.

B. Stimuli

Stimuli consisted of 6 3D-printed textures (2.5 × 5 × 1 cm) and corresponding visual images, each characterized by a Hurst coefficient (H), ranging from 0.3 (rough) to 0.8 (smooth). Visual stimuli were high-resolution images of the 3D models' surfaces (Fig. 1). [5]

C. Procedure

Participants completed 4 blocks of 36 randomized trials displaying all combinations of haptic and visual stimuli, performing visual inspection and haptic exploration under controlled conditions, with vision of the tactile sample blocked. The roughness difference between paired stimuli was computed as the absolute difference in Hurst coefficients (Δ_{Hurst}). They had to indicate whether the two textures felt visually and haptically congruent (same surface) or incongruent (different surfaces) by pressing 1 or 0, respectively. They performed five random training trials before the main experiment to familiarize with the task.

D. Data Analysis

Psychometric functions were fitted to the percentage of "incongruent" responses as a function of difference in Hurst coefficient. Further analyses examined intra- and inter-subject variability, consistence across texture references, and modality asymmetries.

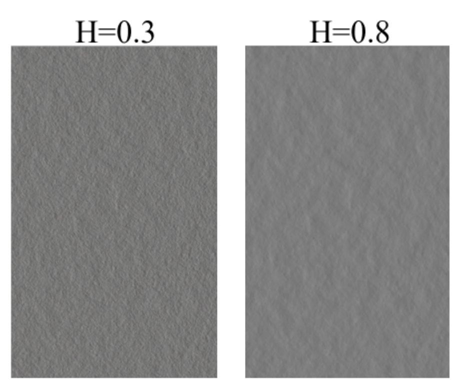

Fig. 1. Image of the 3D-printed haptic stimuli.

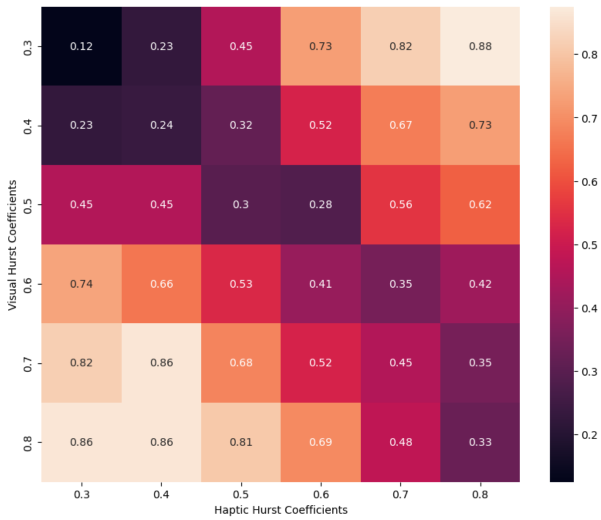

Fig. 2. Confusion matrix showing mean incongruent responses for haptic (x) vs. visual coefficients (y)

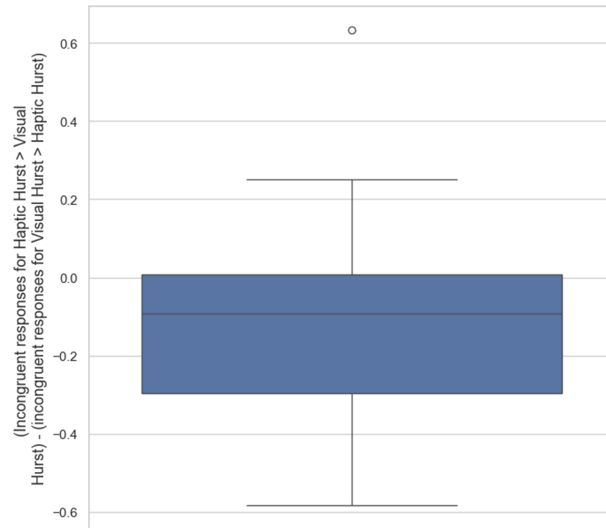

Fig. 3. Boxplot of incongruent response difference for trials where Haptic Hurst > Visual Hurst vs. Visual Hurst > Haptic Hurst, averaged over all participants (median and IQR).

III. Results

A. Incongruence Detection Threshold

Participants' responses revealed a consistent increase in perceived incongruence with increasing Δ_{Hurst}. The threshold at which incongruence was reliably detected (>=75% incongruent responses) occurred at Δ_{Hurst} 0.3 – 0.4. This suggests a tolerance for minor discrepancies in roughness but consistent detection beyond this limit.

B. Invariance Across Roughness Levels

Detection thresholds were similar across references with different roughness. A one-way ANOVA (F = 0.33, p = 0.97) confirmed that thresholds did not significantly differ, supporting the notion that the threshold is constant across the full range of tested roughness values.

C. Modality Bias

Confusion matrix analysis (Fig. 2) highlighted asymmetries: participants more frequently reported a larger incongruence when the visual stimulus was smoother than the haptic one than the opposite. This pattern was significant in some pairings (e.g., 0.4 vs. 0.7 and 0.5 vs. 0.6), suggesting a potential perceptual bias.

Thus, we computed the difference between the percent incongruence responses for the trials with a rougher haptic stimulus and the trials with a rougher visual stimulus (Fig. 3). This analysis verified whether only the comparison matters or also the modality to which each roughness level is assigned. The mean difference for the trials is mostly negative (paired t-test, t(21) = -1.85, p = 0.08), which suggests that incongruence is less felt when the visual modality is smoother than the tactile one for the same amount of roughness difference.

IV. Discussion

The findings confirm that visuo-haptic texture integration is tolerant to minor discrepancies, with a perceptual incongruence threshold at a Δ_{Hurst} of 0.3–0.4. This aligns with earlier studies indicating sensory integration can overlook small mismatches until differences become salient.

The potential generalizability of this threshold across texture intensities suggests that Weber law holds in the roughness comparisons that we considered. This finding suggests a stable mechanism for assessing visuo-haptic consistency that is independent of the particular combination of visual and haptic roughness.

With regard to modality bias, the results offer tentative evidence for a visuo-haptic asymmetry. Participants were more sensitive to incongruence when the visual texture appeared smoother than the tactile one, possibly due to prior expectations or shifted inner tactile and visual scales. However, the effect size is still small, and the uneven effect across combinations of visual and tactile roughness suggests that further experiments are needed.

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