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Vibrations Feel Longer than their Visual Analogs in Virtual Reality

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I. Introduction

Time perception plays a central role in how we make sense of the world. Although there is no dedicated sensory organ for perceiving time, we continuously estimate durations using different cues from the sensory modalities [1]. While time perception may seem coherent, temporal judgments like duration estimation or simultaneity are not modality-neutral. For example, auditory duration estimates are consistently shown to be longer and more precise than visual ones [2], [3]. This contrasts with the idea of a central and universal clock that governs all temporal judgments. Instead, studies support multiple modality-specific timing mechanisms, as different sensory inputs are associated with distinct temporal characteristics [1], [4], [5].

While auditory-visual differences in time perception are widely studied, research comparing tactile duration judgments with auditory and visual modalities has remained limited. Notably, Jones and colleagues [6] found that tactile intervals were perceived as shorter than auditory ones, and similar to visual intervals. However, another study [7] reported that moving visual stimuli were perceived as longer than moving tactile stimuli, even when the apparent speeds were subjectively equalized. Together, these findings suggest that differences in duration judgments between visual and tactile modalities may depend not only on the sensory modality but also on specific stimulus features and the environment.

With the increasing adoption of virtual reality (VR) in various fields, it is crucial to examine how temporal judgments differ in this platform, as the inherent dynamics of VR may significantly influence time perception [8]. For instance, it has been previously shown that the visuotactile temporal binding window (TBW, assessed in a cross-modal simultaneity task) is much wider in VR environments as compared to classical laboratory environments [9], [10]. These changes have been linked to reduced sensitivity to visual events in VR. Given such modality and environment specific effects, tactile intervals may be perceived differently than visual ones in VR environments.

To investigate how duration judgments differ between tactile and visual modalities in VR environments, we devised an experiment where participants compared the duration of visual and tactile stimuli crossmodally. In each trial, participants judged whether a visual stimulus presented on their virtual hands in the VR environment was longer than a tactile stimulus presented on their actual hands.

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II. Methods

27 participants (20 females, 7 males; mean age = 24.6 ± 4.5) with normal or corrected-to-normal vision and no somatosensory impairments took part in the study. They provided written informed consent before the experiment.

Vibrotactile stimuli were delivered via ERM actuators (Vybronics Ltd.) mounted on the back of both hands. Microphone recordings (5 repetitions) confirmed that the actuators delivered vibration durations of the intended length (deviation 1.2 ± 1.7 ms). Visual stimuli — red 2 cm- diameter spheres — were rendered in a VR environment (HTC Vive Pro Eye, Unity 2021.2.7f1). Hand positions were tracked with a Leap Motion device and displayed as virtual hands. Participants sat at a table and responded via foot pedals (Fig. 1).

Stimulus durations were 400,500, 600, 700, 800 and, 900 ms for tactile and 200, 400, 600, 800, 1000, 1200, and 1400 ms for visual stimuli. In each trial we successively presented a tactile (reference) and a visual (comparison) stimulus, in varying order and from the same hand, with a 500 ms inter-stimulus interval. We used a 2IFC (interval forced-choice) task with a full factorial design (7 visual durations × 6 tactile durations × 2 hands × 2 orders × 4 repetitions = 672 trials). The stimuli were spatially congruent. Experimental trials were randomized and preceded by a training block. In each trial, participants indicated whether the first or second stimulus had appeared to last longer. The experiment lasted 75 minutes, including three short breaks.

Data analysis involved fitting logistic psychometric functions to the proportion of "visual longer" responses for each tactile condition. The PSEs (point of subjective equality) were calculated, and their difference from the corresponding tactile durations was used to quantify how visual duration perception differed from tactile perception. These differences were further analyzed.

III. Results

Perceived difference values were significantly greater than zero for all tactile duration conditions (one-tailed t-tests all $t[26] > 4.60$, $p < .001$), indicating that tactile stimuli were consistently judged as longer than visual ones.

A repeated-measures ANOVA revealed a significant main effect of tactile duration, $F(5,130) = 11.65$, $p < .001$, partial

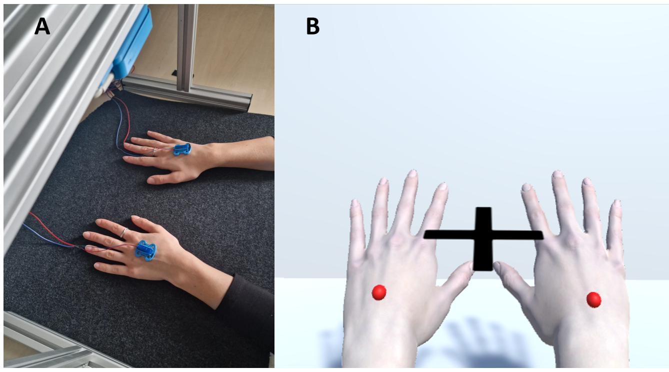

Fig. 1. Actuator positions and setup where participants placed their hands (A). Visual analogues of participants' hands in the virtual environment with all possible locations of the visual stimuli (B).

η^2 = .31. Bonferroni-corrected pairwise comparisons showed that perceived differences were greater in the 500–900 ms conditions compared to the 400 ms condition (all $p < .01$), suggesting that perceived differences increase with shorter reference intervals and stay constant when these intervals get longer. (Fig. 2).

To characterize the relationship between tactile durations and PSEs, we fitted a power function without intercept across participants in the form of:

$$y = b * x^a \tag{1}$$

The fits yielded a median adjusted R^2 of .876 ± .045. The mean parameter estimates were b = 17.33 ± 6.91 and a = .848 ± .050. Thus, cross-modal duration judgments can be considered to conform to the power law [11].

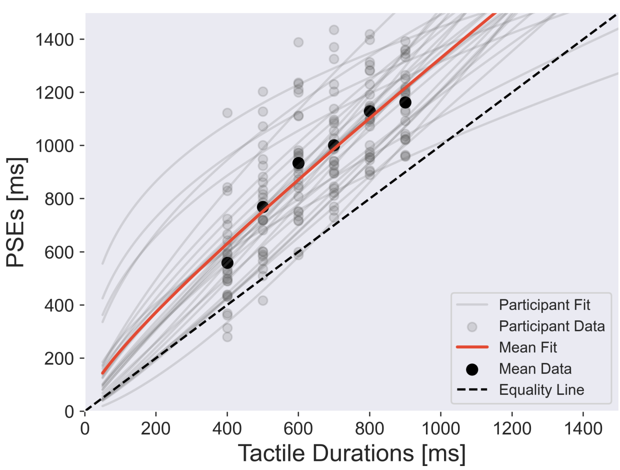

Fig. 2. Fits of a power function for each participant. Gray lines depict the prediction of individual fits and gray dots depict individual PSEs. Black dots depict the mean PSEs and the red line is the average of all predictions across individual fit predictions. Black dashed diagonal shows the equality line between tactile and visual durations.

IV. Discussion

In this study, we investigated whether duration judgments differ across taction and vision in a VR environment using a cross-modal comparison task. Across a range of durations, tactile stimuli were consistently judged as longer than visual ones. This relationship followed a sublinear power law, indicating that perceived durations increased more slowly as interval lengths increased.

Our findings are consistent with previous work showing that time perception depends on the sensory modality, likely due to differences in saliency, attention, or sensory-specific processing mechanisms [1], [3]–[5]. While some studies have found similar or even shorter perceived durations for tactile stimuli compared to visual ones [6], [7], here we found the opposite. These inconsistencies may stem from influences of context and environment on temporal judgments.

Importantly, the current experiment was conducted in VR, where perceptual dynamics can differ from real-world settings. Timing in VR has been shown to differ from non-VR contexts, and our findings may partly reflect such environment-specific influences [8]–[10].

Good fits of the power functions to the PSEs show that cross-modal visuotactile judgments conform to the power law, a hallmark of time perception and other perceptual processes [11] confirming that the perceived intensity of a stimulus is proportionate to a scalar power of its physical magnitude.

Overall, our results show that tactile stimuli are perceived as longer than visual stimuli. These findings highlight how sensory modality and environmental context can shape duration judgements, particularly in VR. VR application designs should account for these differences by adjusting durations—e.g., decreasing tactile duration—to avoid confusing users' sense of time.

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