Sensitivity to empty intervals in multimodal stimulation:
A visuotactile study of time perception

Mercedes B. Villalonga
Rachel F. Sussman
Robert Sekuler
Department of Psychology, Brandeis University, Waltham, MA USA
Email: mbv0@brandeis.edu

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Introduction

- Temporal information is a fundamental aspect of all sensory stimulation
  - Sequences of visual or auditory pulses can communicate useful information[1,2]
  - Less attention has been given to tactile cues
- A recent study from our lab has shown that tactile cues can convey rate information[3]
- In this study, we aim to replicate our previous finding and answer the following:
  - How robust is the temporal information communicated by tactile signals vs. visual signals?
  - How well does each sensory modality resolve temporal gaps between two discrete stimuli?
  - When stimuli are combined across modalities, how are the two components integrated?

Experiment 1

OBJECTIVE:
Study rate discrimination with **tactile** and **visual** stimuli to improve characterization of timekeeping mechanisms

Method

- Task: Observe a sequence of pulsing stimuli, and categorize pulse rate as "fast" or "slow"
  - Stimuli: 50ms pulses, separated by inter-pulse intervals (IPIs)
    - Visual (**V**) pulse: LED flash
    - Vibrotactile (**T**) pulse: vibration from linear resonant actuator (**Fig. 1B**) against left index finger
  - Sequences at mean rates of **4 Hz** or **6 Hz**
    - Mean IPI on 4 Hz trials: 200 ms
    - Mean IPI on 6 Hz trials: 116 ms
    - **Temporal-domain noise** (variability) was independently added to each IPI in a sequence
- Apparatus: Arduino micro-controller controlled activation of stimuli (**Fig. 1**)
- Subjects: n=28, 18-21 years old

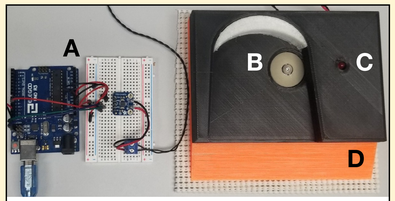

Fig. 1. Stimulus presentation. Signals were sent to an Arduino micro-controller (**A**) to initiate stimulus presentation. On vT trials, a vibrating linear resonant actuator (**B**) produced vibrations against the subject's left index finger. On V trials, a red LED (**C**) produced visual flashes. The vibrotactor and LED were embedded in a 3D-printed hand rest (**D**).

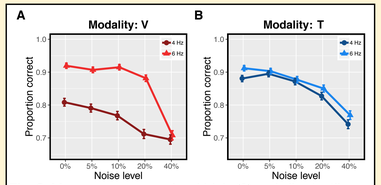

Fig. 2. Mean accuracy on visual trials (**A**) and vibrotactile trials (**B**). Error bars reflect within-subject standard error.

Results

- **Fig. 2**: Overall, accuracy decreased with increased noise, $p < .001$, $\eta_p^2 = .69$
- Mean pulse rate changed the effect of noise on **V** trials, $p < .001$, $\eta_p^2 = .28$
- No rate effect on **T** trials, $p = .723$, $\eta_p^2 = .01$

KEY FINDING:
Tactile sources of timing information are as robust as, if not *more robust* than, **visual** sources

- ***Why*** more errors on **4 Hz V** trials than **6 Hz V** trials? Why no effect on **T** trials?
- One possibility: "smearing" on **6 Hz V** trials made them easier than **4 Hz V** trials
  - If neural responses from successive visual flashes *overlap*, two flashes could look like one
- **T** trials unaffected: implies tactile temporal sensitivity is better than visual

Experiment 2

OBJECTIVE:
Study gap detection with **tactile** and **visual** stimuli to test for *differences in sensitivity* to timing information

Method

- Task: temporal 2AFC (**Fig. 3**)
  - Response: Was the double-pulse stimulus first or second?
  - Double-pulse gap: 2-32ms duration
- Stimuli: **V** and **T** conditions from Experiment 1, with an added bimodal (**VT**) condition
- Apparatus: Same as Experiment 1 (see **Fig. 1**)
- Subjects: n=14, 18-30 years old

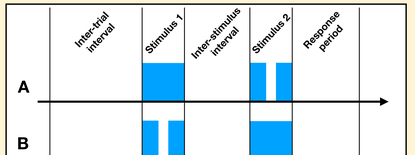

Fig. 3. Experiment 2 trial structure. Subjects were shown two types of stimuli on each trial: a "single-pulse" stimulus (uninterrupted flash, vibration, or flash-vibration pairing) and a "double-pulse" stimulus that contained a short gap. Subjects indicated the position of the double-pulse. The two trial types are shown, with correct responses of "second" (**A**) and "first" (**B**).

Results

- **Fig. 4**: Psychophysical modeling revealed a difference between **V** and **T** sensory thresholds
- **V** threshold: 15ms
- **T** threshold: 5ms
  - 3x shorter than **V** threshold
- **VT** threshold: 6ms
  - Resembled **T** threshold
  - Tactile component of the bimodal stimulus had more weight

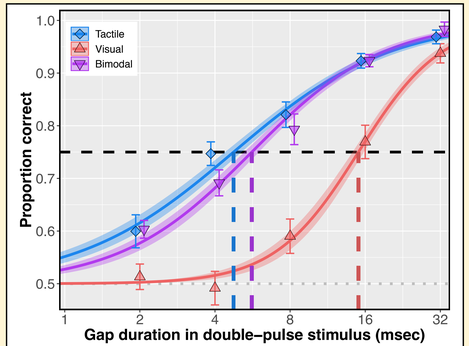

Fig. 4. Logistic psychometric functions (PFs) fit using MLE. Parameters estimated using aggregated subject data. Ribbons show standard error of the PF. Points show mean accuracy in that condition; error bars reflect within-subject standard error. Dashed vertical lines show the 75% threshold for each modality: vT = 4.9 ms, V = 15.7 ms, V-vT = 5.9 ms.

KEY FINDING 1:
Higher sensitivity to **tactile** than to **visual** pulses

KEY FINDING 2:
No evidence of multisensory integration with **bimodal** pulses

Conclusions

- Tactile signals were as robust as, if not more robust than, visual signals in conveying temporal information
  - Bimodal accuracy closely mirrored tactile accuracy in Experiment 2
    - Tactile cues may have been more useful to subjects
- More correct "fast" judgments on visual trials in Experiment 1
  - Experiment 2 showed vision's comparatively poor temporal acuity
  - May have promoted a partially fused percept at 6 Hz, but not at 4 Hz
- Tactile cues have appreciable information-carrying potential
- Further investigation is warranted: tactile stimulation is now used in various devices
  - Cell phones and tablets
  - Medical devices
  - Vehicular alert systems

References: (1) Guttman, SE, Gilroy, LA, & Blake, R (2005). Hearing what the eyes see: Auditory encoding of visual temporal sequences. *Psychological Science*, 16(3), 228-235. (2) Grahn, JA (2012). See what I hear? Beat perception in auditory and visual rhythms. *Experimental Brain Research*, 220(1), 51-61. (3) Villalonga, MB, Sussman, RF, Sekuler, R (2020). Feeling the Beat (and Seeing It, Too): Vibrotactile, Visual, and Bimodal Rate Discrimination. *Multisensory Research*, 33(1), 31-59. We thank Tim Hebert, Alberto Pierobon, Yangyi Shi, Janaki Nair, Rachel Peng, and Tianyou Zhou for their contributions. Research reported in this poster was supported by NIGMS award number T32GM132498 and NIDA award number R90DA033463. This content is solely the responsibility of the authors and does not represent the official views of the NIH.