Sensitivity to empty intervals in multimodal stimulation: A visuo-tactile study of time perception

Introduction

- Temporal information is integral to all sensory stimulation
- Sequences of visual or auditory pulses can communicate useful information
- Less attention has been given to communication via tactile pulses
- A recent study from our lab showed that tactile pulses can convey rate information

In this study, we aim to extend our previous finding and answer the following:

1. How robust is the temporal information communicated by tactile signals vs. visual signals?
2. How well does each sensory modality resolve temporal gaps between two discrete stimuli?
3. When stimuli are combined across modalities, how are the two components integrated?

Method

- **Subjects**: n=28, 18-21 years old
- **Stimuli**: 50ms pulses, separated by inter-pulse intervals (IPIs)
  - **Visual (V)**: LED flash
  - **Tactile (T)**: vibration from a vibrating linear resonant actuator

**Temporal information is integral to all sensory stimulation**

**Study rate discrimination with bimodal stimuli**

Experiment 1

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

- **Task**: Observe a sequence of pulsing stimuli, and categorize pulse rate as “fast” or “slow”
- **Stimuli**: 50s pulses, separated by inter-pulse intervals (IPIs)
  - **Visual (V)**: LED flash
  - **Tactile (T)**: Vibration from a vibrating linear resonant actuator (Fig. 1B) against the 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, 21-28 year olds

**Fig. 1.** Stimulus presentation. Signals were sent to an Arduino microcontroller to initiate stimulus presentation. On each trial, a vibrating linear resonant actuator (produced 28 Hz vibrations) and a light emitting diode (LED) produced visual flashes. The vibrotactor and LED were embedded in a 3D-printed hand rest (Fig. 1B). A stimulus presentation box was shown to the subject, with a double-pulse gap stimulus. The task was to respond as quickly as possible, indicating whether the gap was longer or shorter than 1 ms.

**Results**

- **Fig. 2.** Overall, accuracy decreased with increased noise. p < .001, n = 9.
- **Mean pulse rate changed the effect of noise on V trials**: p < .001, n = 28
- **No rate effect on T trials**: p = .723, n = 32

**KEY FINDING 1:**

- Why more errors on 4 Hz V trials than 6 Hz V trials? Why no effect on T trials?
- One possibility: perceptual “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

- **Task**: Temporal 2AFC (Fig. 3)
  - **Response**: Was the double-pulse stimulus first or second?
  - **Stimulus**: Double-pulse gap: 2-32ms duration
  - **Stimuli**: V and T conditions from Experiment 1, with an added bimodal (VT) condition

**Fig. 3.** Experiment 2 trial structure. Subjects were shown two types of stimulus on each trial: a “single-pulse” stimulus (uninterrupted flash, vibration, or flash-vibration pairing) and a “double-pulse” stimulus that contains 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). Subjects were trained to respond as quickly and accurately as possible.

**Results**

- **Fig. 4.** Psychophysical modeling revealed a difference between V and T sensory thresholds.
  - **V threshold**: 15 ms
  - **T threshold**: 5 ms
  - **3x shorter than V threshold**

**KEY FINDING 2:**

- 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

**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
- **Tactile cues have appreciable information-carrying potential**
- Further investigation is warranted: tactile stimulation is increasingly used in various devices

**References:**