Feeling (and seeing) the beat: Vibrotactile, visual, and bimodal rate perception

Introduction
Temporal information is a fundamental aspect of all sensory stimulation. Studies of rhythm perception and temporal sensitivity have shown that sequences of visual or auditory pulses can communicate useful information.1-2 Less attention has been given to tactile cues, however.

To learn whether vibrotactile pulses can reliably communicate temporal information, we carried out multiple experiments that compared temporal processing in visual and vibrotactile sensory modalities. We sought to answer the following questions:

• How robust is temporal information communicated by vibrotactile signals, compared to visual signals?

• How does vibrotactile performance compare with other sensory modalities?

• 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: 3 Hz/6 Hz discrimination

Subjects: n=23, 18-22 years old
Stimuli: Sequences of pulses separated by empty intervals
Visual (V) pulse: flash on screen
Vibrotactile (vT) pulse: vibration to hands
Bimodal (V-vT) pulse: synchronized flashes and vibrations
Pulse sequences were presented at mean rates of 3 Hz or 6 Hz
Each pulse in a sequence was 33 ms in duration
3 Hz trials, inter pulse intervals (IPIs) were 300 ms on average
6 Hz trials, IPIs were 133 ms on average

Temporal-domain noise (variability) was independently added to each IPI in a sequence
On each trial, subjects categorized the pulse sequence as “fast” or “slow”

RESULTS
• As temporal randomness increased, noise fell (p < .001, η² = .85) and response times lengthened (p < .001, η² = .44)
• Reduced response time on bimodal trials (Fig. 2B, purple) suggested faster accumulation of evidence, confirmed by drift diffusion analysis

Experiment 2: 4 Hz/6 Hz discrimination

Subjects: n=25, 18-21 years old
Apparatus: Arduino micro-controller controlled vibrotactile (Fig. 3).
Stimuli: Sequences of 50 ms pulses separated by empty intervals
Visual (V) pulse: LED flash
Vibrotactile (vT) pulse: vibration from linear resonant actuator
Bimodal (V-vT) pulse: synchronized flashes and vibrations
Pulse sequences were presented at mean rates of 4 Hz or 6 Hz
Each pulse in a sequence was 33 ms in duration
4 Hz trials, inter pulse intervals (IPIs) were 116 ms on average
6 Hz trials, IPIs were 191 ms on average

Noise was added to each IPI as in Experiment 1, with two additional levels
• On each trial, subjects categorized the pulse sequence as “fast” or “slow”

RESULTS
• Fig. 4: Overall, accuracy decreased with increased noise, p < .001, η² = .69
• Mean rate changed the effect of noise on V trials, p < .001, η² = .28, but not on vT trials, p = .723, η² = .01
• We followed up this interaction in a third experiment (see next panel)

Follow up: Minimum resolvable empty interval

Objective: In Experiment 2, noise differentially affected judgments of V and vT trials. This follow-up experiment aimed to determine the minimum detectable gap between two pulses of stimulation.

Methods:
• n=14, 18-30 years old
• 2AC procedure
• Same apparatus and stimuli as Experiment 2, with an added bimodal (V-vT) condition

RESULTS
• Fig. 6: Psychophysical modeling of subjects’ responses revealed a difference between sensory thresholds for V and vT stimuli
• Visual pulses had to be separated by a 16 ms gap for subjects to perceive them as discrete 75% of the time
• Vibrotactile pulses only had to be separated by ~5 ms to produce the same judgment reliably
• The V-vT threshold (~6 ms) resembled that of V stimuli, implying that subjects largely relied upon the vibrotactile component of the bimodal stimulus

Conclusions
These experiments revealed that, in conveying temporal information, vibrotactile signals were as robust as, if not more robust than, visual signals.

• Bimodal accuracy closely mirrored vibrotactile accuracy in Experiment 1, as well as in the follow-up experiment, suggesting that vibrotactile cues were more useful to the subject in these tasks.

• In Experiment 2, noise differentially affected 6 Hz visual trials and 4 Hz visual trials: accurate 6 Hz percepts were immune to the effect of noise until noise reached its highest level.

• How could such a bias arise? We suggest that vision’s comparatively poor temporal acuity, as demonstrated in the follow-up experiment, may have promoted a partially fused percept at 6 Hz.

• Vibrotactile cues have appreciable information-carrying potential and warrant further investigation for use in various applications.

References

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