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Psychophysical investigation of localization of audio-tactile stimuli in active touch

Giulia Esposito, Arthur Courtin, Olivier Collignon, Andre Mouraux

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Esposito G.¹, Courtin A.S.^{1,2}, Collignon O.^{1,3,4}, Mouraux A.¹

(1) Institute of Neuroscience (IoNS), Université catholique de Louvain

(2) Center for Functionally Integrative Neuroscience, Aarhus University

(3) Institute of Research In Psychological Sciences (IPSY), Université catholique de Louvain

(4) School of Health Sciences, HES-SO Valais-Wallis

Introduction

Exploring our environment through touch often entails integration of tactile with auditory and/or visual inputs. While previous research has reported cross-modal interactions between touch and audition in the context of spatial localization^{1,2}, such studies have largely involved passive, vibrotactile stimuli. Cross-modal effects between touch and audition during active, dynamic touch, which is described as an intentional act performed to optimally extract tactile information from the external world³, remain underexplored. Here, we aimed to investigate how well participants can reconstruct the location of tactile stimuli (in the form of transient changes in friction rendered through a haptic tablet using ultrasonic (US) lubrication) and the effects of bimodal (audio-tactile) vs unimodal (auditory or tactile) stimulation on localization performance. We hypothesized that bimodal stimulation would improve localization precision compared to unimodal stimulation, which would be indexed by a steeper slope of the fitted psychometric function.

Materials and Methods

Sensory cues:

- **Tactile stimulation:** Transient friction change (active zone: 0.2 x 10 cm) presented on US display
- **Auditory stimulation:** 200 ms white noise presented via a speaker placed behind the US display
- Visually presented midline (0.5 mm) to split screen in half

Procedure:

- **Conditions:**
 - Tactile-only
 - Auditory-only
 - Audio-tactile
- Two alternative forced-choice task
- Stimulus placement decided via the adaptive Psi+ method
- Left-to-right slide with index of dominant hand
- Q: Was the stimulus presented in the first or second half of the screen? (Fig. 1)

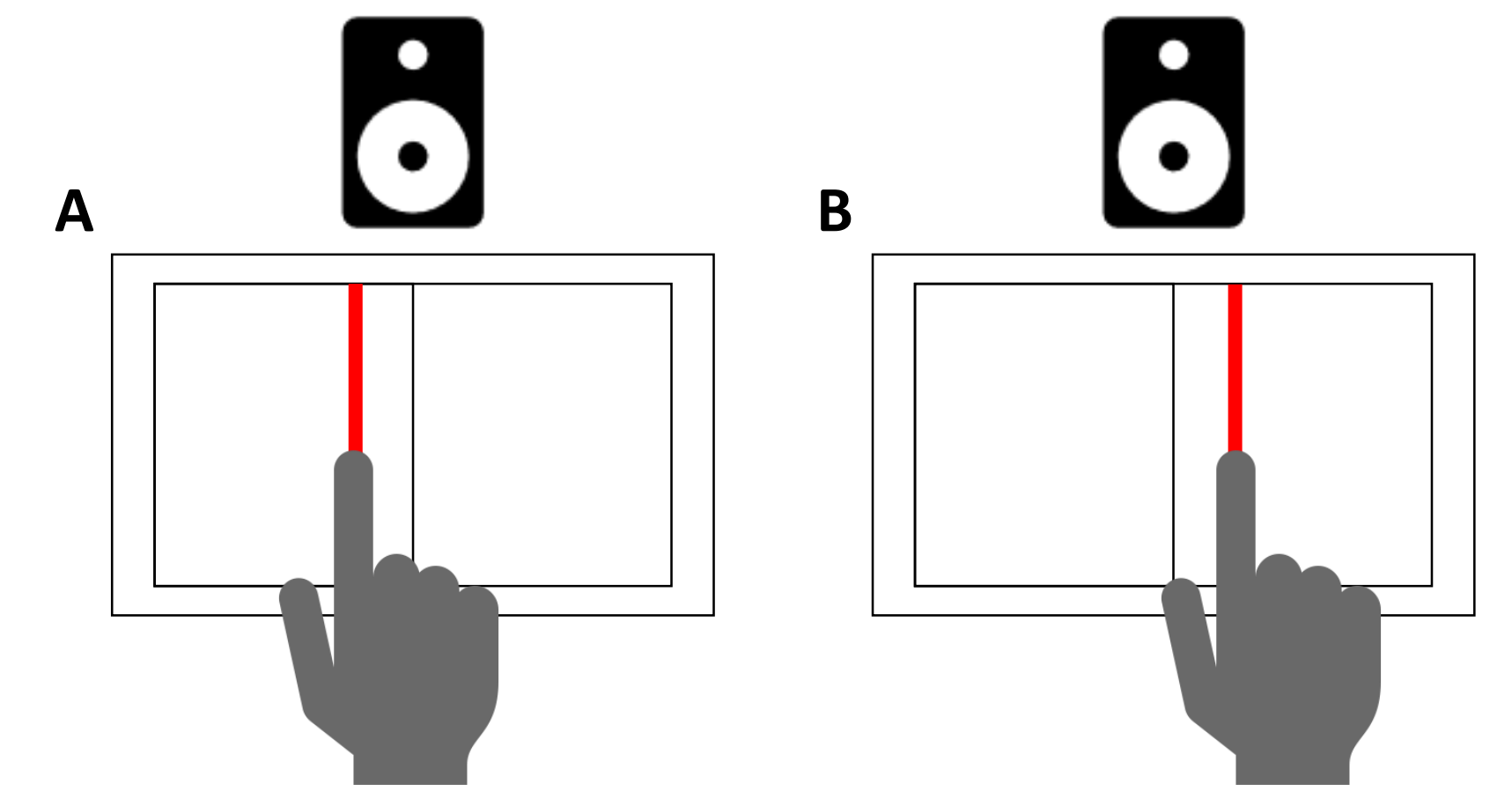


Figure 1. Stimulus presentation on the haptic display.

Experiment 1 (N=20): Conditions presented in separate blocks (12 blocks of 25 stimuli, 100 stimuli/condition, 300 total), participants aware of modality prior to each block.

Experiment 2 (N=20): Conditions interleaved within blocks (10 blocks of 30 stimuli, 10 stimuli/condition within block, 100 stimuli/condition across blocks, 300 total), participants not aware of modality prior to each trial.

Raw stimulus-response pairs refitted to a hierarchical probit model.

Results

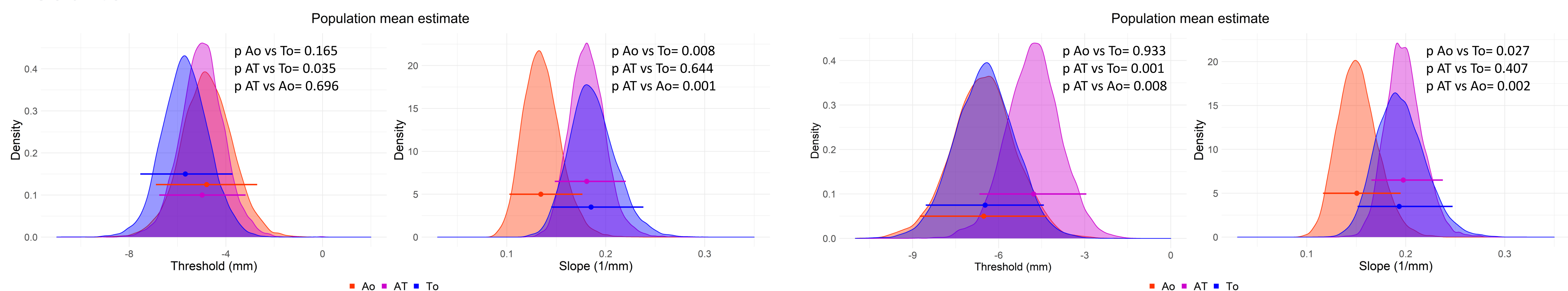


Figure 2: Population means estimate's posterior density for threshold and slope parameters in Experiment 1 (left) and Experiment 2 (right) from the three experimental conditions (Ao=auditory-only, To=tactile-only, AT=audio-tactile).

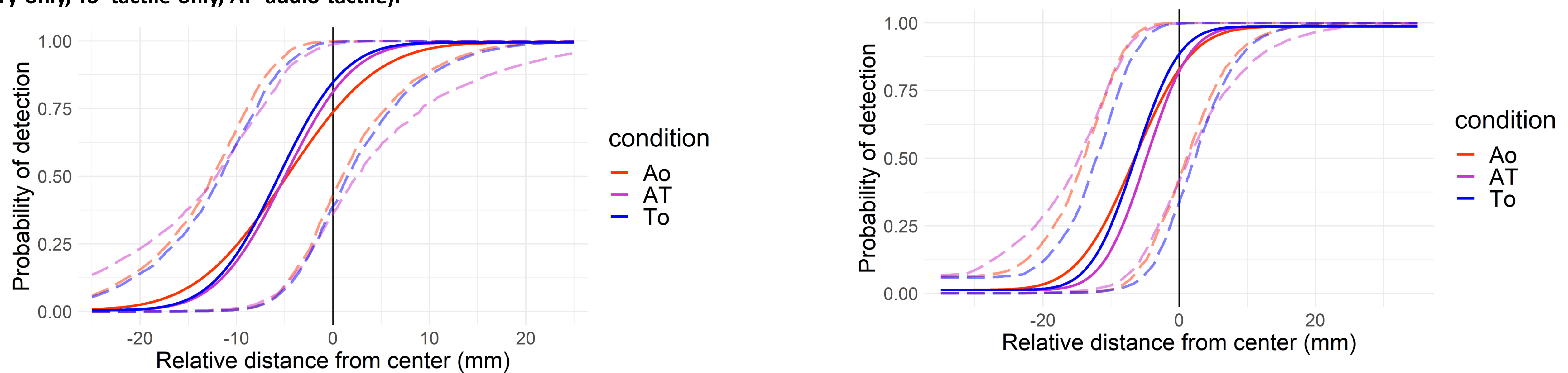


Figure 3: Posterior expected psychometric functions (PF) for Experiment 1 (left) and Experiment 2 (right). Bold lines represent the PF constructed with the most likely parameter values (i.e. the median of 10^4 random draws from the posterior distribution of the model parameters). Dotted lines represent the uncertainty around the posterior expected PF (95% highest probability density intervals).

Conclusions

The results from both experiments show that, in the context of localizing transient changes in tactile friction rendered via an US display, in conditions of active, dynamic touch, concurrent auditory stimulation does not improve localization precision compared to tactile stimulation alone, possibly due to the higher reliability/task relevance associated with the tactile compared to the auditory cues. Overall, our results indicate that participants relied more on tactile cues to perform the task. However, when modality could not be predicted (Experiment 2), we observed a reduction in localization bias in the bimodal compared to either unimodal conditions, suggesting that integration of auditory and tactile stimuli led to a more accurate spatial haptic representation, albeit without a significant reduction in uncertainty.

References

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