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Decoding of auditory and tactile perceptual decisions in parietal cortex

Seth M. Levine [a,c], Jens Schwarzbach [a,b,c,*]

[a] Center for Mind/Brain Sciences, University of Trento, Mattarello, Trentino, 38123, Italy
[b] Department of Psychology and Cognitive Science, University of Trento, Rovereto, Trentino, 38068, Italy
[c] Department of Psychiatry and Psychotherapy, University of Regensburg, Regensburg, 93053, Germany

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ABSTRACT

Perceptual decision making is the process in which stimuli of a rich environment are reduced to a single choice. Parietal cortex is involved in many tasks that require perceptual decisions such as attentional focusing, categorization, and eventually response selection. While much work in both the human and monkey domains has investigated processes related to visual decision making, relatively little research has explored auditory and tactile perceptual decisions. As such, we wanted to know whether these regions also play a role in auditory and tactile decision making. Using functional magnetic resonance imaging on humans and a paradigm specifically designed to avoid motor confounds, we found that one area in the right intraparietal sulcus, contained high-level abstract representations of auditory and tactile category-specific information. Our findings advance the idea that parietal cortex represents information that abstracts away from both the input and output domains.

1. Introduction

Parietal cortex has been linked to a variety of cognitive functions underlying perceptual tasks such as concept encoding (Simanova et al., 2014), flexible adaptation to task demands (Woolgar et al., 2011), and visual decision making (Hebart et al., 2012), which has raised the question about a common role of the parietal cortex in perceptual decision making. One stance posits that all decisions eventually lead to motor acts, and, therefore, the neural activity observed in frontoparietal areas represents motor intentions (Gold and Shadlen, 2001; Shadlen and Newsome, 2001; Cisek and Kalaska, 2005). Thus, such activity would not distinguish between deciding and acting, making these processes theoretically inseparable (Shadlen et al., 2008; Cisek and Kalaska, 2010). However, this view has been criticized by studies that have attempted to decouple perceptual categorization from motor acts (Freedman and Assad, 2006; Filimon et al., 2013).

Alternatively, one can posit that the role of parietal cortex in perception is to represent stimuli on different levels that abstract away from low-level properties, stimulus modalities (i.e., supramodal representations), and/or motor intentions (Eger et al., 2003; Freedman and Assad, 2006; Rishel et al., 2013). This raises the question of whether parietal cortex contains different compartments for different sensory modalities, or whether it contains supramodal representations or even supramodal functions. We tested these ideas in the auditory and tactile domains with functional magnetic resonance imaging (fMRI) and multivariate pattern analysis (MVPA; Haxby et al., 2001).

To investigate abstract auditory (aud) and tactile (tac) perceptual decision making in human cortex, we conducted two different fMRI experiments in which participants ($n_{aud} = 21$, $n_{tac} = 19$) performed a delayed match-to-category task (Fig. 1A) that consisted of categorizing the direction (up or down) of frequency-modulated (FM) auditory or tactile sweeps of various magnitudes (Fig. 1B). A given trial comprised a sample stimulus, a variable delay, and then a test stimulus. Participants were instructed to push a button when the sweep direction of the sample (S1) and test (S2) matched. This paradigm actively engages participants in the task, potentially recruiting cognitive mechanisms that would be otherwise untapped by a passive paradigm (McKee et al., 2014), and dissociates the overt response from stimulus categorization (Freedman and Assad, 2006).

2. Materials and methods

2.1. Participants and experimental sessions

Twenty-two (12 females and 10 males, 29.7 ± 8.7 (μ±σ) years old) and 20 (11 females and 9 males, 29.3 ± 7.8 years old) healthy subjects participated in the auditory and tactile experiments, respectively, after providing written consent. All procedures followed safety guidelines for

* Corresponding author. Department of Psychiatry and Psychotherapy, University of Regensburg, Universitätsstraße 84, 93053, Regensburg, Germany.
E-mail address: jens.schwarzbach@ukr.de (J. Schwarzbach).

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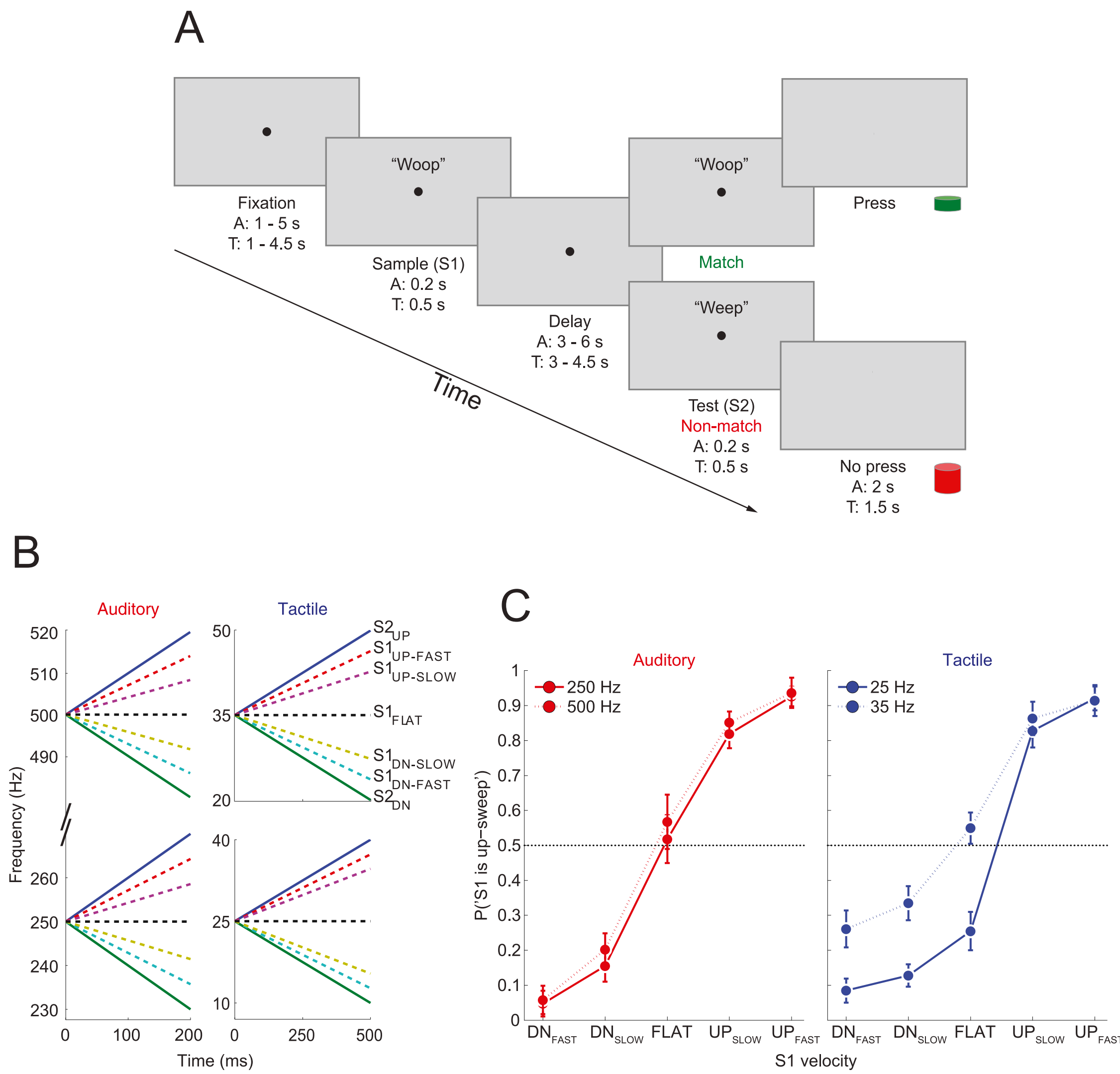

Fig. 1. Behavioral task and performance. (A) Example trial of the auditory delayed match-to-category task. 'Weep' and 'woop' portray up- and down-sweeps. The fixation dot disappeared during the intertrial interval (1000–4000 ms). (B) FM-sweep stimuli in the experiment. For each experiment, stimulus frequencies began at their respective y-axis intercepts and swept upward (blue, red, and purple lines) or downward (green, cyan, and gold lines) for 200 ms. S2 (solid lines) maintained constant sweep speeds, while those for S1 (dashed lines) were determined for each participant using an adaptive procedure[31]. Depicted S1's are average fast sweeps (red and cyan lines, A: ~70 Hz/s, T: ~12 Hz/s), average slow sweeps (purple and gold lines, A: ~40 Hz/s, T: ~9 Hz/s), and flat tones (black lines, 0 Hz/s). (C) Group-level probability that participants perceived S1 as an up-sweep for each of the stimulus velocities. Although no overt responses were given to S1, this information can be recovered from analyzing responses to S2, as a button press was required when S1 and S2 were of the same category. Dashed lines denote chance-performance; error bars represent within-subjects 95% confidence intervals.

MRI research in the Laboratory for Functional Neuroimaging at the Center for Mind/Brain Studies (CIMeC) and were approved by the ethics committee of the University of Trento. Subjects engaged in a threshold acquisition session prior to the main experiment. One participant's auditory dataset was removed from analyses due to the participant having allegedly fallen asleep during experimentation, and one participant's tactile dataset was removed from analyses due to unusually poor behavioral results ($Z(d') < -1.65$). Six participants took part in both experiments.

2.2. Auditory and tactile stimuli

The frequency sweeps were created using MATLAB R2013b (The Mathworks, Natick, MA, USA). Each auditory sweep was generated by a vector of frequencies that differed at each time point over 200 ms sampled at 44.1 kHz while each tactile sweep was a vector of differing frequencies over 500 ms sampled at 1Khz. Each auditory sweep's initial frequency was either 250 Hz or 500 Hz (alternating between runs), while each tactile sweep's initial frequency was either 25 Hz or 35 Hz (pseudorandomized across trials). The sweeps' final frequencies were determined by the condition of the trial (i.e., sweep direction: up/down and sweep speed: fast/slow/flat). All auditory stimuli had a 5 ms rise/fall amplitude envelope. Refer to Fig. 1B for a visual depiction of the stimuli.

2.3. Stimulus presentation

Auditory, tactile, and visual stimulation were carried out using ASF (Schwarzbach, 2011), built on the Psychophysics toolbox (Brainard, 1997) for MATLAB. Visual stimuli (black fixation dots on a gray background) were projected behind participants in the MR scanner onto a semitransparent screen by means of an LCD projector (Epson EMP 9000) at a frame rate of 60 Hz and a resolution of 1280 × 1024 pixels and were viewed via a mirror positioned above the head coil. Auditory stimuli were presented binaurally through MR-compatible headphones (SereneSound, Resonance Technology, Northridge, CA, USA). Tactile stimuli were presented to the tip of the left index finger using a piezo-electric stimulator (Quaerosys, Schotten, Germany), which contained a 2 × 4 matrix of pins (each 1 mm in diameter) that extended and retracted