

# Abstract Choice Representations Generalize Between Task Contexts

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## Abstract:

Humans can make abstract choices independent of motor actions. It is unclear under which conditions, where and when in the brain abstract choices are represented, and whether these representations generalize to contexts in which choices are linked to actions. To disentangle sensory, decision, and motor stages, we measured MEG signals in 33 participants during variants of a sensorimotor decision-making task with known and unknown choice-response mapping. Using multivariate decoding, we found reliable stimulus, choice and response information with distinct cortical source distributions. Choice representations were invariant to whether the response mapping was known at the time of stimulus presentation. Our results suggest the presence of widespread abstract choice representations, independent of sensory and motor representations.

**Keywords:** MEG; Decision making; Decoding; Abstract choices

## Introduction

Sensory decisions are often linked to an appropriate motor action. This has led to a framework of choices being represented as action intentions (Cisek & Kalaska, 2010). In addition, humans and other primates also make abstract choices when a suitable action is not known in advance. Task designs in which the mapping of choices to responses is only revealed after stimulus presentation have revealed neuronal representations of abstract choices in non-human primates and humans (Bennur & Gold, 2011; Horwitz, Batista & Newsome, 2004; Merten & Nieder, 2012; Hebart, Donner & Haynes, 2012; Ludwig, Herding & Blankenburg, 2018). It is unclear if these abstract choice-representations

generalize to choices that are linked to actions. While some recent evidence suggests choice representations in response-modality specific motor and premotor areas only when motor actions can be planned (Herding, Ludwig & Blankenburg, 2017; Ludwig, Herding & Blankenburg, 2018; Wang et al., 2019), other studies have shown choice signals in oculomotor areas before the choice-response mapping was specified (Bennur & Gold, 2011; Horwitz, Batista & Newsome, 2004).

We used magnetoencephalography (MEG) in human participants and employed multivariate decoding analyses to address two questions: First, are there motor- and stimulus-independent choice signatures in human MEG during both, presence and absence of a known motor mapping? Second, do abstract choice representations generalize between these two decision-making contexts?

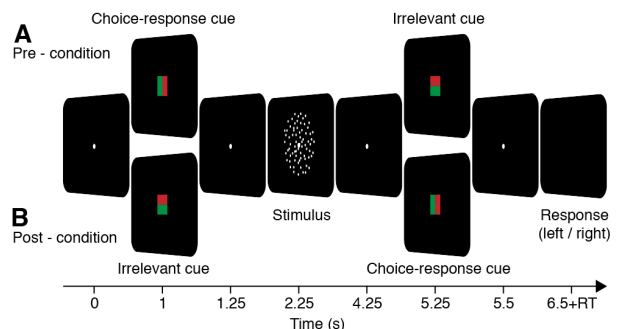


Figure 1: Behavioral Task. Participants decided whether there was coherent motion in a random dot stimulus. Responses were given according to a cue shown after or before stimulus presentation.

## Methods

We measured MEG in 33 healthy participants while they performed variants of a sensorimotor decision-making task (Fig. 1). Participants viewed random dot kinematograms and decided whether these contained coherent motion or not. In each trial, a cue indicated the mapping of a particular choice to a left- or right-hand button press either before (pre-cue – condition) or after the stimulus (post-cue – condition). Stimuli were presented near psychophysical threshold, allowing us to disentangle physical stimulation from perceptual choice and motor response.

Using multivariate decoding (cross-validated MANOVA; Allefeld & Haynes, 2014), we assessed the time-courses of stimulus-, choice-, mapping-, and response information. To estimate the cortical sources of information, we performed the decoding analysis in a searchlight-fashion. We employed cross-condition decoding to investigate whether choice-representations generalized between contexts. We assessed statistical significance using non-parametric cluster permutation tests. We tested the magnitude of cross-decoding against an estimate of cross-decoding under the assumption of identical patterns (similar to Spaak et al., 2017).

## Results

We found that all relevant task variables were decodable from MEG (Fig. 2). Crucially, we found information about participants' behavioral choices in both conditions, independent of stimulus identity and motor response. Source level analysis revealed that the cortical distribution of stimulus information was centered on early visual areas, while response information was present most strongly in motor areas. Choice information showed no distinct spatial peaks but was available throughout cortex in both conditions.

We then directly compared choice representations with known and unknown motor mappings using cross-decoding. There was significant cross-decoding with a time-course similar to the within-condition choice information. Importantly, empirical cross-decoding values were statistically indistinguishable from the expected cross-decoding for identical choice representations in pre- and post-cue conditions.

## Conclusions

Our results suggest the presence of abstract choice representations in the human brain also for choices linked to actions. Within the limits of MEG, these representations seem identical in both contexts, raising

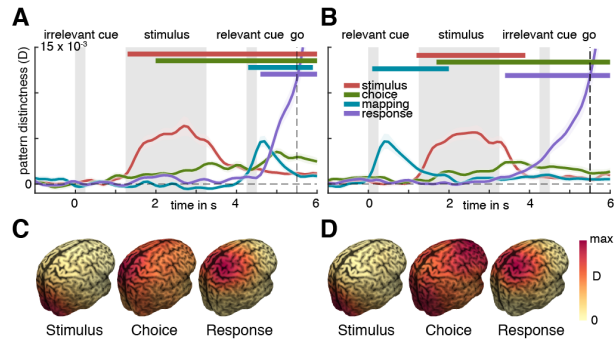


Figure 2: Stimulus, choice, mapping and response information is available (horizontal bars:  $p < 0.05$ , cluster permutation) in both post-cue (A, C) and pre-cue conditions (B, D).

the question whether the formation of abstract choices may be a general process in sensorimotor decision making.

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