This Decision Matters: Sorting out the Factors that Lead to a Single Choice

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Abstract:

While cognitive neuroscientists have uncovered principles of perceptual decision-making by analyzing choices and neuronal firing across thousands of trials, we do not yet know the behavioral or neuronal dynamics underlying one SINGLE choice. For instance, why might a subject judge a given stimulus in category A 70% of the time and in category B 30%? Until we can work out what determines precisely this decision, right now, the mechanisms of single-choices, real-world decision-making (where the agent frequently has just one opportunity) will remain unknown. In tactile psychophysical tasks with rats and humans, we are sorting out factors that explain the variability in judgments (across trials) to the identical stimulus input. We identify four factors: (i) trial-to-trial fluctuations in sensory coding, (ii) temporal context, namely, the history of preceding stimuli and choices, (iii) attention, and (iv) bias, namely, predictions originating in beliefs about the environment's probabilistic structure. The strategy is to bring these factors under experimental control, rather than leaving them to vary according to uninterrogated states within the subject. Psychophysics from rats and humans show that large chunks of variability are accounted for by these factors; evidence from cortical neuronal populations in rats provides some mechanistic grounding.

Keywords: psychophysics; decision-making; tactile; perception

Introduction: perceptual decision-making in rats

Although cognitive neuroscientists have uncovered general principles of perceptual decision-making by analyzing choices and neuronal activity across thousands of trials, we still lack a deep understanding of the behavioral and neuronal dynamics behind *individual* choices. Thus, we can outline the stages of cortical processing underlying the detection of motion direction, but we do not know how a person will assess traffic before crossing the street. Until we decipher the mechanisms governing single-episode choices, the enigma of real-world decision-making will persist.

Parallel psychophysical studies in rodents and humans are informative. Until some 10 years ago, neuroscientists attributed a wide range of perceptual functions to primates but not to rodents. However, as methodologies adapt to natural deportment, rodents have been found to express a surprising range of abilities. Rats hold stimuli in working memory with performance akin to that of humans and monkeys (Fassihi, Akrami, Esmaeili, & Diamond, 2014), integrate separate sensory modalities to create a supramodal object representation (Nikbakht, Tafreshiha, Zoccolan, & Diamond, 2018; Raposo, Sheppard, Schrater, & Churchland, 2012), assess reward statistics (Karlsson, Tervo, & Karpova, 2012), indicate their degree of confidence in the outcome of their choices (Lavan, McDonald, Westbrook, & Arabzadeh, 2011), and extract a rule from a specific task and generalize it to novel experiences (Kuchibhotla & Bathellier, 2018).

Rodents are ever more fulfilling their promise of expressing high level sensory-perceptual cognition (Carandini & Churchland, 2013); importantly, they achieve such cognition through the workings of neuronal circuits that are accessible (Summerson & Kemere, 2015), decodable (Panzeri, Harvey, Piasini, Latham, & Fellin, 2017), and manipulatable (Yizhar, Fenno, Davidson, Mogri, & Deisseroth, 2011). Our approach is to use rats to bring under experimental control the complete set of factors that modulates choices, with the aim of understanding exactly why a given decision will be made on a given trial.

Vibration judgments assessed by the psychometric curve

The behavioral task we have focused on over the past 10 years is the judgment of the features making up a stochastic, or "noisy," vibration (Akrami, Kopec, Diamond, & Brody, 2018; Diamond & Toso, 2023; Fassihi et al., 2014; Reinartz et al., 2024; Toso, Fassihi, Paz, Pulecchi, & Diamond, 2021; Yousefi Darani, Hachen, & Diamond, 2023). A string of trials is shown in Figure 1A. In experiments where vibration amplitude (intensity), must be categorically judged as "weak" or "strong" rats yield psychometric curves similar to those of humans, but with greater lapses, as seen in Figure 1B.

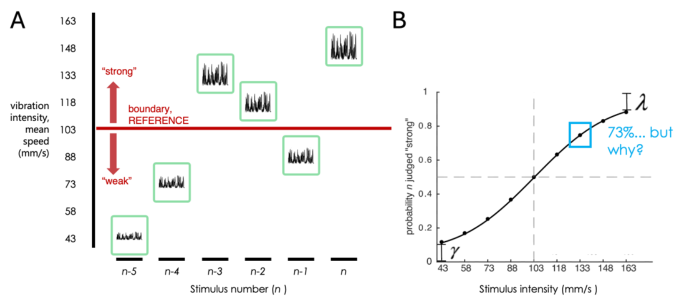

Figure 1. (A) Sequence of tactile stimuli from trial *n-5* to trial *n*. (B) Psychometric curve obtained from a large set of rats.

We pose the single-trial puzzle in reference to the illustrated psychometric curve. For the stimulus of intensity 133 (mm/s), what determines the single-trial judgment as "strong" or "weak" (see blue box)? On 73% of trials that stimulus amplitude will be judged as "strong," but what factors lead the same stimulus to be judged as "weak" on 27% of trials?

Dissection of the factors that explain the choice made on an individual trial

Our working model poses four major factors as playing out in each choice (Figure 2).

Let us consider factors 1-4, in order. First, we will show that, when rats classify tactile vibrations according to perceived intensity, trial-to-trial modulations of the sensory code, enacted by optogenetic intervention, systematically shift psychometric curves. These findings show how small differences in sensory coding affect the single choice. Second, we will show that the choice on trial *n* is systematically shaped by preceding trials, both the stimuli within those trials and the decisions made on them. These findings show how history (stimuli, choices, rewards) affects the choice on the current trial. Third, we will bring the rat's attention under experimental control. In a new paradigm, two stimuli are delivered on each trial; the rat must ignore one stimulus – the distractor – and act upon the relevant one. We have found that the neuronal representation of the distractor stimulus is suppressed in the transmission from sensory cortex to frontal cortex. These findings show how attention, or lack thereof, may affect the choice on the current trial. Finally, we will bring the rat's belief about the probability structure of the environment under experimental control. This is done by creating non-random transition probabilities of reward location across trials, such that the rat can make a prediction about likely reward location, and then receive a sensory input that either confirms or overturns its expectation about the upcoming choice.

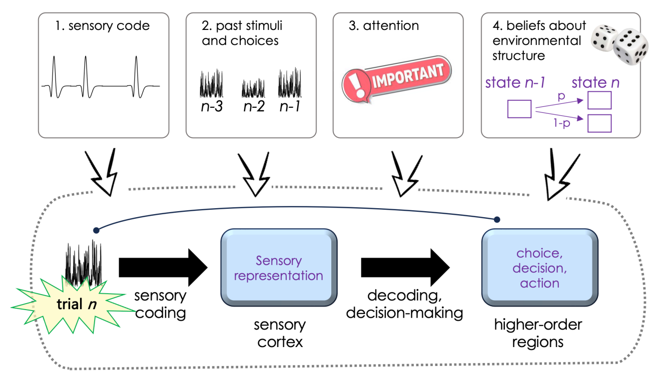

Figure 2. How is trial *n* judged? In our framework, a cortical sensory representation (lower stream) is transmitted to downstream regions where a transformation to decision and action is executed. Four factors, depicted by the boxes above the processing stream, are argued to interact with this processing stream and, together, to account for most of the trial-to-trial variability in the choice made upon a given stimulus input.

Most of the behavioral findings are replicated in humans. In sum, we will present an approach for shifting from average decision making to single decisions and will present evidence for multiple factors that are at work when one sensory input is judged and converted to a decision.

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