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The neural mechanism underlying the effects of preceding contexts on current categorization decisions

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ABSTRACT

Preceding contexts strongly influence current decision-making. To elucidate the neural mechanism that underlies this phenomenon, magnetoencephalographic signals were recorded while participants performed a binary categorization task on a sequence of facial expressions. The behavioral data indicated that the categorization of current facial expressions differed between the contexts shaped by the immediately preceding expression. We found that the effects of the preceding context were linked to prestimulus power activities in the low-frequency band. However, these context-dependent neural markers did not reflect behavioral decisions. Rather, the beta power observed primarily after stimulus onset and located at distinct sensors was predictive of the trial-by-trial decisions. Despite these results, the coupling strength between context-dependent and decision-related power differed between preceding contexts, suggesting that the context-dependent power interacted with decision-related power in a systemic manner and in turn biased behavioral decisions. Taken together, these findings suggest that categorization decisions are mediated by a series of power activities that coordinate the influence of preceding contexts on current categorization.

1. Introduction

Decisions are not made in isolation. Instead, they are often made within a rich context shaped by previous material. Indeed, it has long been established that preceding contexts play a crucial role in biasing current decision-making, as was conceptualized by the adaptation-level theory (Helson, 1964) or the framing effect for example (Tversky and Kahneman, 1981). However, most prior studies have focused on characterizing the flow of neural information in mediating decisions about current percepts, largely ignoring the role of preceding contexts (Freedman et al., 2003; Heekeren et al., 2004; Philiastides and Sajda, 2006). Although a few neuroimaging studies have attempted to determine how prior information is represented in the brain (Gorlin et al., 2012; Preuschhof et al., 2010; Summerfield and Koechlin, 2008), the neural mechanism underlying how a decision is dynamically adjusted according to preceding contexts remains unclear.

To understand the influence of preceding contexts on current decision-making, the present study capitalized on sequential effects during categorization decisions. This trial-to-trial transition effect has been widely investigated in previous behavioral research (Hampton et al., 2005; Stewart et al., 2002; Zotov et al., 2011). When categorizing a sequence of facial expressions in which the physical features of the stimuli morph continuously between two categories of emotion, a recent study (Hsu and Yang, 2013) has shown that the categorical judgments of the current expression vary according to the local sequential context provided by the *immediately* preceding expression. For example, there is a decreased categorization accuracy to a morphed fearful expression when it is preceded by a *distant* fearful prototype (large morphing distance to the current stimulus) as opposed to a *nearby* fearful morph (small morphing distance to the current stimulus). However, these sequential effects are limited to two successive stimuli, as the preceding context provided by the expression presented two trials earlier has little impact on the categorization judgment of the current expression. Although the underlying psychological mechanism remains inconclusive, behavioral and modeling studies have suggested that sequential effects involve using relative difference information between successive items to inform categorization decisions (Hampton et al., 2005; Stewart et al., 2002). According to these models, when the interstimulus distance is large (e.g., a distant preceding fearful prototype vs. a current fearful morph), participants tend to categorize the current stimulus as further from the category of the preceding stimulus (fewer "fear" decisions for the current stimulus). This decision bias may result from a shift in internal criteria for the current category representation after viewing a distant preceding stimulus: the criterion-shift account (Treisman and Williams, 1984; Zotov et al.,

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2011). Alternatively, the bias may reflect the use of a similarity/dissimilarity comparison between the preceding and current stimuli as evidence for categorization decisions; in other words, two dissimilar stimuli are perceived as belonging to two distinct categories: the similarity/dissimilarity account (Stewart and Brown, 2005).

In this study, participants performed a similar binary categorization task on a sequence of facial expressions that included continua of morphs ranging from fearful to neutral, while magnetoencephalography (MEG) signals were recorded. This methodology allowed us to capture the temporal dynamics concerning how neural activity at various processing stages coordinates the influence of sequential contexts provided by preceding facial expressions on the categorization of a current facial expression. Previous studies have suggested that spectral analysis of beta- and gamma-band activity and frequency-specific neural connectivity are particularly valuable for providing mechanistic information regarding decision processing (Hipp et al., 2011; Siegel et al., 2011). Therefore, the goals of this study were to identify the power activities underlying the expression-based sequential effects revealed from behavioral performance and subsequently to characterize how these activities ultimately shape categorization decisions.

2. Materials and methods

2.1. Participants

A total of 17 right-handed participants with no neurological or psychiatric history participated in this study (13 males, mean age = 28 years, range = 23–32 years). All participants had normal or corrected-to-normal vision and provided written informed consent prior to their participation.

2.2. Stimuli

Ten continua of morphed facial expressions from fearful to neutral were generated using FantaMorph (Abrosoft). In each continuum, a neutral prototype was morphed 12.5%, 25%, 37.5%, 50%, 62.5%, 75%, and 87.5% of the physical distance to an *identity-matched* fearful prototype, resulting in 9 face images (Fig. 1A). The stimuli within each continuum were adjusted and matched according to low-level physical attributes, such as luminance, using the SHINE toolbox (Willenbockel et al., 2010). Prototypical examples of fearful and neutral expressions were selected from the FEEST database (Young et al., 2002). A total of 90 face stimuli were used (10 continua with distinct identities × 9 stimuli per continuum). The face images subtended a horizontal visual angle of 2.4° and a vertical angle of 2.7° around the center of the screen. The stimulus presentation was controlled using Psychtoolbox (Brainard, 1997).

2.3. Procedure

Each trial began with a fixation cross located at the center of the screen for 600–800 ms, followed by the presentation of a facial expression for 300 ms and then a blank screen for 250 ms. Next, a response window was displayed with two choices, “fearful” and “neutral”, placed on either side of the fixation cross. The positions of these response choices were randomized across trials. Participants had up to 3 s to categorize the face they had just viewed as fearful or neutral by pressing a button with their right index or middle finger. Performance feedback was not provided. The button press initiated a new trial after a 1400–1800 ms inter-trial interval. The participants took part in two sessions on separate days, with 3 repetitions per continuum. In each session, the participants completed 15 blocks, with a break between blocks. The trials were blocked by continuum. Within each block, each face was randomly repeated 9 times, resulting in a total of 81 trials (9 repetitions × 9 faces per continuum). The participants first completed 1–2 blocks of practice trials to familiarize themselves with the procedure. The practice trials included a separate set of face continua that were not used in the actual experiment.

A central goal of this study was to understand how categorization decisions on current stimuli varied according to the preceding contexts. Because evidence has shown that sequential contexts exert the strongest influence on the categorization of ambiguous stimuli (Hampton et al., 2005; Hsu and Yang, 2013; Stewart et al., 2002; Zotov et al., 2011), all of our analyses focused exclusively on ambiguous expressions at the boundaries between two emotion categories, where the percentages of “fearful” and “neutral” responses were approximately 50%. This analysis strategy may also allow us both to examine how categorization

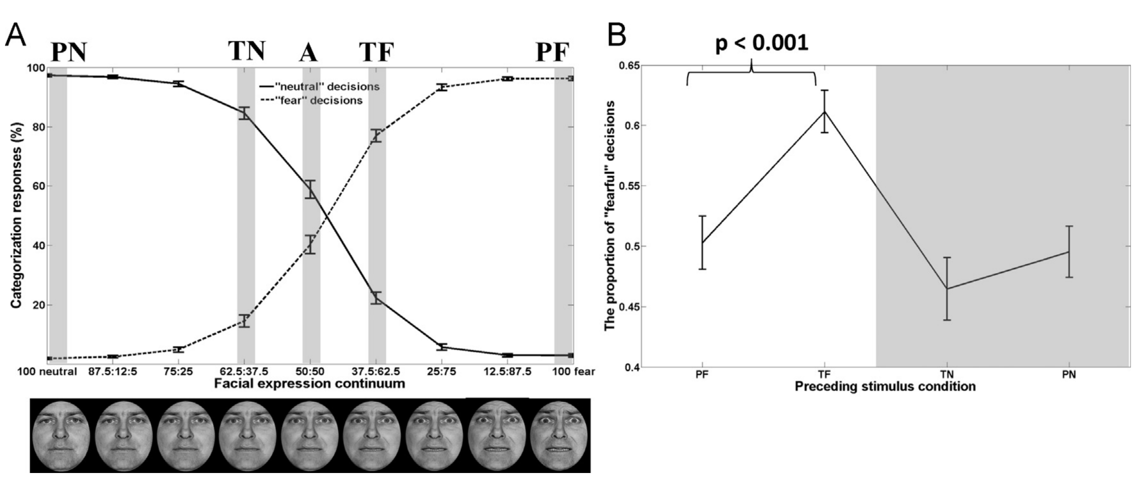

Fig. 1. Behavioral performance. (A) Categorization of facial expressions in one representative continuum. The expression continuum progresses from the fearful prototypes to the neutral prototypes in 8 steps. The notations PF, TF, A, TN and PN represent the fearful prototypes, the fearful morphs that were closest to the ambiguous expressions, the ambiguous expressions, the neutral morphs that were closest to the ambiguous expressions and the neutral prototypes, respectively. Notably, because the category boundary was located between the 62.5:37.5 and 37.5:62.5 fearful:neutral morphs across continua and individuals, the gray bars in the figure simply provide an example of how the expression stimuli were selected to analyze the sequential effects. Error bars represent ± SEM. (B) The proportion of “fearful” categorization decisions of the current ambiguous expressions as a function of the four preceding expression types. The shaded region indicates that the preceding stimuli are from the “neutral” category. Error bars represent ± SEM.