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EFFECT OF TARGET PROBABILITY ON PRE-STIMULUS BRAIN ACTIVITY

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Abstract—Studies on perceptual decision-making showed that manipulating the proportion of target and non-target stimuli affects the behavioral performance. Tasks with high frequency of targets are associated to faster response times (RTs) conjunctively to higher number of errors (reflecting a response bias characterized by speed/accuracy trade-off) when compared to conditions with low frequency of targets. Electroencephalographic studies well described modulations of post-stimulus event-related potentials as effect of the stimulus probability; in contrast, in the present study we focused on the pre-stimulus preparatory activities subtending the response bias. Two versions of a Go/No-go task characterized by different proportion of Go stimuli (88% vs. 12%) were adopted. In the task with frequent go trials, we observed a strong enhancement in the motor preparation as indexed by the Bereitschaftspotential (BP, previously associated with activity within the supplementary motor area), faster RTs, and larger commission error rate than in the task with rare go trials. Contemporarily with the BP, a right lateralized prefrontal negativity (lateral pN, previously associated with activity within the dorsolateral prefrontal cortex) was larger in the task with rare go trial. In the post-stimulus processing stage, we confirmed that the N2 and the P3 components were larger for rare trials, irrespective of the Go/No-go stimulus category. The increase of activities recorded in the preparatory phase related to frequency of targets is consistent with the view proposed in accumulation models of perceptual decision for which target frequency affects the subjective baseline, reducing the distance between the starting-point and the response boundary, which determines the response speed. © 2016 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: event related potentials (ERPs), Bereitschaftspotential (BP), prefrontal negativity (pN), stimulus probability, speed–accuracy system, decision-making.

INTRODUCTION

Behind the response to a target, a cascade of neurocognitive processes has been described starting from early phases of response readiness, passing through sensory perception and decision-making, and ending with the response execution (e.g. Di Russo et al., 2016). The behavioral output of this processing chain is usually quantified measuring the speed and the accuracy of the response. The proverb "haste makes waste" well summarizes the idea that acting excessively fast does not allow to reach high accuracy; rather, good performance requires a compromise between speed and accuracy. In cognitive psychology this compromise is known as speed–accuracy tradeoff (SAT), which is a basic property of decisional behaviors, nearly ubiquitous in animal kingdom (for a review, see Heitz, 2014). A model addressing the issue of the SAT is the "Diffusion Model" (for a review, see Ratcliff et al., 2005). This model assumes that decisions are made by a process that accumulates evidences over time from a *starting point* (subjective response bias), and the response is made when a *response criterium* is reached. The rate of evidences' accumulation is called *drift rate*, and it is related to the quality of the information extracted from the presented stimulus. According to this model, increasing response speed in case of constant *drift rate* is due to an increased distance between the *starting point* and *response criterium*. In other words, the large distance between *starting point* and *response criterium* leads subjects to a conservative approach, i.e., they need to accumulate more evidence before giving responses, and/or have priori biases in the decision thresholds (Voss et al., 2013).

Recently, the neuroscience literature renewed its interest in the neural basis of SAT, reporting the contribution of cortical areas, such as the pre-Supplementary Motor Area (pre-SMA) and the dorsolateral prefrontal cortex (DLPC), and subcortical structures, such as basal ganglia (for a review, see Bogacz et al., 2010).

A recent study of our laboratory (Perri et al., 2014a) investigated the neural basis of SAT by means of event-related potentials (ERPs) recorded during an equiprobable Go/No-go task. The authors extracted from a large database the data of subjects, which *a posteriori* showed a spontaneous tendency to be very fast or very accurate. The speed and the accuracy of the performance were

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Abbreviations: ANOVA, Analysis of Variance; BP, Bereitschaftspotential; CEs, commission errors; DLPC, dorsolateral prefrontal cortex; EEG, electroencephalographic; ERPs, event-related potentials; LRP, Lateralized Readiness Potential; Oms, omission errors; PFC, prefrontal cortex; pN, prefrontal negativity; RTs, response times; SAT, speed–accuracy tradeoff; SMA, Supplementary Motor Area.

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associated to the activity of two neuronal systems, which were characterized by their own electrophysiological signatures starting already one second before stimulus presentation. Specifically, the activity of the SMA was associated to the baseline level of the ‘‘speed system”; its electrophysiological correlate was the Bereitschaftspotential (BP), a long-lasting negativity with larger activity over central sites, which is typically observed in response-locked ERP (Shibasaki and Hallett, 2006), and also in stimulus-locked ERP (Di Russo et al., 2013, 2016; Berchicci et al., 2014). In Perri et al. (2014a), a right-lateralized prefrontal negativity (pN) associated with activity of the right prefrontal cortex (PFC) was proposed to play a key role in the regulation of the baseline level of the ‘‘accuracy system”. To summarize, the main result of Perri et al. (2014a) was that in subjects with a spontaneous personal tendency to be extremely fast or extremely accurate, the faster were the response times (RTs), the larger was the BP component; and conversely, the more accurate the performance, the smaller the lateral pN on the right-side. Further, the BP and the lateral pN amplitudes correlated, indicating an interaction between the two systems. Notably, both these components develop largely before stimulus onset, i.e., in the early preparatory phase of the response.

In the present study, we investigated whether the BP and the lateral pN components are affected by an external factor, i.e., the proportion of go stimuli. Response stimulus frequency has an effect on decision processing; this effect is generally a reduction of the speed of response and an increase and errors (SAT; e.g. Bruin and Wijers, 2002; Nieuwenhuis et al., 2003; Lavric et al., 2004), although also a reduction of errors was shown in some tasks (e.g. Leite and Ratcliff, 2011) due to the involvement of perceptual learning (Zang and Rowe, 2014). However, little is known on the effect of the proportion of go stimuli on the neural processing that takes place *before* stimulus presentation, i.e., in the preparatory phase. In fact, previous ERP studies investigating the effect of stimulus frequency in Go/No-go tasks focused on post-stimulus components and observed an enhancement of the late N2 and the P3 components for low-frequency stimuli, regardless the stimulus category (Nieuwenhuis et al., 2003; Donkers and van Boxtel, 2004; for a review see Folstein and van Petten, 2008). According to the conflict monitoring theory, the N2 amplitude (and to some extent the P3) may reflect the cognitive conflict level, which is typically greater after a ‘‘novel” (i.e., rare) stimulus (Botvinick et al., 2001). While the effect of stimulus frequency on post-stimulus components is well assessed, few studies considered the preparation phase. In a two-choice task in which the subjects responded with the left or right hand (Gehring et al., 1992) Lateralized Readiness Potential (LRP) was measured. About 100 ms before stimulus, LRP was evident contralateral to the hand associated to the frequent (80%) stimulus, indicating that the subjects prepared their habitual motor response in advance. However, we failed to found studies investigating the effect of stimulus frequency in Go/No-go tasks focusing on the early preparatory stages, as reflected by BP and pN components. Thus, we investigated this point.

We used two versions of the Discriminative Response Task (DRT): one version had frequent go and rare no-go stimuli; the other version had rare go and frequent no-go stimuli. At behavioral level, if the task involves perceptual learning one could expect improvement of both RTs and accuracy when go stimuli are frequent (Leite and Ratcliff, 2011); however, we minimized learning and consequently we expected to find fast RTs and low percentage of commission errors (CEs) in the frequent-go task, and vice versa slow RTs and high percentage of CE in the rare-go task. At electrophysiological level, Perri et al.’s (2014a) results suggested that these response biases should be associated with the BP and the lateral pN components, which may mark activities of speed and accuracy system, respectively. As for the direction of the effects, Perri et al.’s (2014a) data suggest that the faster and less accurate subjects should have both larger BP and lateral pN. However, note that those data were collected in subjects with extreme individual tendency to be fast or accurate, which is not the same as manipulating an experimental parameter. In contrast, we have clear expectation about post-stimulus components. We expect to replicate previously reported findings on the N2 and the P3 components. Thus we expect enhancement of both N2 and P3 related to rare stimuli (for a review, see Folstein and van Petten, 2008).

EXPERIMENTAL PROCEDURES

Participants

Thirty-four right-handed volunteers participated in the study (14 males; mean age 24, years; SD ± 4.8). All subjects were healthy, had no history of neurological, psychiatric or chronic somatic diseases, and were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971). After a full explanation of the procedures, the subjects provided their written informed consent prior to the experiment. The study and the procedures were approved by the IRCCS Santa Lucia Foundation of Rome ethics committee.

Stimuli, procedure and task

Four visual stimuli (i.e., four squared configurations made by vertical and horizontal bars) were randomly presented for 260 ms with equal probability. Two stimuli were defined as targets (go stimuli) and the other two as non-targets (no-go stimuli). We manipulated the occurrence frequency of go e no-go stimuli, obtaining two experimental conditions: (a) Go-Rare/No-Go-Frequent (hereafter Go-Rare) condition (i.e., 12% of go stimuli vs. 88% of no-go stimuli); (b) Go-Frequent/No-Go-Rare (hereafter Go-Freq) condition (i.e., 88% of go stimuli vs. 12% of no-go stimuli). To avoid perceptual learning effects, subjects were randomly assigned to one of the two conditions, obtaining two groups of seventeen subjects. Three subjects executed both tasks in separate sessions. Before starting the experiment, a warming-up block (100 trials) was presented. In both tasks, the ISI was fixed at 2000 ms. The entire experiment consisted of 10 blocks, each one containing