International Journal of Psychophysiology 99 (2016) 103–107

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Switches of stimulus tagging frequencies interact with the conflict-driven control of selective attention, but not with inhibitory control

Stefan Scherbaum *, Simon Frisch, Maja Dshemuchadse

Department of Psychology, Technische Universität Dresden, Germany

ARTICLE INFO

Article history:
Received 27 August 2015
Received in revised form 20 November 2015
Accepted 21 November 2015
Available online 22 November 2015

Keywords:
Frequency tagging
Steady state visual evoked potentials
EEG
Selective attention
Cognitive control
Conflict adaptation
Inhibition

ABSTRACT

Selective attention and its adaptation by cognitive control processes are considered a core aspect of goal-directed action. Often, selective attention is studied behaviorally with conflict tasks, but an emerging neuroscientific method for the study of selective attention is EEG frequency tagging. It applies different flicker frequencies to the stimuli of interest eliciting steady state visual evoked potentials (SSVEPs) in the EEG. These oscillating SSVEPs in the EEG allow tracing the allocation of selective attention to each tagged stimulus continuously over time. The present behavioral investigation points to an important caveat of using tagging frequencies: The flicker of stimuli not only produces a useful neuroscientific marker of selective attention, but interacts with the adaptation of selective attention itself. Our results indicate that RT patterns of adaptation after response conflict (so-called conflict adaptation) are reversed when flicker frequencies switch at once. However, this effect of frequency switches is specific to the adaptation by conflict-driven control processes, since we find no effects of frequency switches on inhibitory control processes after no-go trials. We discuss the theoretical implications of this finding and propose precautions that should be taken into account when studying conflict adaptation using frequency tagging in order to control for the described confounds.

1. Introduction

Selective attention and its flexible adaptation to environmental demands by cognitive control processes are a central prerequisite for goal directed behavior. To study the temporal evolution of these processes, EEG frequency tagging has gained momentum in recent years: It tags stimuli with flicker frequencies to elicit steady state visual evoked potentials (SSVEPs), oscillations in the EEG. The amplitude of these oscillations in the EEG indicates the time continuous allocation of attention (Andersen and Müller, 2010; e.g. Fuchs et al., 2008; Keil et al., 2003; Müller et al., 1998). While most studies use frequency tagging to investigate attention *within trials*, the technique also allows tracing attention *across trials*, i.e. to study adaptation by control processes from trial to trial. Here, we investigate, whether the used tagging frequencies can themselves become relevant for the adaptation of selective attention by control processes *across trials* and hence whether tagging frequencies are not only a tool to trace control processes, but influence control processes in their own right. This would indicate the need of precautions when using frequency tagging to study processes across trials.

1.1. Tracing selective attention continuously with frequency tagging

Selective attention is thought of as a top-down bias that facilitates the processing of goal-relevant sensory stimulation and which is adapted continuously to changing task demands through cognitive control processes (Cohen et al., 1990; Desimone and Duncan, 1995; Miller and Cohen, 2001; Scherbaum et al., 2012). In the study of selective attention and its adaptation, frequency tagging complements classical neuroscientific methods – fMRI and event related potentials (ERPs) (e.g. Egner and Hirsch, 2005; Nigbur et al., 2011; Stürmer et al., 2002, 2009) – as it allows tracing the temporal evolution of the processes underlying selective attention (Andersen and Müller, 2010; Fuchs et al., 2008; Müller et al., 1998) continuously from the begin of a trial until its end (e.g. Morgan et al., 1996; Müller and Hübner, 2002; Müller et al., 1998). For example, in a number discrimination task, two digits could be presented simultaneously on the screen, one digit flickering with a frequency of 9 Hz and the other one with a frequency of 12 Hz (Scherbaum et al., 2011). The flickering of the stimuli elicits SSVEPs of their specific frequencies, i.e. 9 Hz and 12 Hz, in the EEG of participants. The amplitude of these SSVEPs is sensitive to attentional modulation (Morgan et al., 1996): If attention is directed to the digit tagged with a 9 Hz flicker, the amplitude of the 9 Hz potential will be increased during the course of a trial and the amplitude of the 12 Hz potential will be attenuated. Thus, by determining the amplitudes of different SSVEPs over

* Corresponding author at: Department of Psychology, Technische Universität Dresden, Zellescher Weg 17, 01062 Dresden, Germany.
E-mail address: Stefan.Scherbaum@tu-dresden.de (S. Scherbaum).

http://dx.doi.org/10.1016/j.ijpsycho.2015.11.012
0167-8760/

the course of single trials, researchers are able to trace the allocation of covert attention to each frequency tagged stimulus. Accordingly, SSVEP amplitude as a marker of attentional deployment has been shown to correlate reliably with behavioral performance (Andersen and Müller, 2010; Müller et al., 1998), thus attesting to the validity of the frequency tagging method.

1.2. The interaction of stimulus flicker and cognitive control

By having stimuli flicker in different frequencies, an additional feature is added to the stimuli and this feature needs to be controlled for experimentally. Indeed, most SSVEP based studies balance the assignment of flicker frequencies to stimuli or check for basic influences of flicker frequencies *within trials*, e.g. on RT (e.g. Müller et al., 2006; Störmer et al., 2013). It seems that in principle, cognitive processing is robust against influences of flicker, as evident in equal RT for a variety of flicker frequencies. However, in a recent study (Scherbaum et al., 2011), a higher order effect of flicker frequencies was discovered, concerning the interaction of switches in flicker frequency and cognitive control processes *across trials*. In this study, SSVEPs were used to investigate the adaptation of selective attention and cognitive control in the face of conflict between a target stimulus and distracter stimuli (digits) at different spatial locations in an adapted version of the Eriksen Flanker Task (Eriksen and Eriksen, 1974). The authors expected conflict between target and distracters in one trial to increase attentional selection of the target in the following trial, as proposed by conflict monitoring theory (Botvinick et al., 2001; Egner and Hirsch, 2005). The measured SSVEPs of target and distracters showed this hypothesized *conflict adaptation* and underlined the merits of frequency tagging in this context. However, the study also indicated an interaction of flicker frequency and control processes, both in behavioral and neural data: while the conflict adaptation effect was stable when flicker frequencies of targets and distracters were kept *constant across trials*, the conflict adaptation effect reversed when flicker frequencies of target and distracters *switched from one trial to another*. Hence, aside from providing a measure for the adaptation of selective attention, the flicker frequencies interacted with control processes on their own.

Here, we ask whether this interaction of flicker frequencies and control processes is a very specific phenomenon that could only be found for control processes involved in conflict adaptation or if it generalizes to other attentional processes across trials, i.e. inhibitory control as indicated by stop-signals. Furthermore, we aimed to check whether the use of more distinct flicker frequencies influenced this generalization. If the interaction generalized to other processes (and frequencies), it would ask for rigid precautions when using SSVEPs for the study of selective attention and cognitive control *across trials*. Therefore, the behavioral study presented here aimed to check for the generalizability of the interaction between switches in cognitive control processes, first by studying the effect of switches in tagging frequencies on both, conflict adaptation and inhibitory top-down control, and second by using slightly different flicker frequencies compared to the original study. To this end, we mainly followed the design of the original study by Scherbaum et al. (2011). We used the same flanker task (Eriksen and Eriksen, 1974) and analyzed standard trials, in which participants had to respond to a centrally presented target digit with a key-press while ignoring surrounding distracter digits, and so-called no-go trials, in which a stop-signal appeared at the location of the distracters indicating to withhold/inhibit the key-press associated with the shown target stimulus.

We were interested in three behavioral effects that would typically be expected in this task. First, trials with corresponding – or response-congruent – target and distracter digits should show faster RT than trials with conflicting – response-incongruent – target and distracter stimuli (compare Simon, 1969; Simon et al., 1976; Stroop, 1935). This *congruency effect* indicates a cost of selecting the relevant information in a distracting environment. In the original study, this basic effect was not influenced by frequency-switches.

Second, the congruency effect has been shown to vary in dependence on previously experienced conflict such that trials following an incongruent trial show a smaller congruency effect than trials following a congruent trial (Gratton et al., 1992). This *conflict adaptation effect* is assumed to be triggered by the detection of response conflict in the anterior cingulate cortex (Botvinick et al., 2004; Kerns et al., 2004) and has been used as a marker for the adaptation of selective attention through cognitive control processes (Botvinick et al., 2001; Ullsperger et al., 2005; but see Spapé and Hommel, 2014; Hommel et al., 2004; Mayr et al., 2003). Importantly, the original study found the conflict adaptation effect when flicker frequencies were held constant from trial to trial. However, the effect reversed when flicker frequencies switched between trials: instead of increased attentional selection of the target following conflict, we found decreased attentional selection. In the current study, we expected to replicate this reversal of the conflict adaptation effect in order to demonstrate its stability.

Third, no-go trials should trigger increased control by top-down inhibition as it is found in stop-signal or no-go tasks that require participants to inhibit a response that they usually perform (Logan et al., 1997; see also Botvinick et al., 2001 for a similar logic for post-error trials). In our setup, stop-signals were presented at the locations of distracters, indicating participants to withhold their response (no-go trials). For trials following such a no-go trial, we expected increased RT as an adaptation to the inhibitory demands in the previous trial. If flicker frequency generally interacted with processes of cognitive control, one would expect switches in tagging frequencies to interact with top-down inhibition triggered by previous no-go trials: instead of increased RT following no-go trials, we would expect the opposite effect, similar to the pattern in conflict adaptation. However, if flicker frequency only affected cognitive control as reflected in the top-down adaptation of selective attention and not inhibitory control, one would expect no interaction of switches in tagging frequencies and the increase of RT following no-go trials.

2. Method

2.1. Participants

20 students (18 female, mean age = 21.9 years) of the Technische Universität Dresden took part in the experiment. All participants had normal or corrected to normal vision. The study was approved by the institutional review board of the Technische Universität Dresden and conducted in accordance with ethical standards of the 1964 Declaration of Helsinki and of the German Psychological Society. All participants were informed about the purpose and the procedure of the study. They gave written informed consent prior to the experiment and received class credit or 5 € for their participation. All data were analyzed anonymously.

2.2. Apparatus and stimuli

The experiment was controlled by Presentation software (Neurobehavioral Systems), running on a Windows XP SP2 personal computer. Stimuli were presented on a 17 in. screen running at a resolution of 1024 × 768 pixels with a refresh rate of 75 Hz.

The target stimulus (randomly selected from the digits 2, 5, 6, and 9) was presented at the screen center, surrounded by four identical distracter stimuli (either a digit from the same set or the letter H, see Fig. 1). All stimuli were shown in white, surrounded by a gray circle on a black background. Stimuli had a width of 0.6° and circles had a width of 1.41° at 1.5 m viewing distance. The entire number display had a visual angle of 4.5°. Distracter and target stimuli flickered with different frequencies of 7.5 or 12.5 Hz (50% of cycle time on, 50% of cycle time off; frequency balanced across trials; see below).