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Cardiac cycle time effects on mask inhibition

Lisa Pramme[a], Mauro F. Larra[b], Hartmut Schächinger[b], Christian Frings[a,*]

[a] University of Trier, Department of Psychology, Cognitive Psychology, Campus I, D-54286 Trier, Germany
[b] Institute of Psychobiology, University of Trier, Clinical Psychophysiology Unit, Germany

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ABSTRACT

Research on the interaction of the cardiovascular and the central nervous system has demonstrated inhibitory effects associated with baroreceptor stimulation. One way of examining baroreceptor influence on behavior and central nervous processes is by making use of naturally occurring variations in baroreceptor stimulation in the course of the cardiac cycle. In terms of perceptual and sensorimotor processes, until today, research has focused primarily on cardiac cycle time effects on the perception of and reaction to simple stimuli. The present study is the first to investigate modulatory effects of variations in baroreceptor activity in the context of a more complex stimulus configuration using a visual masking task in which a target has to be selected against an interfering mask. The results suggest that baroreceptor stimulation enhances inhibitory processes needed to solve perceptual interference.

1. Introduction

Ever since animal experimentation revealed inhibitory effects of carotid sinus stimulation not only on the autonomic but also on the central nervous system (e.g., Bonvallet, Dell, & Hiebel, 1954; Koch, 1932; Kreindler, 1946) several ways of research on circulation–brain interaction in humans have been pursued (for a review, see Vaitl & Schandry, 1995). The loading and unloading of carotid and aortic baroreceptors and its neural connectivity was identified as a mechanism mediating effects on cognition (Elbert & Rau, 1995; Rau & Elbert, 2001). In particular, it could be shown that, by and large, baroreceptor activation exerts inhibitory effects on cortical structures and diverse functions of the organism (Dembowsky & Seller, 1995). Accordingly, stimulation of the baroreceptors does not only reduce cardiovascular parameters, i.e. heart rate, heart contractility, peripheral resistance (Brownley, Hurwitz, & Schneiderman, 2000; Davos, Davies, & Piepoli, 2002), but also dampens sensory and motor functions, such as pain perception, reflexes and sensorimotor control. A reduction in baroreceptor activation, on the other hand, results in an enhancement of sensorimotor functioning (e.g., Dworkin et al., 1994; Pauli, Hermsdörfer, Marquardt, Birbaumer, & Rau, 1993; Rau, Brody, Brunia, Damen, & Elbert, 1993).

One way of examining central influences of arterial baroreceptors is by making use of naturally occurring variations in baroreceptor stimulation during the course of the cardiac cycle. Arterial baroreceptors, located within the vessel walls of the aortic arch and the carotid sinus show a pulsatile excitation pattern which parallels the pulse pressure wave, and peaks as the systolic pressure wave reaches the aortic and carotid sinus, respectively (Dembowsky & Seller, 1995; Mancia & Mark, 1983).

Several studies demonstrated variations in cortical activity associated with different cardiac cycle phases (e.g., Cohen, Lieb, & Rist, 1980; Lacey & Lacey, 1970; Sandman, Walker, & Berka, 1982; Walker & Sandman, 1982). Furthermore, effects of stimulus presentation time within the cardiac cycle on sensorimotor functions could be shown for different sensory modalities and measures. For instance, simple reaction times in response to auditory stimuli were faster for stimuli presented during the P wave of the electrocardiogram (ECG), i.e. during the ventricular diastole, as compared to stimuli presented during earlier phases of the cardiac cycle (cardiac systole; Birren, Cardon, & Phillips, 1963). Similar results were found for visual and tactile stimuli. Again, stimulation at early phases of the cardiac cycle, i.e. during systolic stimulation of the baroreceptors, lead to an increase in total and pre-motor reaction times by comparison with the late phase (Edwards, Ring, McIntyre, Carroll, & Martins, 2007; McIntyre, Ring, Edwards, & Carroll, 2008).

Additionally, higher sensory sensitivity thresholds were observed for visual and auditory stimulation during the cardiac systole compared to an enhanced perceptual sensitivity at the end of the cardiac cycle (Requin & Brouchon, 1964; Saxon, 1970; but see Edwards, Ring, McIntyre, Winer, & Martin, 2009).

In the same vein, a study conducted by Sandman, McCanne, Kaiser, and Diamond (1977) showed that accuracy rate for the

* Corresponding author. Tel.: +49 0651 201 2958.
E-mail address: chfrings@uni-trier.de (C. Frings).

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identification of shortly presented visual stimuli (6 ms) during the P wave exceeded that of stimuli presented during R or T wave. The modulation of visual perception by cardiac cycle phase was further substantiated by a study, which also analyzed cortical potentials evoked by the stimuli. It was found that averaged right hemispheric evoked potentials, especially the P1 component, which can be linked to early spatial attention processes (e.g., Clark, Fan, & Hillyard, 1995; Clark & Hillyard, 1996), proved to be smaller during the systole in contrast with the diastole (Walker & Sandman, 1982).

Moreover, several studies indicate that changes in baroreceptor stimulation have an impact not only on the sensorimotor level but also on higher order central processes. For example, baroreceptor activation affected the evaluation of intensities of startle stimuli shown in a cardiac cycle time paradigm (Schulz et al., 2009). Also, long-term visual recognition memory seems to be influenced as indicated by the systematic manipulation of baroreceptor activity via the administration of either peripheral resistance and blood pressure increasing drugs (norepinephrine) or a vasodilatation drug (sodium nitro-prusside) (Moor et al., 2005). Further, performance on various cognitive tests associated with chronic hypertension have been shown to be impaired (e.g., Blumenthal, Madden, Pierce, Siegel, & Appelbaum, 1993; Harrington, Saxby, McKeith, Wesnes, & Ford, 2000). However, a chronic increase in blood pressure as it is the case in chronic hypertension is not necessarily associated with increased baroreceptor activity (e.g., Eckberg & Sleight, 1992; McCubbin, Green, & Page, 1956). The relationship between hypertension and baroreceptor functioning is still not fully disclosed (e.g., Heusser et al., 2010; Lohmeier, Hildebrandt, Warren, May, & Cunningham, 2005).

Taken together, these studies suggest that differential baroreceptor activation across the cardiac cycle, impacts cortical activity, simple reaction time, sensory sensitivity, as well as higher cognitive processes.

The present study was designed to further investigate the impact of circulatory mechanisms on sensory and cognitive functions. In particular, we analyzed the impact of baroreceptor activity on early visual selection. That is, we used a visual detection task in which a perceptually degraded target (presented near the sensory threshold) had to be identified against a visually strong distracting stimulus presented before the target (i.e. a forward mask).[1]

Visual masking refers to the presentation of two stimuli in spatial and/or temporal contiguity to each other, one stimulus (*mask*) impairing the visibility of the other (*target*) (Enns & Di Lollo, 2000). In order to detect a target in the presence of interfering stimuli, selection can take place at different levels of processing (Kiesel, Kunde, & Hoffmann, 2007). In the case of a forward mask, spatially overlapping stimuli and a close temporal relationship between mask and target impede perceptual selection processes within the visual system and hence prohibit a clear separation of the mask and the target stimulus (Enns & Di Lollo, 2000). At the level of early perceptual processing different attentional processes are considered to be involved in resolving conflicts due to the exposure to multiple stimuli indicating different modes of behavior (e.g., Kiesel et al., 2007; Kunde, Kiesel, & Hoffmann, 2003; Lingnau & Vorberg, 2005). The suppression of irrelevant information has been shown to be an important factor (e.g., Machado, Wyatt, Devine, & Knight, 2007). As early as on the level of sensory processing, sensory selection is accomplished by reciprocal suppression of the neural activations elicited by each stimulus presented at the same time (Kastner & Ungerleider, 2000). Moreover, the inhibition of response tendencies, elicited by distracting stimuli, seems to be a crucial factor, allowing the organism to select relevant from irrelevant information and therefore to interact effectively with the environment (e.g., Frings, Wentura, & Wühr, 2012; Wühr & Frings, 2008). That is, when both, the distracting and the target stimulus, are assigned to a response, early activation of the neural activity elicited by the distractor is inhibited in order to avoid any reaction in response to the distractor but to allow a correct response indicated by the target stimulus (e.g., Eimer & Schlaghecken, 1998, 2003; Lingnau & Vorberg, 2005; Schlaghecken & Eimer, 1997).

In our experiment, the direction of a target arrow had to be identified and mask-target sequences were presented with mask-onset either 170 ms after the R wave, that is, during the systolic stimulation of the baroreceptors, or 470 ms after the R wave of the ECG, that is, during the cardiac diastole. Presentation times were based on the time course of the systolic pressure wave subsequent to the R wave (e.g., Kroeker & Wood, 1955) and the firing characteristics of the baroreceptors in response to a distension of the vessel walls (e.g., Bronk & Stella, 1932, 1934; Landgren, 1952). As, for example, pointed out by Edwards et al. (2009), an increase in baroreceptor firing rate in the course of the cardiac cycle at both aortic and carotid vessels prevails approximately 90–390 ms after the R wave. As we used a sequence of stimuli we adapted the stimulus presentation times accordingly in order for both mask and target to be presented during the same cycle phase. The presentation times chosen were further validated by the delay between the R wave and systolic upstroke at the earlobe measured to control for interindividual differences in the progression of the pressure wave. The mean transmission time from R wave to the right earlobe was $M = 183$ ms ($SD = 13$ ms; ranging from $M = 162$–217 ms) and can be seen as approximation for the arrival of the systolic upstroke at the carotid sinus.

Furthermore, difficulty of the perceptual processing of the target was increased both by displaying it in low contrast to the background and by using a visually strong forward mask while using a short ISI of 100 ms. As the direction of the mask was statistically unrelated to the direction of the target (i.e. the mask's direction was orthogonally varied to the target's direction), the mask hampered the target identification. Participants were informed that the mask could not be used for predicting the target stimulus and hence were instructed to completely ignore the mask. Within the framework of heart–brain interaction, the target-identification should be easier when the interference of the mask is reduced. That is, if the postulated inhibitory effect of baroreceptor activation during systolic upstroke in the cardiac cycle holds true, inhibition of the mask should be increased during the cardiac systole and as a result target identification should increase. Therefore, the identification rate of the target should be higher with the mask presented 170 ms after the R wave (cardiac systole) in comparison to its presentation with a delay of 470 ms after the R wave (cardiac diastole).

2. Method

2.1. Participants

Twenty-eight healthy right-handed students from the University of Trier (12 female) with a mean age of $M = 24.07$ (range 19–30 years; $SD = 2.98$ years) participated in the study. Prior to their participation the physical health status was assessed using a health questionnaire. Exclusion criteria were any actual health complaints, abuse of illicit drugs within the last six months, medication other than occasional pain killers and oral contraceptives, confirmed somatic or psychiatric diseases within the last six months other than banal infections or minor injuries. Heart rate and blood pressure of the participants were within normal range. Mean resting heart rate was $M = 69.83$ ($SD = 6.16$) bpm, mean systolic blood pressure was at $M = 113.78$ mmHg ($SD = 13.49$), and mean diastolic blood pressure was at M =65.73 mmHg ($SD = 6.07$). Mean BMI was $M = 22.79$ kg/m^2 ($SD = 2.28$). All participants signed written informed consent and were made aware of their right to discontinue participation in the study at any time. They received 15€ expense allowance for their participation.

[1] Note that we conducted a pilot experiment ($N = 10$) as to ensure that the chosen stimulus presentation parameters lead to near threshold identification performance of the average participant.