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Stress and selective attention: Immediate and delayed stress effects on inhibition of return

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

[a] Clinical Psychophysiology Unit, Institute of Psychobiology, University of Trier, 54290 Trier, Germany
[b] Cognitive Psychology Unit, Institute of Psychology, University of Trier, 54286 Trier, Germany

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ABSTRACT

The relationship between attention and stress is far from understood. In fact, some studies reported better attentional selection during and after stress, some studies reported worse attentional selection, and some studies reported no effects of stress on attentional selection at all. We argue that given the complexity of both concepts more data are needed as to ultimately understand this relationship. Here we use an established attentional task that yields the inhibition of return (IOR) effect which is assumed to tap attentional control of oculomotor behavior. Participants were stressed with a Cold Pressor Test (CPT) and immediate and delayed effects of stress on hypothalamus-pituitary-adrenal (HPA) axis activation and IOR were analyzed. IOR was neither by immediate nor by delayed after-effects of the CPT stress procedure modulated, instead, we observed reliable and significant IOR in all experimental conditions. Attentional control of oculomotor behavior is therefore not altered after CPT stress, nor related to the post-stress activity of the HPA axis.

1. Introduction

It is now well-established in the cognitive sciences that at each and every waking moment, an abundance of stimuli impinges upon our sensory systems, with each stimulus potentially affording a range of different actions. In order to maneuver our way through the complex world around us, our brain has to rely on a limited number of simple and efficient processes and mechanisms. One important mechanism is selective attention, that is, the ability to discriminate between relevant and irrelevant information. Attending and responding to only those aspects of our environment that are related to our goals, and not being distracted by stimuli that are irrelevant for or might interfere with the current task, is important for the top-down control of behavior (Allport, 1987; Tipper, 1992). The prefrontal cortex (PFC) has repeatedly been suggested as the central brain region that underlies cognitive processes contributing to selective attention (e.g., Miller & Cohen, 2001). In particular, inhibitory functions have been identified mainly in prefrontal areas and/or networks. For example, the inferior frontal cortex, the middle frontal gyrus and the insula have been linked to response inhibition (e.g., Aron & Poldrack, 2006; Verbruggen & Logan, 2008), the dorso-lateral prefrontal cortex has been linked to distractor inhibition (DI) (e.g., Frings, Schneider, & Fox, 2015), and real-time adaptation of behavior in response to performance feedback. It is assumed that these prefrontal structures are part of an executive control network that impinges a cognitive bias on a salience based competition for attention (Hermans, Henckens, Joels, & Fernandez, 2014).

Yet, an automatic mechanism, the inhibition of return (IOR) (Posner & Cohen, 1984), further helps to control the deployment of selective attention by biasing salience based orienting. The IOR effect is a well-known and reliable phenomenon in human visual-spatial attention (for a review see, Klein, 2000). IOR is typically observed when people attend sequential displays or scan complex visual scenes (Klein, 1988), or when they move their attention from one object to another until an interesting or searched-for object has been found. Cuing the location of a visual target by means of a randomly varying, peripheral stimulus (e.g., a flash around the location where the target will occur) can improve performance at very short cue-target intervals but impairs performance at longer cue-target intervals. Once a given location has been cued and attention has moved to another location, the time needed to return to that previous location is increased – presumably to enhance the efficiency of attentional scanning by biasing it away from old (putatively irrelevant) information and to prepare the system for the intake of novel information (Klein, 1988). Mediated by the midbrain superior colliculus (Sapir,

* Corresponding author.
E-mail address: larra@uni-trier.de (M.F. Larra).

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Soroker, Berger, & Henik, 1999) the IOR effect does not follow a volitional deployment of attention (Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989) but automatically biases salience maps towards novel, potentially relevant stimuli. It therefore provides an early compensating mechanism allowing for a disengagement of attention that would be hampered in a purely salience based processing (Itti & Koch, 2001). There is a large body of literature concerning IOR (and its underlying mechanisms) which points to the relevance of the effect of inhibitory control for interacting with a visual environment.

An effective and fast selection of the relevant features of a scene is of utmost priority in stressful and dangerous situations. Therefore, it seems plausible that the human body provides mechanisms by which stress can influence selective attention. Based on the actions neuromodulators released during stress exert on PFC functioning it has been proposed that stress inhibits the volitional cognitive control of selective attention inducing a switch to an automatic salience based processing (Arnsten, 2009; Hermans et al., 2014). Specifically, stress leads to an immediate and short-lived release of catecholamines through activation of the sympathetic nervous and adrenomedullary systems. Consequently, heart rate and blood pressure are increased and activation of catecholaminergic projections mainly emanating from the locus coeruleus (LC) result in a decreased firing rate of PFC neurons. Delayed activation of the hypothalamus-pituitary-adrenal (HPA) axis follows proceeding in several steps. Neurons in the paraventricular nucleus of the hypothalamus release CRH into portal vessels that reach the pituitary triggering a release of ACTH into the general circulation. ACTH, ultimately, leads to the production and secretion of glucocorticoids by the adrenal cortex, which are released into the blood stream. A large fraction of glucocorticoids will bind to plasma proteins. Only unbound cortisol then crosses the blood brain barrier to act on glucocorticoid receptors that are abundantly expressed in the PFC (e.g., Perlman, Webster, Herman, Kleinman, & Weickert, 2007) finally leading to altered prefrontal brain activity (Qin, Hermans, van Marle, Luo, & Fernandez, 2009; Weerda, Muehlhan, Wolf, & Thiel, 2010). Behavioral effects are evident in studies employing task-switching and Stroop type distraction tasks to assess cognitive control of attention. Here, stress has been shown to impair top-down control as reflected in reduced task shielding (Plessow, Kiesel, & Kirschbaum, 2012; Plessow, Schade, Kirschbaum, & Fischer, 2012; Steinhauser, Maier, & Hubner, 2007) and heightened distractibility by salient stimuli (Sanger, Bechtold, Schoofs, Blaszkewicz, & Wascher, 2014). However, conflicting results exist suggesting reduced distractibility (Hoskin, Hunter, & Woodruff, 2014; Plessow, Fischer, Kirschbaum, & Goschke, 2011) and improved task switching (Beste, Yildiz, Meissner, & Wolf, 2013; Kofman, Meiran, Greenberg, Balas, & Cohen, 2006).

It should be noted that previous research mainly focused on whether stress impairs prefrontal functions and thereby executive control of selective attention. The complementary hypothesis, i.e. whether stress leads to an enhancement of early salience based processing received little empirical testing. There is encephalographic evidence suggesting an enhancement of early processing stages and an impairment of late ones (Elling et al., 2012; Shackman, Maxwell, McMenamin, Greischar, & Davidson, 2011). Yet, whether and how a modulation of IOR contributes to stress effects on early selective attention remains completely unknown. The superior colliculus that underlies IOR is heavily innervated by the LC and the hypothalamus (Edwards, Ginsburgh, Henkel, & Stein, 1979; Rieck, Huerta, Harting, & Weber, 1986), which are primarily involved in the stress response, providing a physiological basis for stress effects. Furthermore, several lines of research suggest a possible involvement of HPA axis activation in modulating IOR. Specifically, IOR has been shown to be impaired in stress related diseases as depression (Dai & Feng, 2009; Hauschildt, Wittekind, Moritz, Kellner, & Jelinek, 2013) and PTSD (Hauschildt et al., 2013; Pineles, Shipherd, Mostoufi, Abramovitz, & Yovel, 2009; Wittekind, Muhtz, Jelinek, & Moritz, 2014). Moreover, prepulse inhibition (PPI) which partly results from IOR (Burke & Hackley, 1997) has been shown to be modulated by the stress hormone cortisol (Richter et al., 2011). Taken together these findings hint to a possible modulation of IOR by acute stress, especially HPA axis activation. Surprisingly, to the best of our knowledge effects of acute stress on IOR have never been directly investigated.

Thus, in the present study we sought to explore the possible modulation of IOR by stress induced HPA axis activation. Participants underwent the bilateral feet cold pressor test (CPT), a stress induction procedure that has been shown to activate the HPA axis (Larra, Schilling, Rohrig, & Schachinger, 2015), or a control condition before performing a classical IOR paradigm. As previous research demonstrated that HPA effects on selective attention vary with time (Plessow et al., 2011), we tested IOR at several time points. The baseline assessment was scheduled after a resting period before the CPT was performed. The first post-stress assessment was done 10 min after CPT end, when cortisol levels start to rise in plasma and saliva as a result of stress-induced HPA axis activation. Importantly, during this period cardiovascular effects of the CPT have disappeared, but cortisol may start to act on the CNS via non-genomic pathways (Richter et al., 2011; Strelzyk et al., 2012). The second post-stress assessment was carried out 45 min after when brain exposure to glucocorticoids can be expected to last sufficiently long to affect gene expression (Haller, Mikics, & Makara, 2008).

2. Materials and methods

2.1. Sample

40 healthy men and women (mean age: 23 years, SD: 2.9 years) participated in the experiment. They were randomly assigned to either the stress group (CPT, N = 20, 10 female) or a control condition (warm water bath, N = 20, 10 female). Subjects were mostly students from the University of Trier, recruited via email digest. Participation was limited to right handed, healthy people with normal weight (Body Mass Index between 19 and 25) and age between 18 and 35 years. Applicants were not included if they showed any evidence of acute or chronic diseases of the circulatory system (deviations from sine rhythm, glaucoma, Raynaud's disease, history of fainting, resting blood pressure above 140/90 mmHg), history of psychiatric disease or family history of arterial hypertension, and cerebral or aortic aneurisms. Furthermore, the following exclusion criteria were applied: smoking of more than five cigarettes per day, drug intake or current use of medication, increased objective or subjective sensitivity to cold.

A personal screening interview determined if all criteria for inclusion in the study were met. All participants gave written informed consent. They were compensated with 20 € after completion of the whole experiment.

2.2. Procedure

2.2.1. General procedure

The study protocol started with a ten minute resting period to familiarize the participants with the laboratory setting. Hereafter, the first block of the IOR task was conducted followed by a five minute resting period during which baseline measures of heart rate and blood pressure were taken. After that, the CPT or a warm-water control procedure was carried out. A resting period of about eight minutes followed before the second block of the