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Trier Social Stress Test in vivo and in virtual reality: Dissociation of response domains☆·☆☆

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ABSTRACT

The Trier Social Stress Test (TSST) is considered a reliable paradigm for inducing psychosocial stress. Virtual reality (VR) has successfully been applied to ensure a greater degree of efficiency and standardization in the TSST. Studies using the TSST in VR (VR-TSST) have reported significant stress reactions, with subjective and peripheral physiological reactions comparable to those in response to the in vivo TSST and with lower cortisol reactions. The current study examined whether an additional virtual competitive factor triggers larger stress responses than a standard VR-TSST. Forty-five male participants were randomly assigned to either in vivo TSST, VR-TSST (VR) or VR-TSST with a virtual competitor (VR+). A significant increase of self-reported stress, electrodermal activity, and heart rate indicated a pronounced stress reaction with no differences between groups. For salivary cortisol, however, responder rates differed significantly between groups, with in vivo participants showing overall higher response rates (86%) than participants of both VR groups (VR: 33%, VR+: 47%). In contrast, participants of both VR groups judged the task significantly more challenging than did in vivo TSST participants. In sum, our results indicate successful stress induction in all experimental conditions, and a marked dissociation of salivary cortisol levels on the one hand, and the physiological and psychological stress reactions on the other hand. The competitive scenario did not significantly enhance stress reactions. VR technology may serve as a standardized tool for inducing social stress in experimental settings, but further research is needed to clarify why the stress reaction as assessed by cortisol differs from peripheral and subjective stress reactions in VR.

1. Introduction

Psychosocial stress is an important risk factor for physical and mental diseases, for example depression, cardiovascular disease (CVD) or HIV progression (Cohen et al., 2007). As research over the last three decades has shown, the Trier Social Stress Test (TSST), originally developed by Kirschbaum et al. (1993), is one of the most reliable, valid and standardized ways to induce psychosocial stress in the laboratory (see Dickerson and Kemeny, 2004; Williams et al., 2004). The TSST consists of a simulated job interview and comprises a preparation phase, a speech task, an arithmetic task and a recovery phase. Typically, increased salivary cortisol levels (Kudielka et al., 2007a) and a significant heart rate elevation in response to the TSST (Kirschbaum et al., 1993) are found. A substantial rise of subjective stress (Arch et al., 2014) and a pronounced skin conductance activity (Gilissen et al., 2008) have been noted as well. A crucial disadvantage of the "in vivo" TSST, however, is the difficulty in keeping experimental conditions controlled. Additionally, the TSST requires considerable resources, since it involves at least three people. Hence, the question arises whether and how the TSST can be enhanced to diminish these disadvantages (Jonsson et al., 2010).

An economical and highly standardized possibility to investigate emotional reactions is the use of virtual reality (VR), which has become a well-established research method and has proven its ability to induce ecologically valid emotions in participants with specific phobia (Mühlberger et al., 2007a; Diemer et al., 2014). Interestingly, it has been shown that perceptual cues induce more self-reported fear in phobic participants than the knowledge of the presence of a real phobic animal or situation not seen by the participants (Peperkorn et al., 2014; Shiban et al., 2016). Notable evidence for the possibility to induce not only phobic, but also psychosocial stress in VR has been found in two studies by Hemmeter et al. (2005) as well as Bullinger et al. (2005). A dynamic VR environment in combination with a cognitive stressor

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was able to elicit a significant activation of the hypothalamus-pituitary-adrenal (HPA) axis.

The findings of Kelly et al. (2007), Ruiz et al. (2010), and Wållergard et al. (2011) provided evidence that a social stress test in VR can evoke heart rate responses similar to those in vivo, whilst cortisol responses were less pronounced under VR conditions. Kotlyar et al. (2008) found significant increases in blood pressure, heart rate and catecholamines, but no significant changes in plasma cortisol. Using a room size virtual environment (CAVE-system) assessing a VR version of the TSST, Jonsson et al. (2010) assessed the stress response habituation across two TSST sessions conducted with a one week interval. Whilst they found significant increases in heart rate and salivary cortisol during session 1, such an effect could no longer be found for the cortisol data in session 2. Cardiovascular measures, however, were approximately the same at both sessions and were comparable to HR values found in real-life TSST experiments (e.g. Kirschbaum et al., 1993; Kudielka et al., 2004). However, it must be noted that the sample size in this study was small ($n = 10$). In another study, the researchers varied the virtual environment, observing behaviors in open and closed spaces. The result showed prolonged cortisol reactivity for participants undergoing the paradigm in the closed room as opposed to reactivity levels in the open room, whereas no group differences were reported for the electrodermal activity (Fich et al., 2014).

To sum up, there is some evidence for stress reactions to the TSST in VR (VR-TSST). In terms of cortisol reactions, these were considerably lower than under in vivo conditions, whereas heart rate measures showed no distinction between a VR-TSST and an in vivo TSST. Therefore, the question arises whether it is possible to enhance the stress-inducing effects of the VR-TSST by introducing an additional component. Referring to Dickerson and Kemeny's (2004) meta-analysis, which emphasizes of social-evaluative threat as a key component of successful stress induction, we hypothesized that the stress reaction can be increased by an additional competitive virtual agent. In various studies increased endocrine stress levels have been reported in competitive situations (Suay et al., 1999; Kivlighan et al., 2005; Rohleder et al., 2007). Furthermore, the Montreal Imaging Stress Task (MIST; Dedovic et al., 2005), derived from the TSST and the Trier Mental Challenge Task (Kirschbaum et al., 1992), includes a comparison of the subjects' own performance with the average performance of all subjects. Studies have shown a significant stress reaction to the MIST as indicated by a substantial rise in salivary free cortisol (Dedovic et al., 2005; Pruessner et al., 2008). To our knowledge, no TSST studies so far have explicitly investigated the effects of a competitor in the TSST.

The aim of the present study was to test whether the stress reaction during a VR-TSST is increased by adding a virtual competitor. Further, we investigated whether the TSST in VR, just as in vivo, triggers an endocrine, physiological, as well as a subjective stress response. For this purpose, the stress response in the three conditions in vivo TSST, TSST-VR, and TSST-VR plus competitor (VR+) were evaluated and compared. We assessed endocrine (salivary cortisol) and physiological (heart rate, electrodermal activity) reactions, self-reported stress, and cognitive appraisal. We expected to find an endocrine, physiological, and self-reported stress reaction in all conditions and that the endocrine reaction would be higher in the in vivo condition than in the VR-TSST. Physiological and subjective stress reactions were not expected to differ between these two groups. Besides, we expected the stress reaction in the VR condition that included a competitor (VR+) to be higher than in the standard VR-TSST.

2. Method

2.1. Participants

Forty-five male volunteers were recruited through advertisements at the University of Regensburg ($M_{age} = 23.76$, $SD = 2.52$). Due to the impact of the female menstrual cycle as well as the usage of oral contraceptives on HPA axis stress responses women were excluded from this study (Kudielka et al., 2009). The participants were screened for the following exclusion criteria: current involvement in psycho- or pharmacotherapy, cardiovascular or neurological diseases, current depression or addiction (alcohol, psychotropic substances), history of psychotic disorder, and previous experience with the TSST. Habitual smokers (>5 cigarettes/day) were excluded due to previously proven systematic changes in cortisol levels in smokers (Kirschbaum et al., 1992; Kirschbaum et al., 1994). Demographical information was acquired by means of a self-designed questionnaire. Additionally, a medical survey assessing the current health state of the participant was used to evaluate existing allergies, drug usage, chronic or physical illness and sleep disturbances as well as smoking behavior. To rule out mental disorders the relevant sections of the Mini International Neuropsychiatric Interview (German version Sheehan et al., 1998; M.I.N.I., Ackenheil et al., 1999) were administered. All participants gave written informed consent and received compensation of 10€. The study was approved by the Ethics Committee of the University of Regensburg.

2.2. Apparatus

The VR environment consisted of a simply furnished room, modelled on the laboratory in which the in vivo TSST took place (see Fig. 1). The room included a cupboard, a large table and a camera, supposedly to record the participants' performance as in the in vivo TSST (see Kirschbaum et al., 1993). Two virtual agents constituting the committee, a young woman and a middle-aged man, were seated behind the table facing the participants. Both had notepads in front of them.

The committee members moved their lips whilst speaking and nodded their heads slightly in synchrony with the comments or made subtle movements, such as shifting their head. However, they expressed no emotions or social feedback towards the participants, presenting a neutral facial expression. The virtual investigator was a young woman who introduced the participant to the virtual environment and explained the upcoming task.

Instructions from the virtual investigator and comments from the committee were given by pre-recorded voices, according to standard TSST protocol, and activated using a keyboard by the investigator who was hidden for the participant. The participant's competitor during the VR-TSST was a young woman, always performing tasks first, quickly, and faultlessly (see Fig. 1B). To enhance the competition effect, the committee gave slightly positive feedback to the competitor, whilst staying completely neutral during the participant's tasks.

The VR environment was generated using the Steam Source engine (Valve Corporation, Bellevue, Washington, USA) and controlled and timed by the VR simulation software "Cybersession" (VTplus GmbH, Würzburg, Germany). The experiment was run on a desktop computer (Intel Core2Duo E8600, NVidia GeForce 285 GTX, 4 GB RAM). A Head Mounted Display (HMD; nVisor SX, NVIS Inc., Reston, VA, USA; resolution: 1280 * 1024 pixel; monooccular diagonal field of view: 60°) and a Head-tracking System, the Patriot electromagnetic tracking device (Polhemus Corporation, Colchester, Vermont, USA) were used for VR simulation. For participants in the VR groups sounds were presented via headphones. Physiological data were monitored and recorded via the software "Brain Vision Recorder" (Version 1.20, Brain Products GmbH, Gilching, Germany) using the digital amplifier "V-Amp" (Brain Products GmbH, Gilching, Germany).

2.3. Measures

2.3.1. Measures of social anxiety

Social anxiety was assessed via the Social Phobia Inventory (SPIN) (Connor et al., 2000; German version Stangier and Steffens, 2002). The SPIN is a self-rating scale, assessing fear, avoidance and physiological symptoms relating to social phobia with 17 items on a five-point Likert scale ranging from 0 (*not at all*) to 4 (*extremely*). Both the English and