Evoking Stress Reactivity in a Virtual Dance Competition

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Abstract. Stress reactivity involves a physiological response to a stressful task, as a biological mechanism related to mental and physical health outcomes. Traditional stressors evoke social evaluative threat, which is fear of judgment and a threat to social status, typically via public speaking tasks. To be well-suited for virtual reality, however, a novel approach is necessary in the design of new stress tasks. We hypothesized that a virtual reality stress task involving social evaluative threat through a dance competition in front of an audience, elicits a stress response, measured by autonomic nervous system, cortisol, and testosterone reactivity. Participants (n = 18) showed autonomic nervous system reactivity in terms of increased heart rate and decreased respiratory sinus arrhythmia, indicating a stress response. Levels of cortisol increased in response to the dance competition, especially within responders, whereas testosterone levels did not change significantly over time. A virtual reality dance competition involving physical social evaluative threat elicits a stress response.

Keywords: Stress reactivity · Virtual reality · Dance competition

1 Introduction

A physiological stress response predicts health and wellbeing [1, 2] beyond the influence of perceived or self-reported stress [3]. To operate as objective indices of stress, biomarkers must show reliable changes in response to stress exposure [4]. Stress biomarkers often include autonomic nervous system (ANS) indices and hormonal measures such as cortisol and testosterone, respectively [1, 2, 5]. While there is a colloquial understanding of situations that are perceived as stressful [6], it is surprisingly difficult to generate a stress response without careful attention to the elements of stress [7]. It is essential to further understand how stress biomarkers mechanistically link stress exposure with long-term health, decision-making and behavior outcomes.

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While some studies investigate real-world stress scenarios [5, 8], it is typical to probe the physiological stress response pattern in acute laboratory stress tests. The gold-standard stressor is the Trier Social Stress Test (TSST), which consists of a verbal speech and mental arithmetic involving negative evaluation by a trained audience [9]. The TSST works because it contains three key elements of stress including uncontrollability, unpredictability and social evaluative threat (SET) – when one feels judged or that their social status is threatened [10]. The TSST does not uniformly lead to a physiological stress response: typically only ~50–70% of participants mount a physiological stress response [3]. Furthermore, the TSST is often impractical as it is time-consuming, requires four trained research assistants, and is difficult to standardize.

Human Factors and Human Computer Interaction research has turned to virtual reality (VR) environments to simulate objective stress tests with the goal of reducing time and personnel and increasing standardization. Previous work, including a meta-analysis, indicates virtual TSST's are not as effective in eliciting a stress response as the standard TSST [11, 12]. Explanations for reduced efficacy of virtual TSST's is that neither the audience nor the speech is sufficiently immersive. Given that some studies with virtual audiences have been efficacious [13, 14], instead we probed whether the limitation of virtual stressors is that the speech modality reduces immersion when delivering a virtual speech which leades to a reduction in SET and the stress response.

Our design of a novel VR stress task focused on SET as the mechanism to trigger a stress response because previous research indicates SET as the key factor in stress tests [15]. Since previous research indicates a dance competition could be used as a stress task [16], we focused our task around a dance competition involving SET. We hypothesize that a VR stress task involving SET through a dance competition in front of an audience will elicit a stress response, measured by a change from pre- to post-VR stressor in cortisol, testosterone and autonomic nervous system activity.

2 Methods

2.1 Participants

Eighteen participants (50% males) were recruited at Iowa State University. Participants were between 18 and 40 years of age and without a history of motion or simulation sickness. The study protocol was approved by the Institutional Review Board of Iowa State University. The average age was 24.6 (SD = 6.9) years of age.

2.2 Procedures

In order to minimize the impact of circadian rhythmicity, all participants were scheduled in the late afternoon and early evening. After reviewing and providing written informed consent, participants provided the first saliva sample through passive drool. Next, a same-sex researcher placed electrodes for ANS data collection. Participants filled out questionnaires for 20–40 min to allow for physiological acclimation to the laboratory setting. Participants then wore a VIVE HTC headset and completed two VR tasks which had been programmed in C# language and implemented with Unity.

Control Task. The control task setting consisted of a kitchen with plates and small appliances which allowed participants to become familiarized with the VR headset and virtual environment without introducing stressful elements. Participants could break plates to ensure the control task matched the level of physical activity during the dance competition. After the control task, participants provided the second saliva sample.

Stress Task. Participants observed and copied dance moves performed by a neutral dance instructor avatar. Participants then observed a skilled virtual competitor perform these dances in front of a virtual audience (Fig. 1). The virtual competitor matched the race and sex of the participant. The audience applauded the virtual competitor. Participants then performed these dances on the stage in front of the virtual audience, but the audience remained neutral to their performance.

After the stress task, participants provided the third saliva sample and completed the remaining questionnaire items. The fourth, fifth and sixth saliva samples were provided at 15-min intervals. After the sixth saliva sample, participants were debriefed about the nature of the task and the nonresponsive virtual audience. Saliva samples were stored at −80 °C.

Fig. 1. Virtual competitor dancing in front of the audience.

2.3 Autonomic Nervous System Reactivity

ANS data was collected continuously via an ambulatory impedance cardiograph that clips to a belt (Mindware Technologies, LTD). Electrocardiogram sensors were placed on the right clavicle, the lower left rib, the back on the vertebra prominens, lower-middle spine, the suprasternal notch and xiphoid process. Heart rate (HR) is the number of ventricular contractions in a minute; respiratory sinus arrhythmia (RSA) extracts the high-frequencies (>.15 Hz) of the R-R peak time series. Physiological data was cleaned in 60 s intervals using Mindware analysis software programs. Data within these 60 s epochs was only analyzed if there was 30 s of continuous, viable data without excessive noise. Data collected during (1) the acclimation period (baseline), (2) the control task and (3) the stress task was averaged resulting in mean values for these three time points, and we present minute-by-minute epochs.

2.4 Salivary Cortisol and Testosterone Levels

Saliva was thawed, vortexed and centrifuged at 3000 rotations per minute for 15 min. Commercially available enzyme immunoassay kits were used to obtain cortisol and testosterone levels (Salimetrics, LLC). All standards, controls and samples were assayed in duplicate and samples with intra-assay coefficients of variance (CV) > 7% (cortisol) or CV > 10% (testosterone) were reassayed. The average intra-assay CV was 3.26% for cortisol and 4.55% for testosterone. The average inter-assay CV%, typically below 15%, was 3.76% for cortisol and 2.38% for testosterone.

2.5 Statistical Analyses

Missing salivary cortisol and testosterone data (0.9% of data was missing) was imputed using the mean value for that timepoint for one participant at one timepoint. Repeated measures ANOVAs were used to calculate the within-person change over time in levels of HR, RSA, and logarithmically transformed levels of cortisol, and testosterone. Results at different timepoints were compared using post-hoc tests which were conducted in one-minute epochs for HR and RSA. The individual response pattern over time for each outcome was used to split participants in two groups: (1) responders and (2) non responders, following prior work [17]. Responder group membership was used as an interaction factor and grouping factor in the repeated measures ANOVA.

3 Results

3.1 Autonomic Nervous System Reactivity

Heart rate significantly increased over time ($F(2,32) = 6.941$, $p = 0.009$, Cohen's $d = 1.32$) with the onset of the stress task demonstrating the most pronounced increase compared to the control task ($F(1,16) = 12.123$, $p = 0.003$), indicating a stress response characterized by autonomic arousal (Fig. 2). There was a significant interaction between time and responder group membership ($F(2,30) = 12.950$, $p < 0.0001$), such that heart rate significantly increased over time in responders (61%) but not in non-responders (39%). RSA was significantly lower during the stress task compared to the control task ($F(1,16) = 5.482$, $p = 0.032$, Cohen's $d = 0.67$), with the largest drops in RSA occurring between the first and second minute epochs of the stress task ($p = 0.019$) compared to the control task, indicating a stress response characterized by parasympathetic withdrawal. Interaction analyses showed that RSA decreased over time was significant in the responder group (78%) ($F(2.26) = 16.925$, $p < 0.0001$), but not within non-responder group (22%).

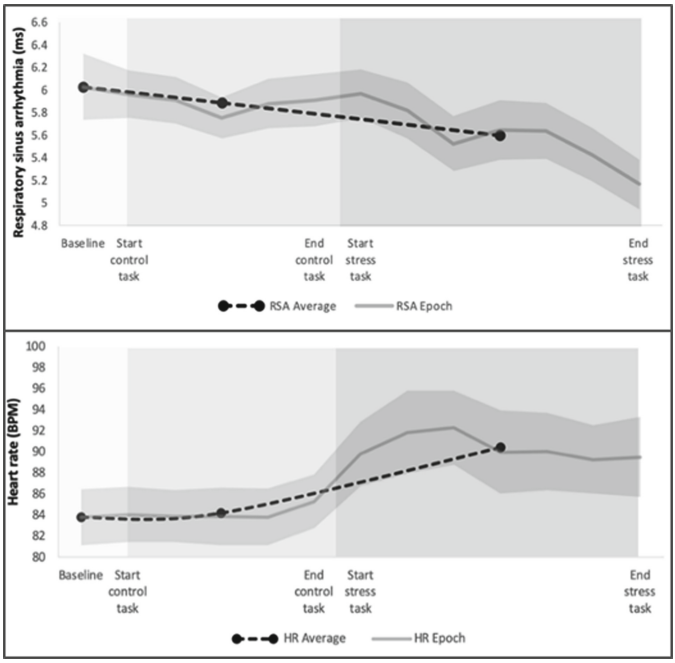

Fig. 2. Heart rate in beats per minute and respiratory sinus arrhythmia in milliseconds over time.

3.2 Salivary Cortisol and Testosterone Levels

Cortisol changed significantly over time ($F(5,85) = 2.703$, $p = 0.037$) with peaks directly after the control task and 15 min after the stress task, as expected for this slow-acting biomarker, with a large effect size (Cohen's $d = 0.8$). A trend for an interaction between time and responder group membership was observed ($F(2,228) = 2.228$, $p = 0.059$). Non responders (78%) showed no change over time whereas responders (22%) showed a significant change over time ($F(5,15) = 3.996$, $p = 0.017$) with cortisol peaking after the stressor in responders which was significantly different from cortisol levels 45 min post stressor ($p = 0.028$) (Fig. 3). Testosterone levels did not significantly change over time ($F(5,85) = 1.992$, $p = 0.088$, Cohen's $d = 0.69$) and no differences between responders (33%) and non responders (67%) ($p > 0.05$).

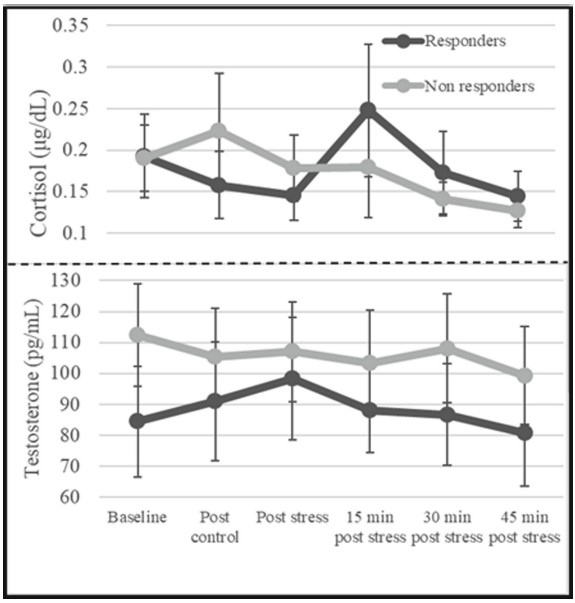

Fig. 3. Cortisol rose over time, especially in responders. Testosterone change was not significant.

4 Discussion

The results from this study indicate that a VR stress task invoking SET through a dance competition in front of an audience elicits a stress response in terms of decreased RSA as well as increased HR and cortisol. Significant biomarker change over time was driven by participants classified as responders. Testosterone did not show reactivity.

These results support the idea that VR can be used to simulate objective stress via SET in a non-verbal virtual task. A study strength is that we used multiple physiological measures to objectively measure stress reactivity across biomarkers with different stress reactivity thresholds. Stress theory suggests the ANS operates as the first line of defense, with parasympathetic withdrawal being a fast acting and low threshold stress response and an autonomic "fight or flight" response via HR indicating greater stress [7]. The present study found responder rates were ~80% for RSA, ~60% for HR, ~20% for cortisol, and ~30% for testosterone. This pattern across biomarkers suggests our task induced a strong stress response for low threshold autonomic biomarkers, but maximized individual differences in reactivity among endocrine biomarkers. The non-reactive testosterone pattern may indicate that the virtual dance competition was not objectively stressful at this high threshold, or that participants did not view virtual dancing as a challenge. Interestingly, cortisol responders did not overlap with testosterone responders; we speculate individuals differed in whether virtual dancing was a social threat or an engaging challenge.

Focusing on cortisol, our effect size to a virtual dance competition was larger than the mean effect size for cortisol reactivity across multiple virtual TSST studies (0.8 versus 0.65) [12]. This larger effect size fits with our *a priori* hypothesis and task design that capitalized on the non-verbal nature of the dance competition to induce SET. Nonetheless, the effect size for SET stressors like the TSST is larger than VR-TSST's (d = .67 − .86, ∼70% reactivity) and real world stressors like skydiving trigger robust stress responses across physiological systems (∼90% responders for cortisol and testosterone) [8, 10]. Other research suggests that physical threat in VR also elicits an objective stress response [18, 19]. Guided by stress theory and capitalizing on the strengths of VR, future research should explore other stress elements, in addition to SET or physical threat or in combination as multiple stress elements are most effective [7, 10].

There are limitations to this study. Although most VR stress studies are comparable in size, the small sample size limited statistical power and our ability to probe the array of individual differences in response patterns to stress. Another limitation concerns generalizability. Stress research typically aims to design non-specific stress tests that operate similarly across populations so generalizability is presumed. Unfortunately, this assumption is not always supported in the literature; a stress test involving SET resulted in cortisol reactivity in socially dominant but not subordinate army recruits [20]. Future research should confirm generalizability by examining stress biomarkers in individuals in high-stress careers (such as military veterans, correctional officers or astronauts) who might demonstrate distinct stress patterns due to their adaptability to high stress. Prior studies show that VR stress tests work better in young populations [12], so future research should examine developmental differences in VR stress reactivity.

In conclusion, a virtual dance competition elicits an objective stress response which maximizes individual differences and is potentially more effective than verbal virtual stress tasks. Social evaluative threat is an effective stressor in a VR environment.

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