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Evaluation of a remote, internet-delivered version of the Trier Social Stress Test

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ABSTRACT

The Trier Social Stress Test (TSST) is a widely used, reliable, and ecologically valid method for inducing acute stress under controlled conditions. Traditionally, the TSST is administered with staff physically present with participants, which limits the participant populations that can be exposed to the TSST. We describe an adaptation of the TSST to remote, online delivery over video-conferencing, which we call the internet-delivered Trier Social Stress Test (iTSST). This adaption has participants use wearable, self-administered ECG monitors received and returned via mail. Fifty participants were recruited to take part in a pilot study evaluating stress-reduction interventions and completed the iTSST at two occasions separated by approximately 12 weeks. Perceived stress and heart rate variability (HRV) were measured during both administrations of the iTSST. Forty-one participants completed both assessments and were included in the set of analyses. Both administrations were characterized by an increase in self-reported stress and reduction in self-reported relaxation from the resting phase to the speech task, which returned to baseline during recovery. In terms of HRV, we observed a significant parasympathetic response to the iTSST in 90% of participants, evidenced by a decrease in RMSSD and increase in heart rate from resting to the speech task, which recovered during the recovery phase. In terms of repeatability, there was little evidence of habituation and the iTSST elicited a stress response during both the initial administration and the 12-week follow-up. While the utility is limited by the lack of a measure of sympathetic and HPA-axis activity, the iTSST represents a promising research tool when physically interacting with participants is not feasible.

1. Introduction

Psychological stress is recognized as an important and potentially modifiable risk factor associated with the development, progression, and maintenance of various chronic diseases, including cardiovascular disease (Steptoe and Kivimäki, 2013), cancer (Lutgendorf and Andersen, 2015), and the metabolic syndrome (Bergmann et al., 2014). The reactivity hypothesis stipulates cardiovascular reactivity responses to acute stressors that are large in magnitude play a role in the development of cardiovascular pathology (Obrist, 1981). Observational studies have supported the reactivity hypothesis and observed associations between magnitude of cardiovascular responses to acute psychological stress tasks and the development of hypertension (Carroll et al., 2001, 2003), coronary artery calcification (Matthews et al., 2006), and acute cardiovascular events (Carroll et al., 2012a). Blunted cardiovascular reactivity in response to acute stress has been associated with the development of depression, obesity, and anxiety (de Rooij, 2013), indicating that the most optimal response to stress is a moderate reaction (Carroll et al., 2012b).

The Trier Social Stress Test (TSST; Kirschbaum et al., 1993) is an ecologically valid stressor that is based on public speaking. It includes a social-evaluative stressor where participants are instructed to speak in front of an unresponsive committee of experts, followed by a surprise mental arithmetic stressor (Allen et al., 2014; Kudielka et al., 2007). The TSST has become one of the most widely utilized tests to induce acute psychological stress, and is associated with reliable increases in perceived stress, heart rate, blood pressure, cortisol, pro-inflammatory cytokines, and adrenaline/noradrenaline (Allen et al., 2014). The effect of the TSST on parasympathetically mediated control on heart rate (i.e., respiratory sinus arrhythmia; RSA) has been more variable, with most (Giese-Davis et al., 2006; Lackschewitz et al., 2008; Yim et al., 2015), but not all (Jönsson et al., 2010; Rohleder et al., 2006) studies

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reporting significant reductions in parasympathetic cardiac control during speech/mental arithmetic or an increase in heart rate from baseline to speech/mental arithmetic (e.g., Hellhammer and Schubert, 2012; Jönsson et al., 2010; Kirschbaum et al., 1993; Way and Taylor, 2011).

Cardiovascular reactivity induced during laboratory testing does not always approximate that observed in naturalistic settings (Fredrikson et al., 1989). The TSST has been modified to include virtual reality (VR) versions that are more flexible to administer (Hawn et al., 2015). Reliable change in indices signaling stress reactivity have been reported in most (Jönsson et al., 2010; Kelly et al., 2007; Montero-López et al., 2016; Shiban et al., 2016), but not all (Kotlyar et al., 2008), of the studies that have implemented the TSST using virtual reality. The TSST has undergone a number of additional modifications. Repeated measures designs have demonstrated some habituation of the HPA-axis response measured using salivary cortisol, with little to no habituation across cardiovascular reactivity (Gerra et al., 2001; Mischler et al., 2005; Schommer et al., 2003; von Känel et al., 2006). Greater procedural differences between testing sessions (e.g., longer inter-testing duration, speech content, serial subtraction) appear to be associated with less habituation (Allen et al., 2014).

One major limitation of the TSST (in both normal and VR format) is that it must be administered with staff physically present with participants, and, in the case of the normal TSST, in a laboratory setting. Not only can this be costly and difficult to administer, it greatly restricts the subject pool to those within driving distance of the research facility. Development and assessment of the TSST delivered remotely and online is both timely and important, particularly given that most in-person assessments have been suspended or cancelled due to the impact of Covid-19. Up until now, there has been little to no research evaluating the effect of the TSST using a video-conferencing platform, which has the potential to overcome these limitations. If the TSST could be delivered via a video-conferencing platform, it would open the TSST up to a much wider set of applications.

This paper describes an initial effort to adapt the TSST to a video-conferencing platform, delivered in the context of a stress-intervention study. Below, we detail the protocol for the online delivery of the TSST, stress-response data from participants, challenges encountered adapting the TSST to online delivery, and limitations of the present study.

Adapting the TSST to online delivery raised many important questions that we sought to answer with this study. Most significantly, we did not know whether online delivery of the TSST would be sufficiently stressful in order to evoke a strong and reliable stress response. Additionally, we wondered whether online delivery might introduce too much environmental variability to reliably measure an individual's stress response given that the TSST is typically delivered in a highly controlled environment. Finally, we faced a host of logistical challenges, not least of which was finding a device that could both be used to remotely collect ECG data and be self-administered by participants. Our goal was to adapt the TSST for use as an ecologically valid measure of stress in ambulatory research investigations with the hopes that such adaptations could one day be used in clinical settings.

2. Material and methods

2.1. Participants

We developed what we term the internet-delivered TSST (iTSST) for use in the Selah Stress Reduction Pilot Program (Selah), a pilot study of several interventions designed to improve the ability of clergy to respond to stress. Participants were recruited from a population of United Methodist clergy in North Carolina via email invitations to participate in the program. Participants signed up via a website. The study website described the four interventions and compared the choices. After electronically consenting to the study, participants could choose between four different stress-reduction interventions: centering prayer, daily examen, stress inoculation, and mindfulness-based stress reduction (MBSR) (see Supplemental materials for intervention descriptions). The first three interventions began with a 1 or 2 day in-person workshop and then participants were asked to practice the skills they learned on a daily basis. These participants received an additional hour-long seminar reinforcing the skills learned at approximate 5 weeks from the initial workshop. MBSR was delivered completely online over a period of 8 weeks, and participants were given tasks to perform through that time period and beyond. All participants were followed for a total of 12 weeks. In addition, we recruited a group of participants who served as a no-contact condition. Because this was a pilot feasibility study undertaken to inform a later trial, participants were not randomized to condition. This study was approved by the Duke University Campus Institutional Review Board.

One week prior to the start of their chosen intervention, participants completed an intake survey that captured demographics, health information, and a variety of psychological measures. At the in-person workshops, participants received training on how to use the ambulatory heart rate monitoring device. Participants who completed MBSR or who were in the no-contract control group were mailed the ambulatory heart rate device and received training about self-administration through a video-conference call. Participants scheduled a time to complete the iTSST within one week of attending the workshop or participating in the first MBSR session. Approximately 12 weeks after the start of the intervention, participants completed a second iTSST.

Participants were provided an instruction sheet that detailed the procedures to follow on the days of testing. Participants were provided with a number of instructions to mitigate potential confounds of stress testing (Quintana and Heathers, 2014), including to: 1) refrain from smoking nicotine during the 6-h before stress testing; 2) avoid intense physical activity or consumption of alcohol for the 24 h prior to testing; and 3) try and refrain from eating the 2-h before the assessment. Self-reported adherence to instructions was recorded. We excluded all participants who reported wearing a pacemaker.

2.1.1. Initial ambulatory stress testing

Participants attached the ambulatory heart rate monitoring device 1 h prior to the scheduled iTSST. A research assistant (RA) contacted the participant using the Zoom video-conferencing platform to commence a version of the TSST (Allen et al., 2014; Kudielka et al., 2007) modified for an ambulatory repeated-measures design (iTSST). The RA was seated in a bare office, with a table, chairs and white background.

The iTSST consisted of several phases completed in a structured order:

1) ***Resting baseline***: The RA told participants to try their best to clear their mind and relax for a duration of 5 min. The RA then left the room, but kept the web camera on.
2) ***Anticipation***: The RA returned to the room and instructed participants to think about their dream job and prepare a speech to deliver in front of a selection panel to convince them why they are the best candidate for such a job. They were informed that members of the selection panel were trained in behavioural coding, would ask follow-up questions, and video record the interview to help them critically evaluate whether they were the best candidate for the position. The RA then left the room.
3) ***Speech***: After 5 min of preparation, two new RAs who were clothed with white lab-coats, stop watches and writing materials and unacquainted with the participant entered the room and sat behind the conference table. RAs were trained to communicate in an unresponsive and neutral manner, and refrain from providing facial or verbal feedback. Participants were instructed to deliver their speech and informed that they would not be able to use the materials they had prepared during the anticipation phase. RAs selected questions from a list of standardized responses in cases where the speech lasted

fewer than 5 min (e.g., “Why do you think that you are better qualified than our other applicants?” “What are your major weaknesses or shortcomings?”).

4) ***Mental arithmetic***: The chair of the “selection committee” interrupted the participant at 5 min during the speech task and informed them that they would be commencing the second phase of the assessment which involved the completion of a timed performance task. Participants were instructed to serially subtract the number 17 from 2023 as quickly and accurately as possible. The participant was asked to return to 2023 and restart the process upon each mistake. Participants performed the arithmetic task for 5 min.
5) ***Recovery***: Participants were then informed that the interview procedure was complete, and they were to spend the next few minutes trying to relax. The RAs left the room and allowed the participant to relax for a period of 5 min. The session was then concluded.

2.1.2. Second ambulatory stress testing

The second ambulatory stress test was comparable to the initial ambulatory stress test with the following exceptions: 1) participants selected a job different from their first iTSST, but still a dream/ideal job; 2) numbers in the mental arithmetic task were changed; and 3) participants were instructed to use one skill that was learned during the stress reduction intervention during the recovery phase.

2.2. Apparatus and measures

Demographics. Demographics, including age, sex assigned at birth, self-reported height and weight and racial/ethnic identity, were collected to describe the sample.

Physical activity was measured using the Godin Leisure-Time Exercise Questionnaire (GLETQ Godin, 2011). The GLETQ is a 3-item self-report measure of exercise used to assess conformance to Canadian physical activity guidelines. Participants reported their weekly frequencies of strenuous (heart beats rapidly, sweating), moderate (not exhausting, light perspiration), and mild (minimal effort, no perspiration) physical activities that they perform for more than 15 min. Frequency of mild, moderate and vigorous physical activity were converted into metabolic equivalents by multiplying weekly mild, moderate, and vigorous intensity by 3, 5, and 9 metabolic equivalents and adding the total score (Brown and Bauman, 2000). An independent evaluation confirmed the reliability and validity of the GLTEQ compared to nine other self-report measures of exercise (Jacobs et al., 1993).

Self-reported stress and mood in response to the iTSST was measured by asking participants to rate their mood at the start of the iTSST and following completion of each phase using the following descriptors: tense, calm, upset, relaxed, worried, content. Ratings were made on a 4-point Likert scale: 1 “not at all,” 2 “somewhat,” 3 “moderately,” and 4 “very much.”

Heart rate was measured using continuous electrocardiographic (ECG) recording sampled at a rate of 1000 Hz. Participants wore a Bittium eMotion Faros 180 recording device (Bittium) connected by electrode leads to two wet-gelled, Ag/AgCl, disposable Ambu Bluesensor ECG electrodes attached beneath the right clavicle and left ribcage.

2.3. Data reduction

Participant reports of feeling tense, upset, and worried during the iTSST were averaged to create an index of self-reported “stress.” Self-reports of feeling calm, relaxed and content were averaged to create an index of self-reported “relaxation.”

Using Mindware 3.0.3 software (Gahanna, OH), the ECG data were partitioned into 60-s segments and then scanned for artifacts according to accepted standards (Berntson et al., 1990). Each segment was linearly detrended and subject to a Hamming window. Mean values of heart rate (HR) and root mean square of successive difference (RMSSD) were calculated for each 60-s segment within each phase. RMSSD is a time-domain measure of heart period variability that reflects fast changes in successive inter-beat-intervals that correspond with respiration and are typically attributed to parasympathetic activity. We chose to use RMSSD as a marker of parasympathetic cardiac control because it is less prone to movement than frequency domain measures and is considered the most precise marker (Minarini, 2020). RMSSD was calculated with the following formula.

$$RMSSD = \sqrt[2]{\frac{1}{(N-1)}\sum_{i=1}^{N}(RR_{i+1} - RR_i)^2} \tag{1}$$

The average value of HR and RMSSD were calculated for each phase by calculating the mean value of 60-second segments within resting, speech/arithmetic, and recovery. The average value for the resting phase was calculated using 4-minute segments (1:00–5:00) to avoid potential reactivity during the first minute of recording that can occur as participants get settled. The mean value for speech/arithmetic was calculated by combining 5 min (0:00–5:00) of the speech task and 4 min (0:00 to 4:00) of arithmetic. We excluded the final minute of arithmetic as participants often evidenced a sigh of relief at the end of the math portion. For the recovery phase, we calculated the average of 5 min (00:00–5:00). Peak change in RMSSD was calculated as the difference of the lowest value of RMSSD during the speech and arithmetic test subtracted from the average RMSSD in the resting phase. We also calculated percentage change in RMSSD from resting to peak using the following formula:

$$\%Change\ RMSSD = 100 \times \frac{(RMSSD_{lowest\ task} - RMSSD_{resting})}{RMSSD_{resting}} \tag{2}$$

3. Analytical approach

Separate 2 (Time: first ambulatory stress test, second ambulatory stress test) by 3 (Phase: resting, speech/arithmetic, recovery) mixed models analyses of variances (ANOVAs) were conducted with self-reported “stress,” self-reported “relaxation,” HR and RMSSD as dependent variables in order to evaluate whether the iTSST resulted in reliable change and whether the pattern of responses varied across first and second administration. The criteria to establish statistical significance was set at $\alpha = 0.05$.

4. Results

4.1. Participants

As shown in Fig. 1, the sample consisted of 72 participants who were recruited and provided informed consent to participate. Of these, five participants withdrew from the study before it began and five were medically ineligible (two had pacemakers and three had active atrial fibrillation), leaving 62 who completed the initial iTSST. Of those recordings, one discontinued the iTSST before completion, five did not have epoch transition times recorded, four had readings that were unusable due to excessive motion and other artifacts, and two had lost data. This left a total of 50 recordings that were analyzed from the initial iTSST administration. 41 recordings were available for analysis following the second iTSST administration. We were unable to schedule appointments with 6 participants and another 3 participants could not be scheduled prior to the completion of the study. At the initial iTSST administration, participants were a mean 50.4 years of age ($SD = 11.1$), majority men (56%), primarily White (92%), had a mean BMI of 29.5 ($SD = 7.2$), and self-reported a mean leisure-time physical activity score of 37.3 ($SD = 28.6$) units.

4.2. Change in self-reported mood in response to the iTSST

There was a significant main effect of Phase on self-reports of stress, *F*

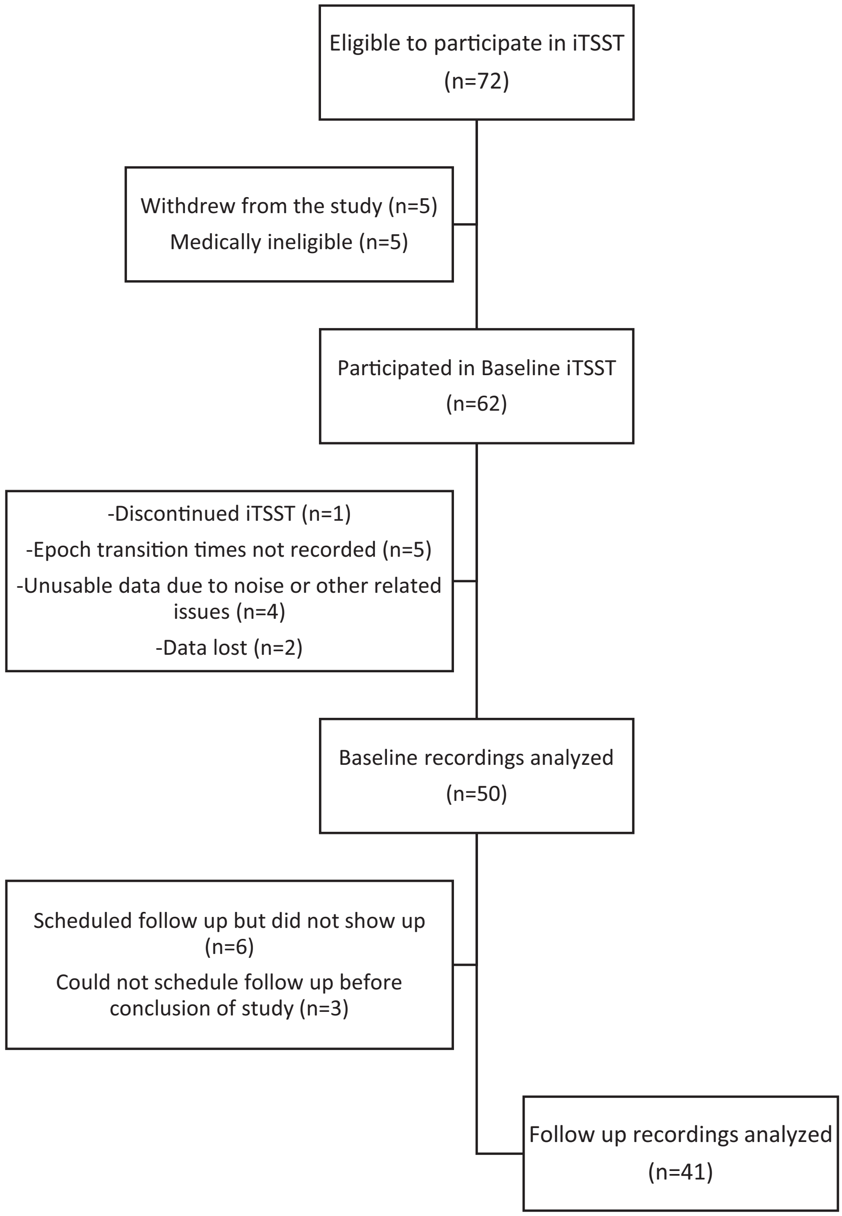

Fig. 1. Flowchart of participants in the pilot iTSST study.

(1, 40) = 25.68, standard error (*SE*) = 0.18, $p < .01$, $\eta_p^2 = 0.17$. Participants reported a significant increase in self-reported stress from resting ($M = 1.54$, $SE = 0.07$) to speech/mental arithmetic ($M = 1.77$, $SE = 0.07$), $M_{Diff} = 0.23$, $SE = 0.08$, $p < .01$, followed by a reduction during recovery ($M = 1.39$, $SE = 0.05$), $M_{Diff} = 0.38$, $SE = 0.05$, $p < .01$, when averaged across the two iTSST administration sessions. Self-report of stress was significantly lower at recovery than baseline, $M_{Diff} = 0.16$, $SE = 0.07$, $p = .02$. There was a main effect of Time on self-reported stress, F (1, 41) = 8.32, $SE = 0.36$, $p < .01$, $\eta_p^2 = 0.56$, with higher self-reports of stress during the first iTSST administration ($M = 1.67$, $SE = 0.07$), relative to the second administration ($M = 1.46$, $SE = 0.04$). There was no Time (i.e. initial or second administration) by Phase interaction, $p = .57$, $\eta_p^2 = 0.03$.

There was a significant main effect of Phase on self-reports of relaxation, F (1, 40) = 79.05, $SE = 0.33$, $p < .01$, $\eta_p^2 = 0.80$. Participants reported a significant reduction in self-reported relaxation from resting ($M = 3.29$, $SE = 0.09$) to speech/mental arithmetic ($M = 2.48$, $SE = 0.08$), $M_{Diff} = 0.81$, $SE = 0.11$, $p < .01$, followed by an increase during recovery ($M = 3.27$, $SE = 0.07$), $M_{Diff} = 0.79$, $SE = 0.6$, $p < .01$, when averaged across the two iTSST administration sessions. Self-report of relaxation did not differ between baseline and recovery, $M_{Diff} = 0.02$, $SE = 0.09$, $p = .82$. There was a main effect of Time on self-reported relaxation, F (1, 41) = 6.21, $SE = 0.44$, $p = .02$, $\eta_p^2 = 0.13$, with lower self-reports of relaxation during the initial iTSST administration, ($M = 2.91$, $SE = 0.08$), relative to the second administration, ($M = 3.12$, $SE = 0.08$). There was no Time by Phase interaction, $p = .06$, $\eta_p^2 = 0.13$.

4.2.1. Change in heart rate in response to the iTSST

There was a significant main effect of Phase on heart rate, F (1, 39) = 37.03, $SE = 19.31$, $p < .01$, $\eta_p^2 = 0.66$. A significant increase in heart rate was observed from resting ($M = 71.81$ bpm, $SE = 1.22$) to speech/mental arithmetic ($M = 77.16$ bpm, $SE = 1.34$), $M_{Diff} = 5.36$ bpm, $SE = 0.72$, $p < .01$, followed by a decrease during recovery ($M = 70.42$ bpm, $SE = 1.14$), $M_{Diff} = 6.74$ bpm, $SE = 0.78$, $p < .01$, when averaged across the two iTSST administration sessions. Heart rate was significantly lower at recovery than baseline, $M_{Diff} = 1.39$ bpm, $SE = 0.53$, $p = .01$. There was no main effect of Time, $p = .36$, $\eta_p^2 = 0.02$, or Time by Phase interaction, $p = .99$, $\eta_p^2 = 0.00$.

4.2.2. Change in RMSSD in response to the iTSST

There was a significant main effect of Phase on RMSSD, F (1, 39) = 11.41, $SE = 174.91$, $p < .01$, $\eta_p^2 = 0.38$. A significant reduction in RMSSD was observed from resting (M = 44.81, SE = 9.15) to speech/mental arithmetic (M = 37.05, SE = 7.09), M_{Diff} = 7.76, SE = 2.64, p < .01 followed by an increase during recovery (M = 45.43, SE = 0.8.44), M_{Diff} = 8.38, SE = 1.77, p < .01, when averaged across the two iTSST administration sessions. RMSSD did not differ between baseline and recovery, M_{Diff} = 0.61, SE = 1.73, p = .73. There was no main effect of Time, p = .90, η_p^2 = 0.00, or Time by Phase interaction, p = .50, η_p^2 = 0.03.

4.2.3. Percentage change in RMSSD in response to the iTSST

In Fig. 2, we plot RMSSD over the course of the Trier for one representative participant. While we examined plots for each individual, for ease of presentation, we present the data from only one participant. The anticipation phase was not included in analyses; it is shown in the figure for completeness. The large spike in RMSSD observed at minute 6 was due to a motion artifact and not included in the calculation of resting RMSSD (i.e. RMSSD was calculated as the average of minutes 0:00–5:00 of the resting phase).

In Fig. 3, we present a histogram of the percent change in RMSSD from resting to the lowest value observed in the speech/arithmetic of the iTSST. As this figure shows, 2 participants showed an increase in RMSSD, and one participant had a less than 10% change in RMSSD. The rest of the observations (94%), showed between a 10% to 100% decrease in RMSSD from resting during the speech/arithmetic phase of the iTSST. The average percentage change from resting to speech/arithmetic was 44.8% (sd = 23.2%). In supplemental analyses that are not shown, we examined if any control variables (female gender, White, age, BMI and Godin score) were correlated with percent change in RMSSD during the initial iTSST administration. None of the control variables were correlated with percentage change from resting to speech/arithmetic phase.

4.2.4. Repeatability

The observed percentage change from resting to speech/arithmetic during the second iTSST administration was similar to the first administration with a mean percentage change of 46.2% (SD = 19.7%). Only one participant had a positive change during the second iTSST administration and the rest exhibited greater than a 10% reduction in RMSSD.

5. Discussion

This study represented an initial effort to adapt the TSST for remote delivery through a video-conferencing platform. United Methodist clergy were recruited to participate within the context of a stress-reduction intervention. The iTSST was administered twice over the course of 8 weeks with data available from 50 participants following the first administration and 41 participants following the second administration. The iTSST resulted in a reliable stress response, as indicated by an increase in self-reported stress and HR, and reductions in self-reported relaxation and RMSSD from rest to the speech/mental arithmetic phase. Further, nearly every participant evidenced greater than 10% reduction in RMSSD from rest to speech/mental arithmetic when calculated as percentage change. Rapid reduction of RMSSD is indicative of withdrawal of parasympathetic cardiac control to facilitate rapid increase in heart rate (Berntson et al., 1997), and represents a characteristic response to stress (Kim et al., 2018). It should also be acknowledged that an increase in sympathetic arousal is a characteristic response to stress that may have contributed to the observed increase in heart rate, though this cannot be stated definitively without a pure measure of sympathetic arousal.

The changes in RMSSD between the conditions were similar to the observed changes in HR, except from baseline to recovery. This was not entirely expected given that RMSSD and HR are generally under tight reciprocal control (Monfredi et al., 2014). It is important to note that heart rate is determined by sympathetic and parasympathetic influences. The observation that HR was lower during recovery relative to resting with RMSSD values that were comparable across conditions suggests less sympathetic influence on HR during recovery relative to resting. Participants may have experienced heightened sympathetic arousal prior to undergoing the eTSST, or experienced a sense of relief following completion of the eTSST. Of interest, participant self-reports of relaxation were comparable between rest and recovery, while stress was rated lower during recovery than rest.

The modified iTSST resulted in a stress response that was reproducible over an 8-week duration with some evidence for habituation in self-reported stress and relaxation, but no evidence for habituation in cardiovascular reactivity. This is consistent with repeated measures designs that have demonstrated some habituation of the HPA-axis response to the TSST measured using salivary cortisol, with little to no habituation across cardiovascular reactivity (Gerra et al., 2001; Mischler et al., 2005; Schommer et al., 2003; von Känel et al., 2006). The ability to deliver a modified iTSST that produces a reliable and repeatable

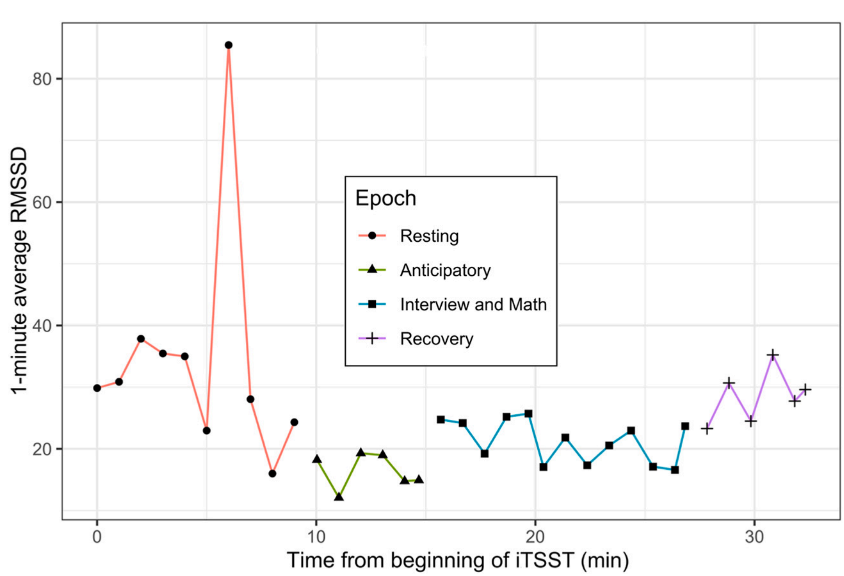

Fig. 2. One-minute average RMSSD values during the iTSST for one representative participant.

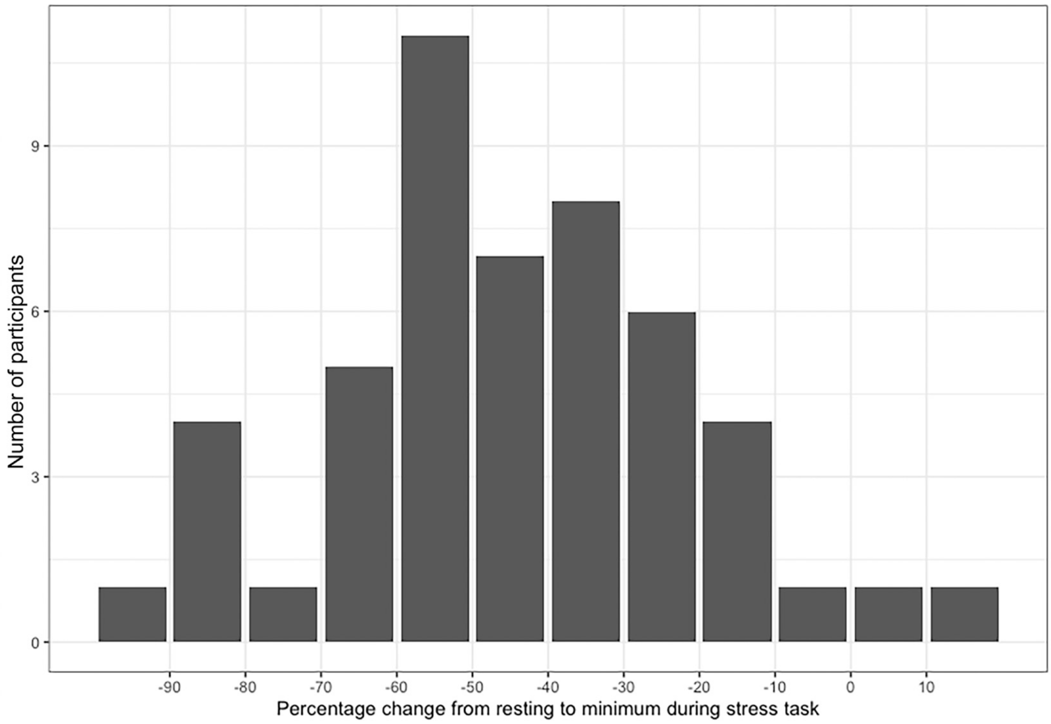

Fig. 3. Histogram of percent change in RMSSD from recovery to stress task in baseline participants ($n = 50$).

cardiovascular response is advantageous under circumstances when researchers wish to evaluate the impact of an intervention (e.g., pre- and post-treatment). The optimal inter-test duration, and impact of procedural variation on habituation to the iTSST is still unknown and represents a fruitful avenue of future exploration.

The modification of the TSST to be delivered remotely has several clear advantages to laboratory-based administration, including reduced participant demand, cost-efficiency, ease of scheduling, ecological validity, and ability to accommodate unforeseen circumstances such as social distancing in response to COVID-19. Despite clear advantages, a number of challenges arose during the adaptation of the iTSST, which highlighted avenues for improving future iTSST administration. Technology presented as a potential barrier. For example, some participants had difficulty orienting to the webcam and those connecting from rural locations sometimes experienced difficulty in audio and video stability which could impact the effectiveness of the iTSST. Further, although we asked participants to turn off notifications and be free from distraction, some participants experienced interruptions during session (e.g., text messages, small children or pets). Furthermore, participants occasionally moved during session (e.g., to find a stronger internet signal) which could introduce movement artifact into cardiovascular recording. Finally, speeches were delivered seated because standing removed their face from the camera view.

The clinical implications of the observed results are not yet known. While observational studies have observed associations between magnitude of cardiovascular responses to acute psychological stress tasks and the development of hypertension (Carroll et al., 2001, 2003), coronary artery calcification (Matthews et al., 2006), and acute cardiovascular events (Carroll et al., 2012a), these studies have typically measured response of the sympathetic nervous system *and* the hypothalamic-pituitary-adrenal (HPA) axis. Fortunately, the cohort evaluated in the present investigation is well characterized with more than a decade of longitudinal research (Blouin and Proeschold-Bell, 2015; cf. Milstein et al., 2019; Proeschold-Bell et al., 2013) and future assessments will provide an answer to this question.

5.1. *Limitations*

There are several limitations that must be considered when interpreting results of this study. First, only one biological marker of stress was included in the present investigation (i.e., cardiovascular reactivity). Research protocols involving the TSST typically acquire saliva and blood to derive markers of activation of the HPA-axis, and immune system function (refer to Allen et al., 2014, 2016 for reviews). Similarly, the present study utilized an index of parasympathetic nervous system activation in RMSSD, but did not employ a marker of sympathetic arousal (e.g., pre-ejection period or α-amylase). The iTSST resulted in a reliable increase in HR, which cannot conclusively suggest an increase in sympathetic arousal due to change in HR being multiply determined by sympathetic and parasympathetic influences. As such, claims can only be made about one facet of a coordinated stress response system, though it is encouraging that parasympathetic activation during stress tends to be reciprocally related to sympathetic (Berntson et al., 1991), and HPA-axis responses (Doussard-Roosevelt et al., 2003). Finally, change in respiration rate can confound change in parasympathetic cardiac control (Grossman and Taylor, 2007) and respiration was not measured nor statistically adjusted for. This concern is somewhat tempered given that RMSSD is less affected by changes in rate and volume of respiration than frequency-domain measures (Penttilä et al., 2001).

6. Conclusions

The TSST was adapted for remote delivery using an online web platform. An initial evaluation indicated that the iTSST resulted in a reliable and prototypical response to stress among nearly every participant. Moreover, the iTSST was observed to elicit a stress response in two administrations separated by 8 weeks, with little evidence for habituation. The iTSST may represent a cost effective and ecologically valid method for ambulatory stress testing during circumstances where laboratory-based assessment is not feasible.

Funder source

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpsycho.2021.03.009.

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