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High Thrill and adventure seeking is associated with reduced interoceptive sensitivity: evidence for an altered sex-specific homeostatic processing in high sensation seekers

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Abstract

Objective—The personality trait of sensation seeking (SS) has been traditionally linked to the construct of exteroception, i.e. sensing of the outside world. Little is known about the relationship between SS and interoception, i.e. sensing originating in the body. Interoceptive sensations have strong affective and motivational components that may influence behaviors such as risk-taking in SS. This investigation examined whether interoceptive differences contribute to different behavioral characteristics in SS.

Method—Using an inspiratory resistive load breathing task, the response to an aversive interoceptive stimulus as a basic homeostatic process was studied in 112 subjects (n=74 females, 38 males). A linear-mixed model approach was used to examine the influence of thrill and adventure seeking (TAS) on the interoceptive response across three levels of breathing resistances (10, 20, 40 cmH_2O/L/sec).

Results—High relative to low TAS individuals were less responsive in evaluating intensities of perceived choking with increasing inspiratory resistive loads. This effect was driven by male, but not female high TAS individuals and was particularly associated with reduced interoceptive sensitivity in males.

Conclusion—The conceptualization of SS as primarily driven by exteroceptive stimuli can be expanded to a view of an altered homeostasis in SS, specifically in males.

Keywords

Sensation Seeking; Thrill and Adventure Seeking; Interoception; Respiration; Inspiratory Breathing Restriction

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Introduction

Deciding to either approach or avoid a stimulus is crucially dependent on the individual's homeostatic situation, e.g. to maintain or achieve an optimal homeostatic level of arousal (e.g. Zuckerman, 1980a). In line with this, sensation seeking (SS) was defined as "seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experiences" (Zuckerman, 1994, p.27). SS is comprised of Thrill and Adventure Seeking (TAS), Experience Seeking (ES), Boredom Susceptibility (BS), and Disinhibition (DIS) (Zuckerman, Eysenck & Eysenck, 1978). ES, BS, and DIS describe SS in cognitive and social domains, whereas behavioral characteristics of TAS are expressed in risky/exciting physical activities (Zuckerman, 1994). SS has been extensively researched using exteroceptive stimuli, i.e. responses and sensitivity to stimuli originating outside of the body. Interestingly, less research is available on the relationship between SS and interoception (i.e., sensing originating in the body), although interoceptive sensations provide the link between the current body state and cognitive/affective processes that in turn may affect behavioral outcomes (Paulus and Stein, 2006). Research using exteroceptive stimuli revealed that high and low sensation seekers show substantial differences in response to novel/aversive stimulation in various dimensions ranging from differences in autonomic response pattern as changes in heart rate and skin conductance (response to deviant tones: low SS > high SS; Pascalis et al., 2006), auditory evoked cerebral potential (response to intense stimulation: low TAS < high TAS; Brocke et al., 1998), to differences in behavioral outcomes as risk-taking (low SS < high SS; Zuckerman, 1994; Roberti, 2004; Kruschwitz et al., 2011). Based on these or similar findings, it was concluded that individuals high in SS show hypersensitivity to intense stimuli, but reduced sensitivity to aversive stimulation (e.g. Joseph et al., 2008).

Combining the concepts of exteroception and interoception, it was proposed that the perception of rewarding and aversive stimuli critically depends on the individual´s homeostatic state sensed through interoception (Cabanac, 1971; Cabanac et al., 2002). Related to this, it was suggested that decision-making (such as risk-taking) can be modeled as part of a homeostatic process in which decisions maintain or bring individuals into a new homeostatic state (Paulus, 2007). Thus, as low vs. high SS individuals not only differ in their reactions to novel/aversive stimulation but also in their risk-taking, it is conceivable that SS behaviors may partly relate to differences in interoceptive processing (i.e., altered homeostatic processing).

Interoception can be defined as the sense of the physiological condition of the entire body entailing sensations of temperature, pain, touch, hunger, respiration, and visceral sensations (Craig, 2002), that are suggested to be integrated in a homeostatic system (Paulus, 2009). Respiration is one example of an interoceptive process with fundamental relevance for homeostasis as lack of oxygen immediately induces air-hunger (Banzett et al., 2008), driving one to regain a homeostatic equilibrium by breathing in. Research has shown that respiratory sensations consist of at least two separate dimensions: an intensity dimension - "what is sensed" (e.g., airflow intensity) and an affective dimension - "how it feels" (e.g., unpleasantness) (von Leupoldt and Dahme, 2005; Davenport, 2009). As humans can easily

detect mechanical loads added to inspiration (Davenport, 2007), inspiratory breathing restriction is a powerful tool to test the interoceptive sensitivity to changes in the described dimensions.

Aims and Prospects of this Study

Previous research primarily focused on interoceptive processing in psychiatric disorders and personality characteristics related to anxiety (Paulus and Stein, 2006; Domschke et al., 2010). Research on its relationship to trait dimensions such as SS is sparse, although it could provide a deeper understanding of the biological processes that contribute to variation across personality traits and associated behaviors, i.e., approach vs. avoidance in decision-making and risk-taking.

This study tested the interoceptive sensitivity in TAS individuals in response to inspiratory breathing restriction. Among SS subscales, TAS obtains a direct relationship with approach/avoidance in situations of increased physical risk (Zuckerman, 1994). Therefore, we were interested in the perception of physiological changes and their associated perceived intensities (i.e., “what is sensed”) during inspiratory breathing restriction in TAS individuals. As interoceptive sensations are closely associated with affective components (Paulus and Stein, 2006), we examined how experienced unpleasantness (i.e., “how it feels”) was associated with increasing intensities of resistive loads in TAS individuals. We hypothesized that high relative to low TAS individuals would show significantly less interoceptive sensitivity to changes in intensity of physiological states associated with different inspiratory breathing restriction loads. We tested for the possibility that high relative to low TAS individuals would perceive less unpleasantness with increasing respiratory restriction loads due to an association with reduced sensitivity to changes in intensity. As males score significantly higher than females in SS (Zuckerman, 1980b; Zuckerman, 1991), and males, compared to females, perceive increasing respiratory restriction loads as less intense (i.e., magnitude estimation of loads greater than 15cmH_2O/L/sec) (Alexander-Miller and Davenport et al., 2010), we hypothesized that altered interoceptive sensitivity during breathing restriction may be observable especially in high TAS males.

Methods

Participants

112 healthy, non-smoking psychology/medicine college students (74 females) age 18.64 ± 1.1 (mean, SD), without substance dependence or Axis I DSM- IV diagnosis, participated in this study. Additional exclusion criteria were current or past drug use (THC, LSD, PCP, barbiturates, stimulants, cocaine, ecstasy, opioids, glue), and any current medication related to respiratory function. All subjects completed the Sensation Seeking Scale Form-V (Zuckerman, 1990), the NEO Five Factor Inventory (NEO-FFI; Costa and McCrae, 1992; Costa and McCrae, 1997) the Barratt Impulsivity Scale BIS–11 (Patton et al., 1995) (n = 1 missing), and the Anxiety Sensitivity Index scale (Reiss et al., 1986). Although we excluded participants with prior drug experience, according to the psychometric properties of the SSS-V (Zuckerman et al., 1978), mean scores of the current sample respectively fall within the

range of mean ± SD of the Zuckerman et al. (1978) sample. Therefore, TAS scores entailed in our sample can be considered to be "normal" for also representing high TAS characteristics. Group statistic variables (gender, age, race/ethnicity) and personality measures are shown in table 1. Subjects were taking part in a study aimed to examine the relationship between anxiety, substance use behaviors and interoception, which was approved by the University of California San Diego Institutional Review Board.

Procedure

After consenting to the study, subjects participated in two sessions. The first session contained a diagnostic assessment based on the SSAGA-II (Semi-Structured Assessment for the Genetics of Alcoholism; Buchholz et al., 1994), then completed the personality questionnaires. In the second session subjects were familiarized with the breathing restriction task and equipment, and subsequently completed the task. Before leaving, subjects were debriefed and received course credit for their participation.

Task and Behavioral Measures

Resistive loads were first introduced by Lopata (Lopata et al., 1977) and Gottfried (Gottfried et al., 1978) and are airflow-dependent loads (Kifle et al., 1997). The perceived magnitude of externally added loads to breathing is directly dependent on the inspiratory muscle force developed and its duration, and indirectly on the added load (Killian et al., 1982).

Resisitve load apparatus—For the breathing restriction task subjects had to wear a nose clip and respired through a mouthpiece and a two-way non-rebreathing valve (2600 series, Hans Rudolph), which was suspended to eliminate the need for the subject to contract mouth muscles but maintained an airtight seal. The resistance loads were sintered bronze disks placed in series in a Plexiglas tube (loading manifold), with stoppered ports between disks. The expiratory port was left unloaded, while resistance loads were placed in the inspiratory port in the following order: 10, 20, and 40 $cmH_2O/L/sec$. Resistances were selected by removing the stopper and allowing subjects to inspire through the selected port.

Experimental procedure—Subjects were asked to breathe through the hose three times for one minute each in which three different levels of breathing restriction were used in the following order: 10, 20, and 40 $cmH_2O/L/sec$. Participants were instructed with emphasis to maintain a "constant" breathing pattern throughout all restriction conditions of the task. During the experimental session the subject was shielded with a room divider from the experimenter.

After each trial subjects evaluated specific variables in terms of intensity (sensory dimension) and a global measure of perceived unpleasantness (affective dimension) of each restriction condition on separate 10 cm Visual Analog Scales anchored from "not at all" to "extremely". Subjects were instructed that experienced intensity contains no affective component and refers purely to intensity level, whereas unpleasantness refers to affective evaluation of the restriction condition. The association of these dimensions (intensity and affect) was not explicitly stated in the instruction, leaving the possibility of an interaction effect.

Behavioral measures—As inspiratory resistive loads evoke dyspnea by increasing the effort of breathing (Harver et al., 1998), the primary variable of interest related to the dimension of perceived intensity was experienced choking across the restriction conditions of the task. Additionally to the absolute values of perceived choking intensity in each restriction condition, we evaluated the subject´s responsiveness (Δ) to discriminate between the experienced intensity of choking in the low and high restriction condition as Δ-choking = 40 $cmH_2O/L/sec$ – 10 $cmH_2O/L/sec$. To account for other less salient body states related to physiological changes in response to the restriction of air, we assessed additional variables (chest pain, trembling, tingling, hot/cold flushes, abdominal distress, palpitations, sweating, dizziness) with focus on experienced intensity during a baseline condition as well as across the task conditions. A global measure of experienced unpleasantness (affective component) was also assessed during the baseline condition and across task conditions. Baseline ratings were performed after the subject completed a first trial in which no resistance load was placed in the Plexiglas tube. The dependent measures were evaluated after each trial of the respective breathing restriction condition.

Statistical Analysis

A-priori determined analyses—To determine differences between males and females (males: n=38; females: n=74) in sociodemographic, psychological, and breathing baseline variables, chi-square tests and *t*-tests were used (table 1). All non-SS measures and breathing baseline measures in which males vs. females differed significantly were identified as potential covariates. Moreover, correlational analyses between TAS and the other non-sensation seeking variables as well as breathing baseline were performed (entire sample and sex specific subsamples) to test for further potential confounds (table 1). As linear mixed models allow explicit modeling of interactions between continuous independent variables (i.e., TAS) and categorical independent variables (i.e., sex) for repeated measures (i.e., restriction conditions) with the possibility to account for additional covariates and inter-individual variability, we performed a linear mixed effects analysis for each assessed variable (intensity: choking, chest pain, trembling, tingling, hot/cold flushes, abdominal distress, palpitations, sweating, dizziness; affect: unpleasantness) to investigate the relationship between inspiratory breathing restriction (three respiratory loads: 10, 20, and 40 cmH2O/L/sec), gender, and continuous TAS score. For each assessed breathing related variable, a separate linear mixed model (*LMM*; using the restricted maximum likelihood (*REML*) estimation method) with continuous TAS score, restriction condition, and gender serving as fixed factors as well as subjects and restriction condition serving as random factors was computed to probe for effects in the a-priori hypothesized dimensions. Based on inspection of the data and on lowest Akaike information criterion (AIC) we determined that models with a first order autoregressive covariance structure including random intercepts and random slopes fitted the data most appropriately as compared to other covariance structures, only random intercepts or slopes. Significant baseline breathing differences between males and females as well as significant TAS-baseline associations (entire sample and subgroups) were accounted as covariates in the respective *LMM*.

Post-hoc analyses—Due to the results of the *LMM* for the variable choking (please refer to the results of the *LMM* for the intensity measures) that revealed reduced interoceptive

sensitivity (i.e., choking sensitivity) particularly for male high TAS individuals in response to increasing inspiratory resistive loads, we decided to compute an additional *LMM* with focus on the affective domain (i.e., unpleasantness) separately for the male individuals in our sample. This approach was chosen post-hoc/exploratory, as specific differences in unpleasantness across increasing respiratory restriction loads between high and low TASs in the male group could be very small and thus, may have been covered by the size of the female sub-sample. For completeness, we also computed such a *LMM* separately for the female subjects (covariates in both sex-specific models: baseline unpleasantness, neuroticism, extraversion, ASI, BIS). As results of the a-priori "unpleasantness-*LMM*" did not reveal a main effect of gender (please refer to the results of the *LMM* for the unpleasantness measures), results of the post-hoc analyses cannot be interpreted as a general gender difference, but reveal a more detailed view on the perception of unpleasantness across task conditions within each group of gender.

To probe whether the TAS subscale among SS subscales obtained specificity to differences in interoceptive processing of choking intensity (based on the characteristics of TAS, we a-priori hypothesized that among SS measures only TAS would be related to differences in interoceptive processing), we performed a stepwise regression analysis with Δ-choking as dependent variable in which all SS subscales (TAS, ES, DIS, BS) were entered in order to compete against each other. This was done for the entire sample as well as separately for gender.

An α level of $p < 0.05$ indicated statistical significance. Analyses were carried out with SPSS 19.0 (SPSS, Chicago, IL, USA).

Results

Psychological Variables

Males and females showed significant differences in sensation seeking (SS) measures (SS total, ES, DIS, BS: males > females), as well as differences in the ASI total score (males < females) while other scales did not differ significantly (Table 1). In addition, TAS score showed significant associations to neuroticism and ASI total score (entire sample, females), to BIS total score (males), and to extraversion (females) (Table 1). Given the significant relationship between TAS and anxiety sensitivity or neuroticism in the presence of gender differences, we included the ASI total and neuroticsm as covariate of no interest in the *LMM*. The decision to include these measures as covariates was further substantiated by literature pointing towards their influence on the sensation of perceived dyspnea (Oswald et al., 1970; Nowobilski et al., 2007; Giardino et al., 2010). As the exact role of extraversion and impulsiveness on perceived dyspnea is not very well studied yet, we also integrated these measures as covariates.

Inspiratory Resistive Load Breathing

Baseline measures—As shown in table 1, we observed significant negative associations of TAS to unpleasantness and chest pain (entire sample, males), palpitations, hot/cold flushes and dizziness (males), and a significant sex-specific difference for the variable

sweating (females>males). No baseline differences or TAS associations were observed for any other variable. The respective baseline measures were accounted as covariates in the respective *LMM*.

LMM Intensity measures—Focusing on the intensity domain across the three restriction conditions for the variable choking (*LMM* covariates: ASI, neuroticism, extraversion, BIS), there was a significant main effect (ME) of the restriction condition ($F(2,158)=10.252$, $p<.001$) revealing generally increased perceived choking with increasing resistive loads (*LMM* predicted means per condition: 10 cmH_2O/L/sec: 0.793 [95% CI: 0.40; 1.18]; 20 cmH_2O/L/sec: 1.07 [95% CI: 0.674, 1.48]; 40 cmH_2O/L/sec: 1.478 [95% CI: 1.05, 1.91]). The *LMM* also revealed a significant interaction effect (IE) of restriction condition*gender ($F(2,158)=3.052$, $p=0.05$) indicating that males as compared to females perceived choking especially in the highest restriction condition as less intense (fixed effects parameter estimates: reference category=females+10 cmH_2O/L/sec; 20 cmH_2O/L/sec: beta= −0.967, p=0.145 [95% CI: −2.26, 0.33]; 40 cmH_2O/L/sec: beta= −1.93, p=0.015 [95% CI: −3.47, −0.38]). Moreover, we observed a significant choking related IE of TAS*restriction condition ($F(2,158)=4.715$, $p=0.010$) revealing reduced interoceptive sensitivity (i.e., choking sensitivity) with increasing TAS score in response to increasing inspiratory resistive loads, whereas this effect was mainly driven by the significant difference for the highest load between high vs. low TAS (fixed effects parameter estimates: reference category=10 cmH_2O/L/sec; 20 cmH_2O/L/sec: beta= −0.09, p=0.232 [95% CI: −0.23, 0.58]; 40 cmH_2O/L/sec: beta= −0.29, p=0.001 [95% CI: −0.47, −0.12]). Furthermore, we found pronounced gender differences between high and low TAS individuals in perceived choking intensity across the conditions of the task (IE TAS*gender*restriction condition: $F(2,159) = 3.307$, $p = 0.039$), indicating reduced choking sensitivity with increasing TAS scores for male as compared to female individuals in response to increasing inspiratory resistive loads; especially in the highest restriction condition (fixed effects parameter estimates: reference category=females+10 cmH_2O/L/sec; 20 cmH_2O/L/sec: beta= −0.09, p=0.290 [95% CI: 0.84, −0.28]; 40 cmH_2O/L/sec: beta= −0.27, p=0.013 [95% CI: −0.58, −0.49]). For ease of visual interpretation and to illustrate effects in a traditional categorical “high vs. low TAS” perspective (entire sample and by sex), figures 1a–c summarize the *LMM* predicted effects stratified by simple median split. Supplementary figures 1a–c show the detailed relationship between continuous level of TAS and experienced choking intensity (coded in grayscale intensities) across the three restriction conditions for the entire sample as well as separated by sex (observed effects, predicted effects, predicted fixed effects). Additional effects for the variable choking were not observed (ME gender: $F(1,114) = 1.036$, $p=0.311$; ME TAS: $F(1,114) = 3.052$, $p= 0.062$; IE TAS*gender: $F(1,114) = 2.003$, $p= 0.160$; all p´s > .05). In the extra variables related to intensity, we only observed a significant ME of restriction condition in the variable chest pain ($F=3.819$, $p=0.024$) indicating generally elevated chest pain with increasing restriction loads (*LMM* predicted means per condition: 10 cmH_2O/L/sec: 0.524 [95% CI 0.33, 0.718]; 20 cmH_2O/L/sec: 0.672 [95% CI 0.37, 0.96]; 40 cmH_2O/L/sec: 1.047 [95% CI 0.62, 1.47]).

LMM Unpleasantness measures

A-priori analysis—Focusing on the entire sample (i.e., males/females included in one model) with regard to the affective domain (i.e., unpleasantness; *LMM* covariates: baseline unpleasantness, ASI, neuroticism, extraversion, BIS), we observed a significant ME of restriction condition (F(2,148)=3.232, p=0.042) revealing generally increased unpleasantness with increasing resistive loads (*LMM* predicted means per condition: 10 cmH_2O/L/sec: 4.152 [95% CI: 3.54; 4,76]; 20 cmH_2O/L/sec: 5.01 [95% CI: 4.37, 5.64]; 40 cmH_2O/L/sec: 5.703 [95% CI: 5.04, 6.36). No other significant effects (besides baseline differences) were observable (ME TAS: F(1,104) = 2.823, p=0.096; ME gender: F(1,104) = 0.04, p=0.841; IE TAS*gender: F(1,104) = 0.514, p=0.475; IE TAS*restriction condition: F(2,148) = 0.802, p=0.450; IE gender*restriction condition: F(2,148) = 2.656, p=0.074; IE TAS*gender*restriction condition: F(2,148) = 2.088, p=0.128).

Post-hoc analysis—Post-hoc, when computing the *LMM* separately for the male group, we observed a significant ME of restriction condition (F(2,184)=4.323, p=0.016) revealing generally increased unpleasantness with increasing resistive loads. Moreover, the *LMM* revealed a marginally significant IE of TAS*restriction condition (F(2,84) = 2.981, p=0.056) including a trend towards reduced perception of unpleasantness with increasing TAS scores when transitioning from the first mild load to the second modest restriction load (fixed effects parameter estimates: reference category=10 cmH_2O/L/sec; 20 cmH_2O/L/sec: beta= −0.19, p=0.065 [95% CI: −0.41, 0.12]). Focusing on the female subsample, no significant effects were observable. As for the variable choking, figures 2a–b summarize effects stratified by simple median split separated by sex, whereas supplementary figures 2a–c depict the observed relationship between continuous level of TAS and experienced unpleasantness (coded in grayscale intensities) across the three restriction conditions for the entire sample as well as separated by sex.

Specificity of sensation seeking subscales to perceived choking: When the SS subscales (TAS, ES, DIS, BS) were entered into a step-wise regression model with Δ-choking as dependent variable for the entire sample, a significant model (F = 4.78; p = 0.031) emerged that only included the TAS subscale as significant predictor with a standardized beta of b = − 0.204 (ES, DIS, BS were removed from the model in a step-wise manner). When the same procedure was performed for the male group, a significant model (F = 9.97; p = 0.003) emerged that only included the TAS subscale with a standardized beta of b = −0.466. In contrast, no significant model emerged when performing this analysis for the female group.

Discussion

This study examined the question whether individuals with different levels of Thrill and Adventure Seeking (TAS) experience an aversive interoceptive stimulus differently and yielded three main findings. First, males as compared to females and high relative to low TAS individuals were less responsive in evaluating intensities of perceived choking with increasing inspiratory resistive loads. Second, the general TAS effect was observed in male but not female high TAS individuals, who showed an attenuated response to the interoceptive stimulus. Third, when focusing specifically on male subjects, high relative to

low TAS individuals showed a trend towards a "delay" in perceived unpleasantness (i.e., trend towards reduced perception of unpleasantness with increasing TAS scores when transitioning from the first mild restriction load to the second modest load). Taken together, different levels of Sensation Seeking (SS) may not be exclusively driven by exteroceptive perceptional differences but may also be due to differences in interoceptive processing. This is consistent with the notion that SS could be viewed as altered homeostasis, especially for men.

Due to the observed interaction of TAS and restriction condition in which high TAS relative to low TAS individuals tended to perceive choking as less intense with increasing resistive loads and the finding that male high TAS individuals perceived choking as less intense, our findings contribute to recent evidence (Lavietes et al., 2000; von Leupoldt, 2006; Giardino et al., 2010) suggesting that differences in response to inspiratory breathing restriction may be partly explained by differences in psychological state/trait and sex. Specifically, Lavietes et al. (2000) found that subjects with higher depression scores reported increased unpleasantness of perceived dyspnea in response to different levels of inspiratory resistive loads. Giardino et al. (2010) provided support for a partial mediator role of anxiety sensitivity on affective dyspnea reports. Moreover, affective dyspnea ratings (as opposed to ratings for intensity of perceived dyspnea) changed, when faced with concomitant positive or negative affective pictures during breathing restriction (von Leupoldt, 2006; von Leupoldt et al., 2008). In another study, von Leupoldt (2007) also reported that attentional distraction reduced the affective but not the sensory dimension of induced dyspnea during inspiratory resistive load breathing. In contrast to these findings, which demonstrate an association of psychological state/trait to the affective dimension of perceived dyspnea, our results add to the prior literature in providing a link between the sensory dimension (i.e., experienced choking intensity) of respiratory sensation and differences in psychological trait, specifically TAS. However, as high relative to low TAS males showed a trend towards a delay in perceived unpleasantness, it seems that reduced sensitivity to choking intensity may partly influence the affective respiratory dimension in high TAS males. This is consistent with the notion that interoceptive sensations are closely associated with affective components (Paulus and Stein, 2006).

Thrill and Adventure Seeking – Altered Homeostatic Processing?

The perception of loaded breathing crucially depends on the sense of the physiological condition of the body (i.e., interoceptive processing). As we observed that high relative to low TAS individuals tended to differ in the perception of loaded breathing induced choking intensity and that high relative to low TAS males showed a trend towards a delay in perceived unpleasantness, it seems nearby that differences in level of TAS are linked to distinct interoceptive evaluation processes in response to respiratory stimuli, particularly in male individuals. As respiration is a very basic interoceptive process of fundamental relevance for homeostasis, it could be speculated that not only the interoceptive response to respiration but also homeostatic processing of other stimuli may be vulnerable to differences in TAS. Thus, differences between SS individuals in heart rate, skin conductance, auditory evoked cerebral potential (Zuckerman, 1994; Pascalis et al., 2006; Brocke et al., 1998) may be partly explained through distinct interoceptive evaluation processes. This hypothesis is

supported by the notion that the perception of rewarding and aversive stimuli critically depends on the individual's homeostatic state sensed through interoception (Cabanac et al., 2002). This idea can further be extended to SS related differences in risk-taking (e.g. Kruschwitz et al., 2012), as decision-making can be modeled as part of a homeostatic process, in which decisions bring or maintain individuals into a new homeostatic state (Paulus, 2007). Specifically, high relative to low TAS individuals were more prone to engage in a risky situation immediately following punishment, which was further associated with neural activity in the posterior insular cortex (Kruschwitz et al., 2012). This area is implicated as the basic receptive area for visceral input encoding physiological states of the body, and is therefore involved in interoceptive awareness (Craig, 2002). Moreover, a recent study subjecting elite athletes to inspiratory breathing load, revealed attenuated insular cortex activation (compared to controls) during and following the aversive interoceptive condition of inspiratory resistive load breathing (Paulus et al., 2012).

Based on these notions, we hypothesize a model where (male) high TAS associated behaviors may partly result from reduced interoceptive sensitivity. A novel stimulus may elicit weaker interoceptive responses in high relative to low TAS individuals, thus leading them to find novel stimuli less aversive or alternatively more interesting. Subsequently, an optimal level of interoceptive stimulation (i.e., homeostatic equilibrium) is achieved by approaching rather than avoiding such stimuli.

The Interplay of Thrill and Adventure Seeking, Gender, and Interoceptive Sensitivity

Using a modified Borg category scale (measuring inspiratory difficulty), Alexander-Miller and Davenport et al. (2010) demonstrated that magnitude estimation of resistive loads greater than 15cmH_2O/L/sec with a sustained 10-breath trial significantly increased in females but either did not change or decreased in males. Moreover, these authors reported that male compared to female subjects tended to obtain a reduced perceptual sensitivity of the resistive loads used in their study (5–40cmH_2O/L/sec). As we observed a significant gender by restriction condition interaction effect, these findings overlap to a considerable degree with our results. Specifically, we found an increase of reported choking intensity with increasing resistive loads in females, whereas males (high in TAS) did not report increasing intensities of perceived choking. When testing the specificity of the TAS subscale in relation to experienced choking intensity for low vs. high restriction (Δ-choking), we observed that TAS scores (uniquely among SS measures) significantly predicted perceived choking intensity for the males, the entire sample, but not for females. Thus, additionally to the results of Alexander-Miller and Davenport et al. (2010), our results show that perceptual sensitivity to increasing resistive loads in males can be separated by high vs. low TAS individuals – resulting in reduced perceptual sensitivity only for high TAS males. Therefore, differences in the sensory dimension of respiration in response to resistive load breathing may be partly explained by the interplay of differences in personality characteristics and gender. Thus, it could be speculated that among other factors, reduced interoceptive sensitivity may drive male relative to female high TAS more frequently to exposure to intense stimulation, thereby achieving an optimal homeostatic equilibrium. In line with this, it was shown that males experienced markedly less arousal/stressful experience than females when faced with rappelling down a rock face (Kerr & Vlaminkx, 1997). In a context closer

related to respiration, it was shown that high SSs inhaled more of cigarette smoke than low SSs did (Zuckerman, 1990). Moreover, it was shown that females exhibit smaller depth of smoke inhalation than males (Eisenberg et al., 1999), and lower levels of smoke intake (Fidler et al., 2008). Thus, it could be speculated that among other factors a perceptual “insensitivity” to respiratory changes in male high TAS individuals may partly contribute to the above-mentioned findings.

Study Limitations

We did not assess lung function and physical fitness, which may have confounded differences between high versus low TAS individuals, as TAS has been associated with more frequent physical activity (Roberti, 2004). Thus, differences in interoceptive awareness could reflect differences in physical fitness. Alternatively, level of physical fitness may be a crucial characteristic of TAS, mediating described effects (i.e., being high in TAS leads to frequent engagement in physical activity and better fitness, then better fitness accounts for the effect of TAS). In this case, described findings would not be spurious (i.e., controlling for variance in physical fitness would entail to control for differences in TAS), but our hypothesized model would be incomplete. Therefore, we have to consider the possibility that reduced interoceptive sensitivity to respiratory changes in high TAS individuals may result as a subsequent TAS specific feature due to antecedence influences of TAS for the engagement in physical activities. Perhaps, both of these models (i.e., physical fitness as a confounding factor versus physical fitness as a crucial characteristic of TAS) are correct to some degree, yielding for the investigation of this relationship in future studies (please also refer to the online suppl. material for a more elaborate discussion on this limitation).

We did not collect physiological variables pertinent to respiratory sensation such as respiratory flow, breathing frequency or CO_2 levels. As airway pressure developed during inspiration (a major determinant of dyspnea) is a function of resistance and flow (Bradley et al., 1986), varying inspiratory flow and time could conceivably vary the esophageal pressure associated with each breath and thus, influence perceived choking. Although we instructed participants with emphasis to remain a “constant” ventilatory pattern (inspiratory airflow), future studies should use spirometry or airflow targeting (Zhao et al., 2003) to control for this potential confound in a more objective manner. In this context it should be stated that although using lower loads (1,34 – 3,54 $cmH_2O/L/sec$), Lavietes et al. (2000) suggested that subjective experience during loaded breathing was in part independent of the ventilatory response (measured with spirometry) of the load (i.e., besides differences in experienced dyspnea no differences in breathing patterns between “responders” and “non-responders” were observed). Tiller et al. (1987) also reported a dissociation of respiratory effort and perceived dyspnea using inspiratory loads ranging from 4 – 51 $cmH_2O/L/sec$. In contrast to expiratory breathing restriction, which affects CO_2 (Lopata et al., 1977) inspiratory breathing restriction results in stable, unchanged CO_2 levels (Lofaso et al., 1992) which is consistent with the finding that CO_2 levels have no regulatory effect on inspiratory breathing effort (Clague et al. 1990). Thus, potential changes in experienced choking evoked by varying CO_2 levels across the conditions of the task are unlikely.

This study does not provide direct evidence for the differential action selection as a consequence of altered homeostatic processing in high TAS individuals. Specifically, participants could not choose whether to engage in the increasing respiratory restriction conditions. Future studies should bridge the gap between SS, decision-making and interoception research in using decision-making tasks that specifically involve the interoceptive system. As we did not observe any effects for any of the other variables of the intensity domain (except association of TAS score to baseline chest pain, palpitations, hot/cold flushes and dizziness in the male subsample), it can be suggested that these variables could have been too unspecific or not salient enough in context of a respiratory task. Thus, future studies should use other variables that appear to be context specific when examining SS and the effects of breathing restriction.

Conclusions

Using respiration as a very basic interoceptive probe, this study provides preliminary evidence of an association between different levels of thrill and adventure seeking and differences in interoceptive processing (i.e., altered homeostatic processing in high TAS males). Results suggest that the sensory dimension of respiratory sensation may crucially depend on psychological trait characteristics, specifically TAS. Furthermore, it appears that TAS associated perceptual “insensitivity” seems to be essentially consolidated by type of gender, specifically male. As findings regarding autonomic or behavioral differences in SS have been classically interpreted within the construct of exteroception, a perspective guided by the assumption of differences in interoceptive processing depending on level of SS (i.e., TAS) and gender could add to the traditional view on these personality constructs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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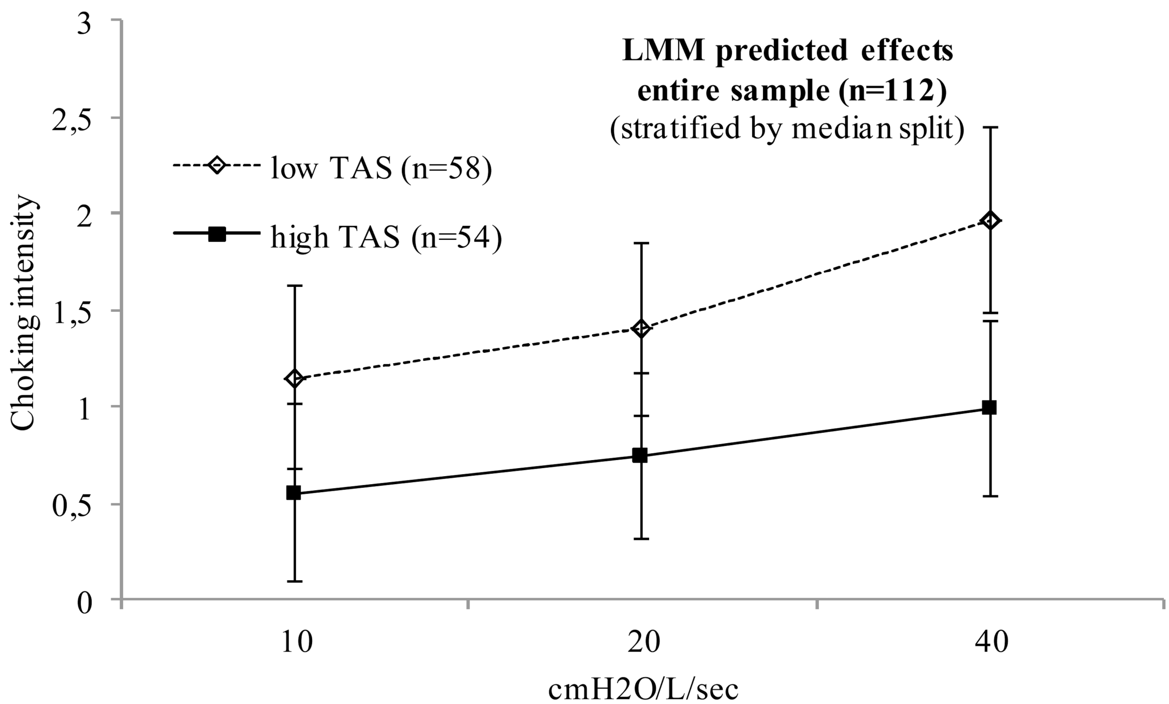
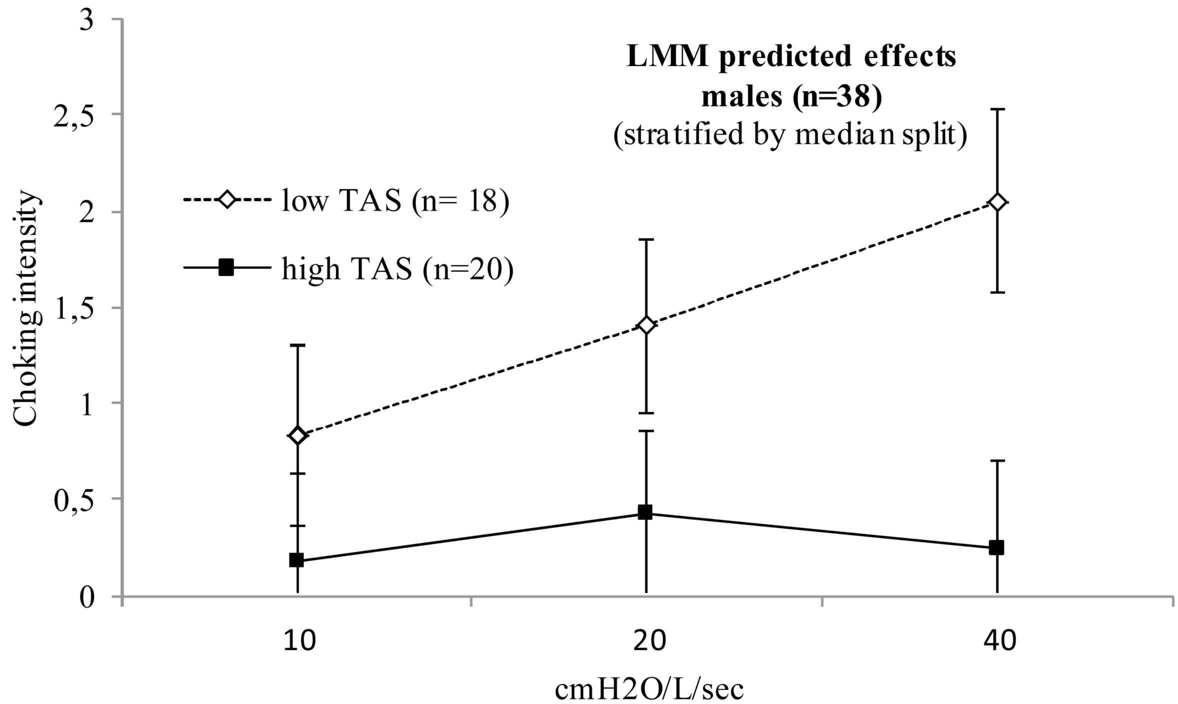
a



LMM predicted effects
entire sample (n=112)
(stratified by median split)
low TAS (n=58)
high TAS (n=54)
Choking intensity
3
2,5
2
1,5
1
0,5
0
10
20
40
cmH2O/L/sec

b


LMM predicted effects
males (n=38)
(stratified by median split)
low TAS (n= 18)
high TAS (n=20)
Choking intensity
3
2,5
2
1,5
1
0,5
0
10
20
40
cmH2O/L/sec

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c

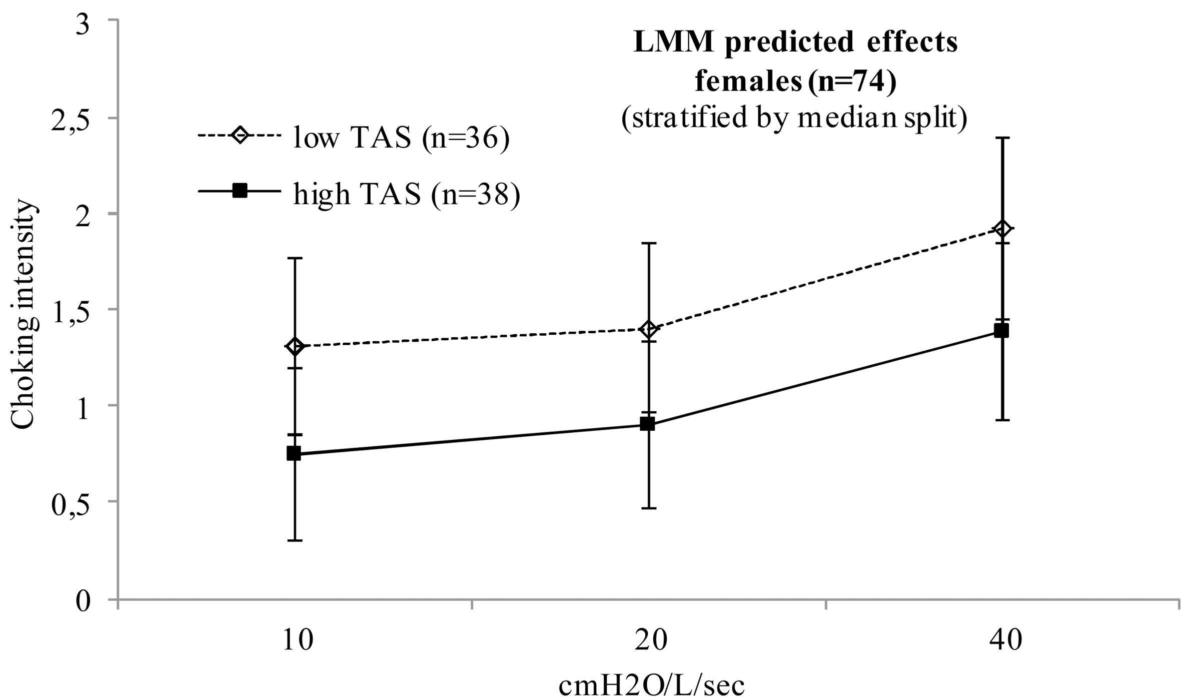
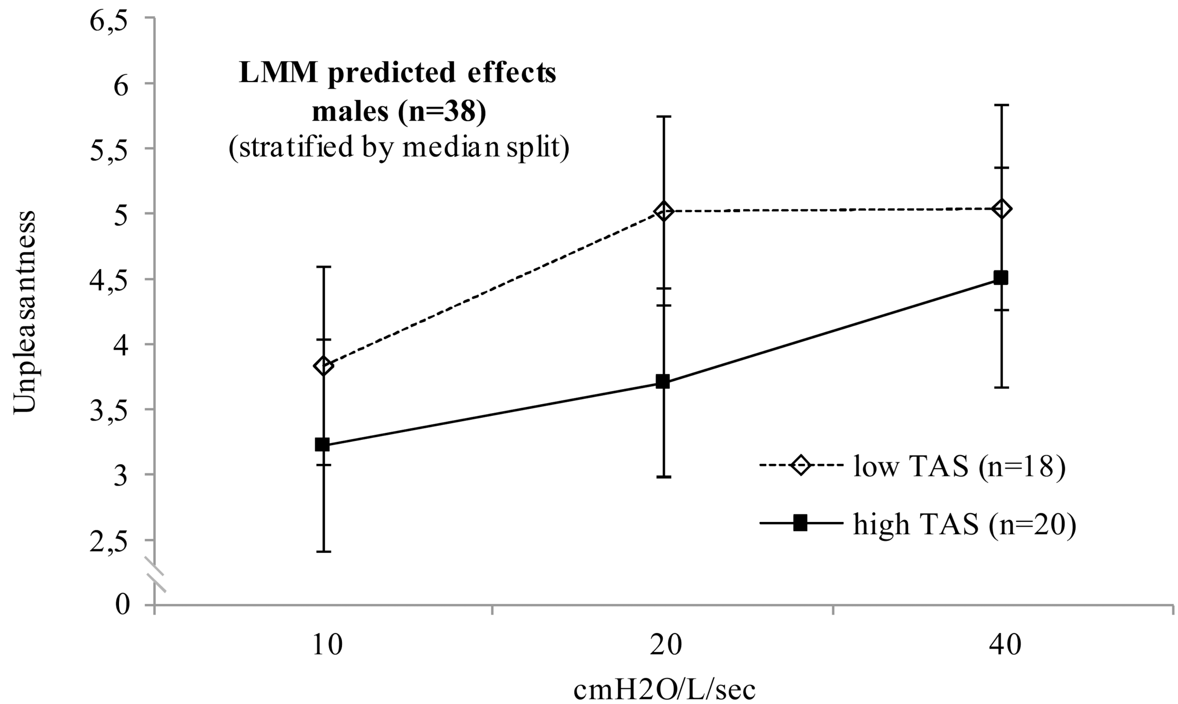


Figure 1.

a–c. *LMM* predicted effects stratified by a simple median split of the entire sample (Figure 2a), males (Figure 2b), and females (Figure 2c) for ease of visual interpretation and to illustrate effects from a traditional categorical "high vs. low TAS" perspective (Suppl. figures 1a–c show the detailed relationship between continuous level of TAS and experienced choking intensity). The *LMM* yielded a significant interaction effect (IE) of TAS*restriction condition (p=0.01) revealing reduced choking sensitivity with increasing TAS score in response to increasing inspiratory resistive loads. Furthermore, we found pronounced gender differences between high and low TAS individuals in perceived choking intensity across the conditions of the task (IE TAS*gender*restriction condition, p=0.039), indicating reduced choking sensitivity with increasing TAS scores for male as compared to female individuals in response to increasing inspiratory resistive loads; in particular at the highest restriction condition. Error-bars represent standard error of the mean.

a


LMM predicted effects
males (n=38)
(stratified by median split)
Unpleasantness
6,5
6
5,5
5
4,5
4
3,5
3
2,5
0
10
20
40
cmH2O/L/sec
low TAS (n=18)
high TAS (n=20)

b

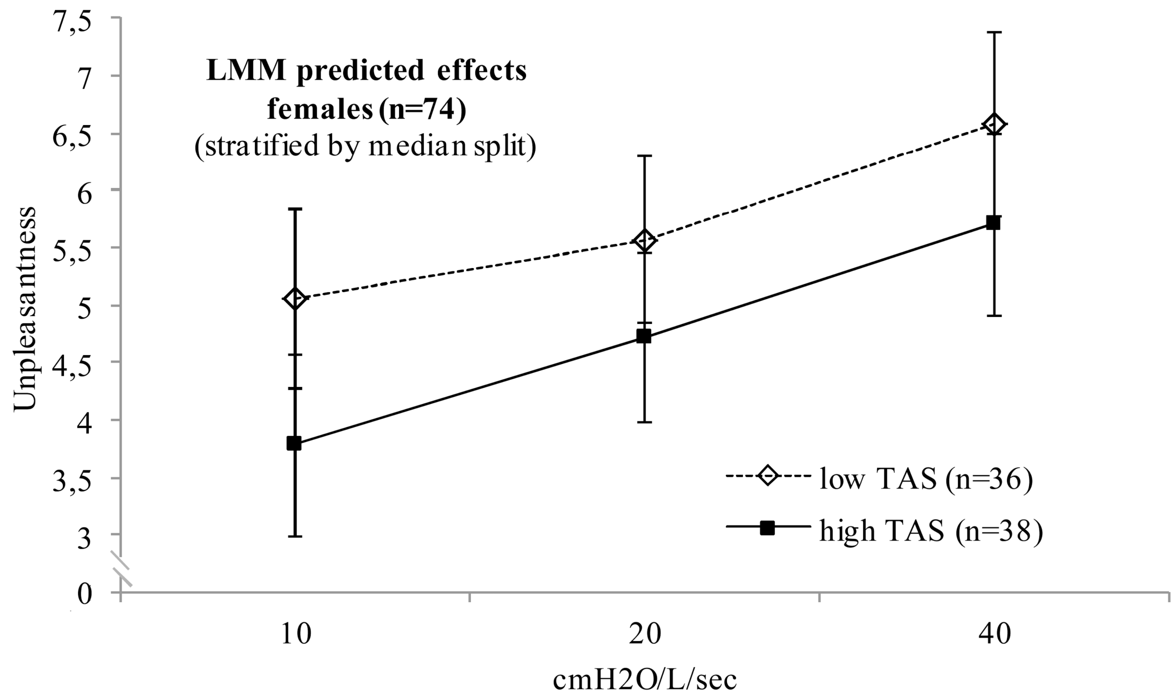


Figure 2.

a–b. *LMM* predicted effects stratified by a simple median split for males (Figure 4a), and females (Figure 4b) for ease of visual interpretation and to illustrate effects from a traditional categorical "high vs. low TAS" perspective (Suppl. figures 2a–c show the detailed relationship between continuous level of TAS and experienced unpleasantness). Post-hoc analyses (separate models for each sex) revealed that male high TAS differed from male low TAS in how they perceived unpleasantness across the three restriction conditions (IE TAS*restriction condition (p = 0.056)). This effect was driven by a trend towards reduced perception of unpleasantness with increasing TAS scores when transitioning from the first mild restriction load to the second modest load. For female subjects no significant effects were observed. Error-bars represent standard error of the mean.

Table 1

Sociodemographics and personality measures of SSS-V, NEO-FFI, ASI, and BIS compared between gender/Baseline measures of breathing restriction.

	Measures	Entire sample (n = 112)			Sex specific subsamples						
					Male (n=38)			*Female (n=74)*			t-test [a] /chi-squared [b]
		Mean	S.D.	TAS *r*	Mean	S.D.	TAS *r*	Mean	S.D.	TAS *r*	p
SS	Total score	17.38	5.01	0.681**	19.44	4.23	0.638**	16.31	5.08	0.704**	<0.001**
	Thrill and adventure seeking	6.45	2.45	1	6.86	2.46	1	6.24	2.43	1	0.041*
	Experience seeking	4.54	1.69	0.327**	5.00	1.65	0.439*	4.29	1.67	0.247*	0.027*
	Disinhibition	3.91	2.27	0.105	4.65	2.03	−0.219	3.53	2.31	0.214	0.009**
	Boredom susceptibility	2.47	1.64	0.107	2.92	1.86	−0.026	2.24	1.47	0.159	0.042*
NEO	Neuroticism	50.68	10.40	−0.275**	51.42	10.33	−0.278	50.32	10.49	−0.286*	0.535
	Extraversion	47.88	9.86	0.169	48.38	8.11	−0.023	47.63	10.71	0.241*	0.690
	Openness	48.29	8.57	0.138	49.44	7.56	0.265	47.71	9.04	0.07	0.326
	Agreeableness	50.82	9.11	0.024	52.07	8.10	0.283	50.17	9.58	−0.105	0.317
	Conscientiousness	51.10	8.15	−0.015	50.14	8.17	0.221	51.59	8.16	−0.120	0.339
ASI	Total score	17.60	10.67	−.0360**	13.09	8.07	−0.105	19.91	11.14	−0.434**	0.001*
BIS	Total score	61.75	10.26	−0.071	63.41	10.72	−0.333*	60.91	10.00	0.045	0.181
BL	Unpleasantness	2.63	2.94	−0.201*	2.32	2.79	−0.409*	2.79	3.02	−0.091	0.411
	Choking	0.51	1.34	−0.054	0.53	1.45	−0.130	0.49	1.29	−0.014	0.878
	Chest pain	0.29	0.52	−0.205*	0.22	0.46	−0.411*	0.33	0.55	−0.102	0.279
	Trembling	0.85	1.66	0.010	0.50	0.91	−0.094	1.03	1.92	0.060	0.105
	Tingling	0.99	1.63	0.029	0.85	1.22	−0.071	1.06	1.81	0.075	0.515
	Hot/cold flushes	0.81	1.81	−0.068	0.61	1.12	−0.387*	0.92	2.08	0.002	0.405
	Abdominal distress	0.38	1.02	0.128	0.21	0.43	−0.083	0.47	1.21	0.207	0.210
	Palpitations	0.49	1.07	−0.177	0.44	1.09	−0.364*	0.52	1.06	−0.074	0.711
	Sweating	0.50	1.19	−0.056	0.20	0.32	−0.088	0.66	1.42	−0.032	0.05*
	Dizziness	0.70	1.43	−0.125	0.62	1.26	−0.540*	0.74	1.52	0.054	0.754

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Measures	Entire sample (n = 112)			Sex specific subsamples						
				Male (n=38)			*Female (n=74)*			t-test [a] /chi-squared [b]
	Mean	S.D.	TAS *r*	Mean	S.D.	TAS *r*	Mean	S.D.	TAS *r*	p
Age (years)	18.64	1.11		18.61	0.94		18.67	1.26		0.277
Race/ Ethnicity (n)										
Caucasian	39			10			29			3.131 [b]
African American	3			2			1			
Asian	15			6			9			
Pacific Islander	12			4			8			
Latin American	37			14			23			
Other	6			2			4			

SS: Sensation Seeking Scale Form-V, NEO: NEO -FFI Five Factor Inventory, ASI: Anxiety Sensitivity Scale, BIS: Barratt Impulsiveness Scale (n = 1 male missing), BL: Baseline measures of breathing restriction, TAS *r*: Correlation with Thrill and Adventure Seeking Scale;

* $p < .05$,

** $p < .01$;

[a] two-sample t-test between males and females in the respective measures;

[b] χ-squared