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Physiological and emotional responses to evaluative stress in socially inhibited young adults

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ABSTRACT

Background: There are large individual differences in dealing with everyday social stress. Therefore, we investigated the association of social inhibition (and its facets) with the emotional and physiological responses to the Trier Social Stress Test (TSST).

Methods: Undergraduate students ($N = 312$) completed the 15-item Social Inhibition Questionnaire (SIQ15) and participated in the TSST, while emotional and cardiovascular stress responses were recorded. We examined the effect of social inhibition across time with repeated-measures ANCOVAs.

Findings: During social stress (and recovery), social inhibition was associated with increased negative mood reactivity (especially the behavioral inhibition facet) and heightened sympathetic activation (especially the social withdrawal and interpersonal sensitivity). Physiological stress reactivity seems to be mostly α-adrenergic in women, and also β-adrenergic in men.

Conclusions: Emotional and physiological stress responses are associated with individual differences in social inhibition. This warrants more research on mechanisms that underlie the relations between social inhibition, stress and health.

1. Introduction

Research to date holds evidence of individual differences in vulnerability to social stress (e.g., Bibbey, Carroll, Ginty, & Phillips, 2015; Kret, Denollet, Grezes, & de Gelder, 2011). A maladaptive response to social threat is characterized by cardiovascular arousal (e.g., increased heart rate and total peripheral resistance (Bosch et al., 2009)) and increased negative emotional arousal (e.g., Childs, White, & de Wit, 2014; Habra, Linden, Anderson, & Weinberg, 2003). Recurrent social stress, but also elevated loneliness and social isolation, have emerged as risk factors for cardiovascular disease and premature mortality (Cundiff & Smith, 2017; Rosengren et al., 2004; Steptoe, Shankar, Demakakos, & Wardle, 2013).

Individual differences in dealing with everyday social stress may be associated with social inhibition, which can be defined as "a broad and stable personality trait characterized by behavioral inhibition during social interaction, increased social-evaluative concerns, and withdrawal from intense social engagement situations" (Denollet & Duijndam, 2019). Socially inhibited adults may be more susceptible to increased levels of social stress because they are more upset at having to interact with people, and are more concerned with others' evaluations of themselves (Denollet & Duijndam, 2019; Denollet, 2013; Marin & Miller, 2013). Previous findings indicate that during social interactions, socially inhibited individuals experience high arousal negative emotions such as anxiety and anger (Lin et al., 2017; Timmermans et al., 2019). However, less is known about low arousal negative emotions, such as sadness or fatigue, and how emotional reactivity is related to social inhibition during social stress.

Previous research showed a greater cardiovascular reactivity in socially inhibited individuals (Bibbey et al., 2015; Habra et al., 2003), but only during tasks with a high social evaluative component. Interestingly, studies without a social evaluation component failed to find social inhibition to be associated with increased stress reactivity (Howard, Hughes, & James, 2011; Williams, O'Carroll, & O'Connor, 2009). Further, an altered breathing pattern has been reported in relation to emotional states, with tense emotions being associated with increased rates and variable or reduced depth (Boiten, Frijda, & Wientjes, 1994). In socially anxious individuals shallow breathing was found during social interaction (Wilhelm, Kochar, Roth, & Gross, 2001). Given the strong association between social inhibition and social

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anxiety (Kupper & Denollet, 2014) and the vigilant nature of social inhibition (Denollet & Duijndam, 2019), social inhibition may be associated with an altered breathing pattern during social stress as well.

Individual differences in social inhibition in relation to emotional and physiological stress reactivity cannot be investigated without taking into account sex differences. Women are more likely than men to report higher levels of negative affect and fear to social stress (Kelly, Tyrka, Anderson, Price, & Carpenter, 2008), indicating a difference between men and women in emotional stress reactivity. There are also substantial sex differences in the autonomic control of the heart (Hinojosa-Laborde, Chapa, Lange, & Haywood, 1999), and hormonal control of blood pressure (Maranon & Reckelhoff, 2013).

Given the difficulties of socially inhibited individuals in dealing with everyday social stress, it is essential to examine how different manifestations of social inhibition play specific roles regarding physiological and emotional stress reactivity. We recently proposed a multifacet model of adult social inhibition (Denollet & Duijndam, 2019; Duijndam & Denollet, 2019), which identified three related lower-order facets, i.e., behavioral inhibition (e.g., difficulty talking to other people), interpersonal sensitivity (e.g., fear of negative evaluation) and social withdrawal (e.g., avoiding social interaction). Sex-related differences in social inhibition showed that women scored higher on the interpersonal sensitivity facet of social inhibition, and men on social withdrawal (Denollet & Duijndam, 2019). It is yet unknown how these facets of social inhibition are related to physiological and emotional stress reactivity.

In this study, we investigated how social inhibition and its different facets (behavioral inhibition, interpersonal sensitivity, and social withdrawal) are related to the emotional and physiological response to social evaluative stress. We hypothesized that social inhibition is associated with negative mood reactivity (Denollet & Duijndam, 2019; Denollet, 2005), increased cardiovascular reactivity (Bibbey et al., 2015; Habra et al., 2003), and an altered breathing pattern (Wilhelm, Gevirtz, & Roth, 2001) during social evaluative stress. Additionally, we explored whether distinct facets of social inhibition are differently associated with stress reactivity. We hypothesized that interpersonal sensitivity would be related to increased emotional arousal in response to stress, due to the negative evaluative character of the stress task. For the relation between the facets and the physiological reactivity, we hypothesized that interpersonal sensitivity was associated with larger physiological arousal. Otherwise, there were no a priori hypotheses and these analyses were exploratory.

2. Methods

2.1. Sample

Data are part of a larger stress study examining individual differences in physiological and emotional stress reactivity (PHEMORE) and data were collected between 2011 and 2016. In total, 766 participants took part in PHEMORE. A subsample who filled out the 15-item Social Inhibition Questionnaire (SIQ15) was used for the current analysis (N = 312). Our participants were first year undergraduate psychology students from Tilburg University in the Netherlands, who participated in the study in exchange for course credits.

2.2. Procedure

Participants were instructed to refrain from smoking and coffee consumption for 2 h before testing as well as not to ingest more than three alcoholic beverages during the 24 h before testing. Upon arrival, all participants were welcomed, placed in a quiet, dimly lit waiting room, and asked to sign for informed consent. Then, after asking about adherence on refraining from smoking, coffee and alcohol consumption, a psychological survey was administered, including dedicated questions on demographics (age, sex, partner status (single/long term relationship)), habitual health behaviors (regular (weekly) exercise (yes/no), smoking (yes/no, detailed in cigarettes per day), weekly alcohol consumption (yes/no, detailed in how many glasses per week), daily coffee consumption (yes/no), detailed in how many cups per day), body composition (length, weight), medication use (free text), and mood disorders (anxiety, depression: Has a medical doctor or registered psychologist told you that you have depression/anxiety, or are you being treated for anxiety/depression?), and a series of standardized psychological questionnaires. Then, participants were fitted with the cardiovascular measurement equipment. Participants were examined in a sitting position. After a 10-min resting period, during which a physiological baseline was recorded, participants took part in a stress test battery. An adapted version of the Trier Social Stress task was performed, after which a 5 min recovery period commenced.

The study protocol and its amendments were approved by the Institutional Ethics Review Board (protocol number: EC-2011.01a). All participants gave informed consent before participating and were debriefed afterwards.

2.3. Adapted Trier Social Stress test

Briefly, the Trier Social Stress test (TSST) is a social stressor during which a participant is asked to perform a math task and to give a prepared speech (Kirschbaum, Pirke, & Hellhammer, 1993). We adapted the original protocol of the TSST in two ways. First, we asked participants to remain seated throughout the entire procedure, because a standing position or changes in posture may cause fluctuations in blood pressure (Olufsen et al., 2005). Second, instead of a job interview, we asked participants to prepare (three-minute preparation period) and give a speech on their own positive and negative social skills (five minutes), in front of a two-person audience. Previous research has shown that the current procedure induces a significant cardiovascular stress response (Kupper, Pelle, & Denollet, 2013). During the arithmetic task, participants were asked to serially subtract one or two digit numbers from four digit numbers verbally in the presence of a socially evaluative audience. Finally, we randomized task order, so that about half of the participants first did the speech task, while the other half started with the five-minute math task. The stress tasks were performed consecutively without a resting period in between (as is usual in the TSST), and task order was included as a covariate in the analyses.

2.4. Measures

2.4.1. Social inhibition

To assess social inhibition, the SIQ15 (Denollet & Duijndam, 2019; Duijndam & Denollet, 2019) was used. This questionnaire was based on the multi-facet model of adult social inhibition, which distinguishes among three different facets of social inhibition: *behavioral inhibition* (difficulties to initiate conversation topics and to get the conversation going), *interpersonal sensitivity* (pervasive social-evaluative concerns), and *social withdrawal* (avoiding engagement in intense social or emotional situations). Subjects rated their personality on a four-point Likert scale ranging from 0 (false) to 3 (true). The scale yields three facet scores, for behavioral inhibition, interpersonal sensitivity, social withdrawal, and a total score. Each facet was represented by five items. Cronbach's alpha in the current study for young adults yielded 0.91 for the total score, 0.86 for Inhibition, 0.89 for Sensitivity, and 0.80 for Withdrawal.

2.4.2. Hemodynamic variables

Systolic (SBP) and diastolic (DBP) blood pressure was assessed using an ambulatory blood pressure monitor (ABP monitor type 90207; Spacelabs Healthcare Ltd., Issaquah, WA). To minimize the burden level of the participants during the resting phase, we assessed blood pressure at 0, 5 and 10 min during the ten-minute rest period. We discarded the blood pressure measurement at the start of the resting period, because

of posture and novelty related arousal. During the adapted TSST and recovery period, blood pressure was assessed at the start, middle and end of the task (essentially every 2.5 min; see also Supplemental Fig. 1).

2.4.3. Myocardial variables

The Vrije Universiteit Ambulatory Monitoring System (VUAMS 4.6; Vrije Universiteit Amsterdam, the Netherlands) was used to record a continuous electrocardiogram (ECG) and impedance cardiogram (ICG; Willemsen, DeGeus, Klaver, VanDoornen, & Carroll, 1996), using non-woven liquid gel AgCl electrodes (Kendall, Medcat, the Netherlands). The event button on the device was used to indicate start and end times of the phases of the experimental protocol.

VU-AMS software automatically detected all markers in the ECG, and all R-peak markers were visually checked and adjusted when necessary. The signal was visually checked for artifacts (e.g., premature atrial or ventricular contractions), which were removed prior to scoring the ECG and ICG data. The software automatically marked the starting points of inspiration and expiration derived from the ICG, which were automatically scored for each breath and checked manually for the presence of signal artifacts before analyses (Kupper et al., 2005).

2.4.3.1. ECG measures. From the corrected ECG signal, period averages were calculated for heart period (IBI). In addition, the root mean square of successive differences (RMSSD) was calculated from the IBI signal as a time domain measure of heart rate variability.

2.4.3.2. ICG measures. From the ICG, we derived respiration rate (RR), and tidal volume (TV; mOhm) which again were averaged per period (i.e. Rest, Math task, Speech task, and Recovery). Breathing patterns (in particular tidal volume), exert a major influence on efferent, post-ganglionic sympathetic nerve activity to skeletal muscle cells, independent of breathing-induced fluctuations in arterial blood pressure, intrathoracic pressure, or inspiratory motor output (Seals et al., 1993), and may be responsive to acute stress. Systolic time intervals (pre-ejection period, PEP; left ventricular ejection time, LVET) were manually scored from ensemble averages of the ICG of each protocol period by an experienced scorer of ICG signals (NK) using the VU-AMS interactive scoring software. Scoring procedures for impedance cardiography have been published previously (Kupper et al., 2005; Kupper, Willemsen, Boomsma, & De Geus, 2006). Systolic time intervals, and especially PEP are a useful non-invasive indicator of cardiac sympathetic activity. The PEP was defined as the interval between the Q-onset in the ECG, indicating onset of left ventricular electrical activity, and the upstroke (B-point) of the ICG signal, indicating the beginning of left ventricular ejection. PEP is an index of cardiac contractility, LVET is defined as the time between the opening and closing of the aortic valves (X-point) (Sherwood et al., 1990). Importantly, in interpreting results, caveats/limitations relating to potential cardiac loading effects (i.e., preload and afterload) need to be appreciated. Nonetheless, the measurement of PEP likely provides valuable non-invasive insights into cardiac autonomic regulation, as PEP is strongly (inversely) associated with cardiac sympathetic activity (Michael, Graham, & Davis, 2017).

2.4.4. Acute emotional responses

Participants rated items reflecting their level of affective arousal, task engagement (engaged/stimulated, interested), and task difficulty (effort, burden, difficulty) on a Likert-type scale of 1 (not at all) to 7 (very much). Change scores (task value minus immediately preceding baseline value) were computed to index task-induced (i.e. math, speech) mood responses and mood recoveries for high (average response to tension, anxiety, irritation, anger, annoyance, and stress) vs. low cortical arousal negative emotions (average response to fatigue and sadness).

2.5. Statistical analysis

Baseline characteristics are presented as descriptive statistics (means (SD) and frequencies), and were compared between men and women with Student's t-tests in case of continuous variables, and chi-square tests in case of categorized variables. Correlations of social inhibition and its facets with resting physiology and baseline emotions were calculated by means of Pearson correlations.

2.5.1. Transformations

The emotion summary scores (high arousal negative, low arousal negative) for each period of the stress experiment were log transformed to account for the right skewness in baseline and recovery scores (math and speech responses were normally distributed, but log transformed anyway so that there were no scale differences in the repeated measures ANOVA). With respect to the physiological parameters, RMSSD was not normally distributed and a log transformation was used to improve the data distribution.

2.5.2. Main analyses

Repeated measures ANCOVA was used to examine the within-subjects effects of time (i.e., change from rest to stress (=reactivity) to recovery (=recovery)), and the between-subjects effect of social inhibition on both emotional and physiological stress profiles. When Mauchly's test of sphericity of variances was violated ($p < .05$), ε was evaluated to choose the proper correction for the F ratio. When $\varepsilon < .75$, the Greenhouse-Geisser correction was used, and when $\varepsilon > .75$, the Huynh-Feldt correction was used. We entered the continuous total score of social inhibition as a covariate. Prior to the main analysis, we tested the habitual health behaviors' associations with stress reactivity (to preserve power in the main analysis where possible). First, a univariate, unadjusted model was tested using the total score of social inhibition. In the second model, the analysis was adjusted for the effects of task order and sex, and tested the significance of social inhibition by sex interaction. We corrected for multiple testing of the various autonomic activity measures by applying the Benjamini-Hochberg procedure, which corrects for false discovery rate (.25) (McDonald, 2014). Then, as a preplanned specification analysis, the facets of social inhibition replaced the total score of social inhibition and were tested together while adjusting the model for the effects of task order and sex.

As previous research showed substantial sex differences in the autonomic control of the heart (Hinojosa-Laborde et al., 1999), and it is known that sex hormones differentially affect blood pressure regulation (Maranon & Reckelhoff, 2013), we tested interaction effects with sex. If a significant interaction was found, sex-stratified contrast analyses took place. For presentation purposes, we divided the social inhibition scores into tertiles to demonstrate differences in emotional and physiological profiles across time. We used IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp. for all analyses.

3. Results

3.1. Sample characteristics

In Table 1, all sample characteristics are presented for the total group. The participants were on average 20.4 years of age ($SD = 2.4$). Of them, the majority was female (68 %), single (57 %), and originating from a two-parent household (66 %), with above modal income (66 %). Importantly, non-adherence to required pretest health behaviors was very limited (< 2.5 %). In total, 4 % of participants was prescribed psychotropic medication, about half of which for depression and the other half for ADHD. Study participants (n = 7) on medication for ADHD voluntarily postponed taking the medication until after the experiment. There were significant sex differences in the sample characteristics, with men being older, more often from a two-parent

Table 1
Sample characteristics.

	Total (N = 312)	Women (N = 212)	Men (N = 100)	Test statistic
Demographics				
Age *Mean (SD)*	20.4 (2.4)	**19.9 (2.3)**	**21.4 (2.4)**	**-5.3*****
Partner status (single)	57% (176)	55% (116)	61% (60)	.95
Family composition (2-parent home)	66% (202)	**58% (121)**	**83% (81)**	**19.1*****
Family income (modal or lower)	34% (106)	*36% (76)*	*30% (30)*	*8.9*
Health behaviors				
Smoking	14% (44)	*12% (25)*	*19% (19)*	*2.9*
If yes, mean cigarettes per week	7.4 (5.7)	7.4 (5.7)	7.4 (5.8)	.000
Alcohol use	76% (237)	**70% (148)**	**89% (89)**	**13.3*****
If yes, mean alcohol consumptions/week	6.3 (6.5)	**4.8 (4.3)**	**9.3 (9.0)**	**65.22*****
Coffee use	44% (335)	**40% (85)**	**56% (56)**	**6.8****
Regular exercise	65% (202)	63% (132)	70% (70)	1.7
BMI *Mean (SD)*	22.0 (3.05)	*21.8 (3.2)*	*22.4 (2.6)*	*-1.7*
Health				
Hormonal contraceptive use (women only)		65% (138)	–	–
Psychological/psychiatric treatment	7% (21)	8% (17)	4% (4)	1.8
Psychotropic medication[a]	4% (12)	3% (7)	5% (5)	.5
Beta-blocking agents	0% (0)	0% (0)	0% (0)	–
Corticosteroids (when needed)	2% (6)	2% (4)	2% (2)	0
Experiment related				
Task order (Speech first)	47% (146)	45% (95)	51% (51)	1.0
Non-adherence to pre-test health behavior rules				
Smoking 2 h preceding test	2% (7)	2% (4)	3% (3)	.4
Limit (≤3) alcohol consumption night before test	0.6% (2)	0.5% (1)	0.6% (2)	.3
Coffee in 2 h preceding test	3% (8)	3% (6)	2% (2)	.2

[a] Antidepressants (n = 5), ADHD medication (n = 7).
*** p < .001.
** p < .01; italic = trend level significance; boldfaced = significant.

household, and more likely to drink alcohol or coffee in daily life (Table 1).

3.1.1. Social inhibition

The average score on the 15 item SIQ15 was 15.5 (SD = 8.6; range 0–42). The average facet scores were 4.6 (SD = 3.4) for behavioral inhibition, 6.1 (SD = 3.6) for interpersonal sensitivity and 4.7 (SD = 3.2) for social withdrawal. The facet inter-correlations ranged between .48 and .65. There were significant sex differences in the social inhibition total score (t = 2.05, p = .04), with women scoring higher than men ($M_{difference}$ = 2.1 (SE = 1.0)). This sex difference could be completely attributed to the sex difference found in the interpersonal sensitivity facet (Fig. 1), showing a significantly higher score for women (t = 4.84, p < .001, $M_{difference}$ = 2.0 (SE = .42)). There were no sex differences in the other two facets. The three facets correlated significantly in both men (r range = .59–.66) and women (r range = .47–.67).

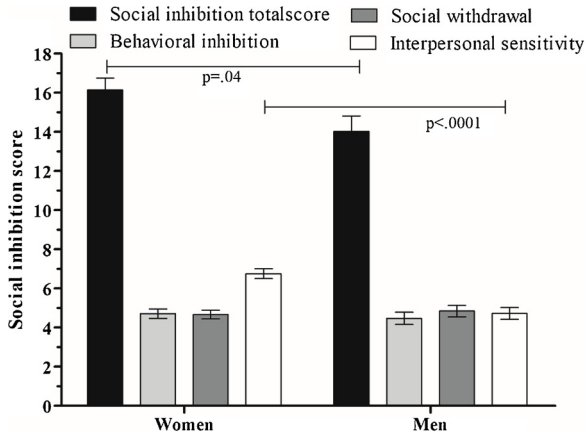

Fig. 1. Mean and Standard Error of Mean (SEM) of social inhibition (facets) for men and women.

3.2. Manipulation check

The TSST induced a significant negative emotional response, both of high (Wilks' lambda = .54, F (3, 292) = 83.86, p < .001, partial η^2 = .463) and low (Wilks' lambda = .93, F (3, 289) = 7.12, p < .001, partial η^2 = .069) cortical arousal negative emotions. The stress tasks also induced a significant physiological response (IBI: Δ = -141.4 (SD = 89.0), F (2.07, 500.67) = 544.91, p < .001; RMSSD: Δ = -20.3 (SD = 24.7), F (1.85, 435.76) = 137.94, p < .001; PEP: Δ = -5.8 (SD = 5.2), F (2.26, 537.33) = 184.72, p < .001: LVET: Δ = -17.1 (SD = 20.7), F (2.26, 529.53) = 183.76, p < .001 SBP: Δ = 17.8 (SD = 9.5), F (2.60, 712.70) = 468.63, p < .001; DBP: Δ = 13.9 (SD = 7.3), F (2.80, 767.29) = 426.60, p < .001; TV: Δ = 43.9 (SD = 43.6), F (2.39, 562.26) = 100.07, p < .001); RR: Δ = -1.34 (SD = 2.0), F (2.27, 542.59) = 68.46, p < .001). Not following health behavior guidelines was associated with a blunted reactivity of SBP (Δ $Mean$ = -5.3, t = -1.99, p = .046) and a blunted high arousal negative emotional response (Δ $Mean$ = -0.7, t = -2.76, p = .006). Because the number of non-adherent participants was so low (max n = 15), non-adherence was not included in further analyses. Importantly, removal of these participants did not affect our results. We also checked the associations of habitual smoking and coffee consumption, and weekly exercise with stress reactivity. These variables were all unrelated to high arousal negative emotional reactivity (p > .13), and were also unrelated to low arousal negative emotional reactivity (p > .07). Habitual smoking, coffee use, and weekly exercise also did not affect physiological (SBP, DBP, HP, RMSSD, RR, TV, LVET) stress reactivity (p > .27), except for smoking, which was significantly associated with smaller PEP stress reactivity (p = .042). To preserve power, and to reduce potential bias from small-group covariates, we only included smoking in the PEP analyses.

3.3. Emotional responses

3.3.1. High cortical arousal negative emotions

Social inhibition was significantly related to the resting levels of

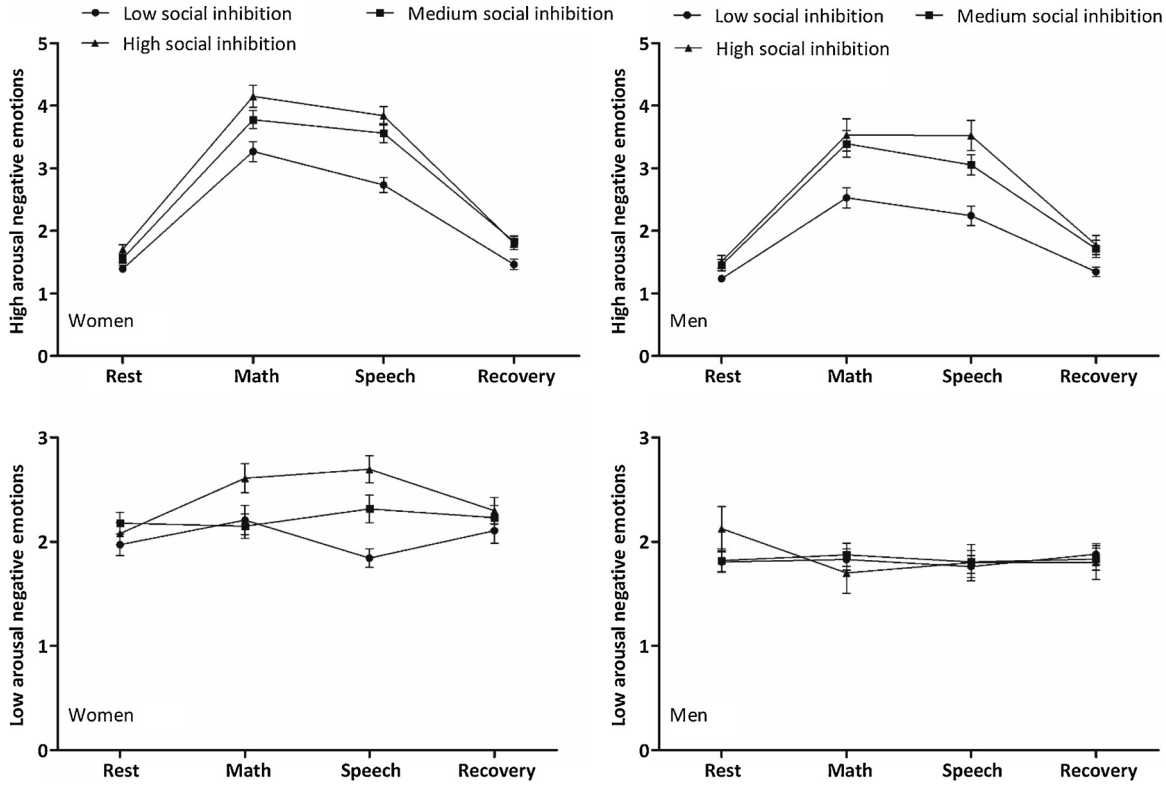

Fig. 2. Mean and Standard Error of Mean (SEM) of high (upper) and low (bottom) cortical arousal negative emotional responses to acute stress.

high arousal negative emotions (r_{total} = .25, p < .001), with the three facets showing low to moderate correlations ($r_{inhibition}$ = .20, p < .001, $r_{sensitivity}$ = .28, p < .001, $r_{withdrawal}$ = .13, p = .018).

With respect to the reactivity/recovery profile, results showed a significant within-subjects effect of social inhibition on the course of the experience of *high arousal* negative emotions across the experiment in both men and women (Fig. 2 , Table 2, upper panel). Task order did not have a significant within-subject effect, nor did sex. Contrast analysis showed that social inhibition was related to increased levels of high arousal negative emotions from rest to stress ($F_{reactivity}$ (1, 292) = 4.99, p = .026, partial η^2 = .017), and from stress to recovery ($F_{recovery}$ (1, 292) = 11.06, p = .001, partial η^2 = .036). This suggests that the higher arousal negative emotional response to stress is higher with elevated social inhibition, and that high arousal negative emotions tend to linger on after stress in people with high social inhibition. The pre-planned facets analysis showed that behavioral inhibition was responsible for the effect of social inhibition on the recovery of high arousal negative emotions after stress (Figure 2, Table 2).

Between-subjects effects were present for social inhibition (F (1, 291) = 41.85, p < .001, partial η^2 = .125) indicating that, overall, the level of high cortical arousal negative emotions was higher with elevated levels of social inhibition.

Table 2
Within-subjects results from the adjusted RM-ANCOVAs of emotional stress reactivity and recovery.

		F (df)	p	η^2
	High cortical arousal negative emotions			
A	Social inhibition total	6.49 (2.89, 843.80)	**< .001**	**.022**
B	Behavioral Inhibition	4.21 (2.91, 842.71)	**.006**	**.014**
	Interpersonal Sensitivity	1.46 (2.91, 842.71)	.229	.005
	Social Withdrawal	0.05 (2.91, 842.71)	.985	.000
	Low cortical arousal negative emotions			
A	Social inhibition total	4.45 (2.83, 824.36)	**.004**	**.015**
	Sex	2.34 (2.83, 824.36)	*.076*	*.008*
	Social Inhibition * Sex	6.35 (2.83, 824.36)	**< .001**	**.021**
	Interpersonal Sensitivity	9.90 (2.91, 250.63)	**< .001**	**.048**
	Social Withdrawal	4.83 (2.86, 557.23)	**.003**	**.024**

Note. Df were corrected for violation of sphericity assumption (High negative: Huyhn-Feldt, Low negative: Greenhouse-Geisser). All analyses were corrected for task order and sex. The size of partial η^2 can be interpreted as small (.01), medium (.06), and large (.14) (Miles & Shevlin, 2001). [1] posthoc test for female subsample only (N = 194).

3.3.2. Low cortical arousal negative emotions

Social inhibition was not related to the resting levels of low arousal negative emotions (r = .08, p = .188). Social inhibition was related to the response profile of low cortical arousal negative emotions, and significantly interacted with sex (Table 2, second panel). When splitting the sample based on sex, results showed that a significant stress response of low arousal negative emotions was only present in women (F (2.82, 555.68) = 3.60, p = .015), and social inhibition was only related to low cortical arousal negative emotions in women. The contrast analysis in the female subsample revealed that social inhibition affected change between all time periods significantly (from rest to stress ($F_{reactivity}$ (1, 195) = 9.30, p = .003, partial η^2 = .046), between the two stress tasks (F = 6.81, p = .010, partial η^2 = .034), and from stress to recovery ($F_{recovery}$ = 24.35, p < .001, partial η^2 = .111). Examination of the three facet scores revealed that in women, all three facets contributed to the main effect of the full scale.

There were significant between-subject effects associated with social inhibition as well. Higher levels of social inhibition were associated with an overall higher level of low arousal negative emotions across time (F (1, 292) = 6.66, p = .010, partial η^2 = .022). Sex was also a significant between-subjects factor, with women having higher overall levels of low arousal negative emotions than men (F (1, 292) = 8.86, p = .003, partial η^2 = .029).

Table 3
Pearson correlations of social inhibition and facets with resting baseline physiology.

	SI total score	Behavioral inhibition	Interpersonal sensitivity	Social withdrawal
SBP	.06	.04	.04	.06
DBP	.07	.05	.08	.06
IBI	-.09	-.03	-.16*	-.04
RMSSD	-.02	.02	-.02	-.01
PEP	-.05	.01	-.13*	.02
LVET	.01	.02	.01	.00
RR	.05	.02	.09	.02
TV	-.06	-.07	-.06	.01

Note: * denotes p < .05.

3.4. Social inhibition and resting physiology

While correlation analysis showed that social inhibition in general was not related to resting physiology, interpersonal sensitivity showed a smaller PEP and IBI at baseline, suggesting an increased sympathetic cardiac drive during rest in individuals with increased interpersonal sensitivity (Table 3).

3.5. Social inhibition & hemodynamic stress reactivity and recovery

3.5.1. Systolic blood pressure

Repeated measures ANCOVA showed that there was a significant within-subject effect of the social inhibition total score on the course of SBP during the stress experiment (Table 4, Fig. 3). In particular, contrast analysis showed significant differences in stress recovery (F (1, 272) = 5.89, p = .016, partial η^2 = .021), i.e. a small to moderate effect. Task order was a significant covariate (results not shown), indicating differences in the size and shape of the stress response, depending on which task was presented first. There were also between-subjects effects for the social inhibition total score, with higher social inhibition scores being associated with a higher overall level of SBP (F (1, 272) = 6.35, p = .012, partial η^2 = .023).

When examining the three facets, results showed that especially withdrawal scores were important in determining the total score effect (Fig. 3, Table 4, B analyses). There were no significant interactions with sex for each of the contrasts. Contrast analysis showed, higher withdrawal scores were particularly associated with an increase in SBP reactivity (F (1, 270) = 6.85, p = .009, partial η^2 = .025).

There were also between subjects effects, such that higher levels of interpersonal sensitivity were associated with higher levels of SBP throughout the course of the experiment (F (1, 270) = 4.21, p = .041, partial η^2 = .015). Sex also was a significant contributor to between-subjects differences in systolic blood pressure such that throughout the experiment, women had a lower SBP than men (F (1, 270) = 22.74, p < .001, partial η^2 = .078).

3.5.2. Diastolic blood pressure

While there were no main within-subjects effects for social inhibition (F (2.84, 768.75) = 1.80, p = .150) and sex (F (2.84, 768.75) = 1.97, p = .121), there was a significant cross-over interaction in the within-subjects effects between social inhibition and sex (see Fig. 3, Table 4), suggesting complete opposite associations between social inhibition and DBP reactivity in men and women (correlations with DBP reactivity split for sex: r_{women} = .09. r_{men} = -.11). Separate RM-ANOVAs for men and women showed trend effects in both groups (Women: F (2.87, 519.04) = 2.52, p = .060, partial η^2 = .014; Men: F (2.84, 252.59) = 2.30, p = .081, partial η^2 = .025). Examining the facets, results showed that while there were no significant main within-subjects effects (results not shown), again a significant interaction was present for social withdrawal by sex (Table 4), suggesting that the differential association of social inhibition with DBP reactivity in men and women is due to individual differences in social withdrawal. Separate RM-ANOVAS for men and women showed the association with DBP was significant in women only, even though effect sizes were equal (Women: F (2.90, 519.57) = 3.25, p = .023, partial η^2 = .018; Men: F (2.91, 253,27) = 1.462, p = .226, partial η^2 = .017).

Table 4
Within-subjects results from the RM-ANCOVAs of physiological stress reactivity and recovery.

		F (df)	p	η^2
	Systolic Blood Pressure (SBP)			
A	Social inhibition total	3.18 (2.62,712.04)	**.023**	**.012**
B	Behavioral Inhibition	1.00 (2.63,710.12)	.484	.004
	Interpersonal Sensitivity	1.85 (2.63,710.12)	.157	.012
	Social Withdrawal	2.48 (2.63,710.12)	*.068*	*.009*
	Diastolic Blood Pressure (DBP)			
A	Social inhibition * Sex	3.17 (2.87, 770.99)	**.026**	**.012**
B	Behavioral Inhibition * Sex	.75 (2.90, 772.49)	.747	.003
	Interpersonal Sensitivity * Sex	.45 (2.90, 772.49)	.714	.002
	Social Withdrawal * Sex	3.76 (2.90, 772.49)	**.012**	**.014**
Inter-beat interval				
A	Social inhibition total	.83 (2.12, 506.54)	.444	.003
	RMSSD			
A	Social inhibition total	.31 (1.87, 436.05)	.721	.001
	Pre-ejection period (PEP)			
A	Social inhibition total	.18 (2.32, 537.12)	.863	.001
B	Behavioral Inhibition * Sex	.41 (2.26, 514.69)	.689	.002
	Interpersonal Sensitivity * Sex	2.15 (2. 26, 514.69)	.111	.009
	Social Withdrawal * Sex	2.99 (2. 26, 514.69)	**.044**	**.013**
	Left Ventricular Ejection Time (LVET)			
A	Social inhibition total	1.35 (2.29, 528.80)	.259	.006
B	Behavioral Inhibition* Sex	.62 (2.34, 528.42)	.840	.001
	Interpersonal Sensitivity * Sex	3.82 (2.34, 528.42)	**.017**	**.017**
	Social Withdrawal * Sex	.44 (2.34, 528.42)	.352	.007
	Respiration rate			
A	Social inhibition total	.05 (2.31, 546.76)	.966	.000
	Tidal Volume (TV)			
A	Social inhibition total	3.12 (2.45, 568.18)	**.035**	**.013**
B	Behavioral Inhibition	4.17 (2.46, 566.04)	**.010**	**.018**
	Interpersonal Sensitivity	1.14 (2.46, 566.04)	.328	.005
	Social Withdrawal	.71 (2.46, 566.04)	.523	.003

Note. Df were corrected for violation of sphericity assumption (SBP & DBP, TV: Huyhn-Feldt, IBI, RMSSD, PEP, LVET, RR: Greenhouse-Geisser). All analyses were corrected for task order, and PEP analysis was controlled for habitual smoking as well. The size of partial η^2 can be interpreted as small (.01), medium (.06), and large (.14) (Miles & Shevlin, 2001). Results were controlled for the false discovery rate by applying the Benjamini-Hochberg procedure. Bosld-faced = significant at p < .05; Italic: trend level association (p < .10).

3.6. Social inhibition & sympathetic cardiac activation

There was no relationship between the social inhibition total score and PEP. Facet analysis showed that while there were no main within-subjects effects, there was a significant facet*sex cross-over interaction for withdrawal on the course of PEP during the experiment (Fig. 3, Table 4, analysis B). Contrast analysis showed that this was particularly so for reactivity ($F_{withdrawal}$ (1, 230) = 4.85, p = .029, partial η^2 = .021), and not so much for recovery (correlations with PEP reactivity split for sex: r_{women} = -.02. r_{men} = -.18). RM-ANOVAs split for sex confirmed that only in men, social withdrawal was significantly associated with the PEP response profile (Women: F (2.33, 358.10) = .47, p = .654, partial η^2 = .003); Men: F (2.05, 152.23) = 3.80, p = .029, partial η^2 = .05). So, social withdrawal was

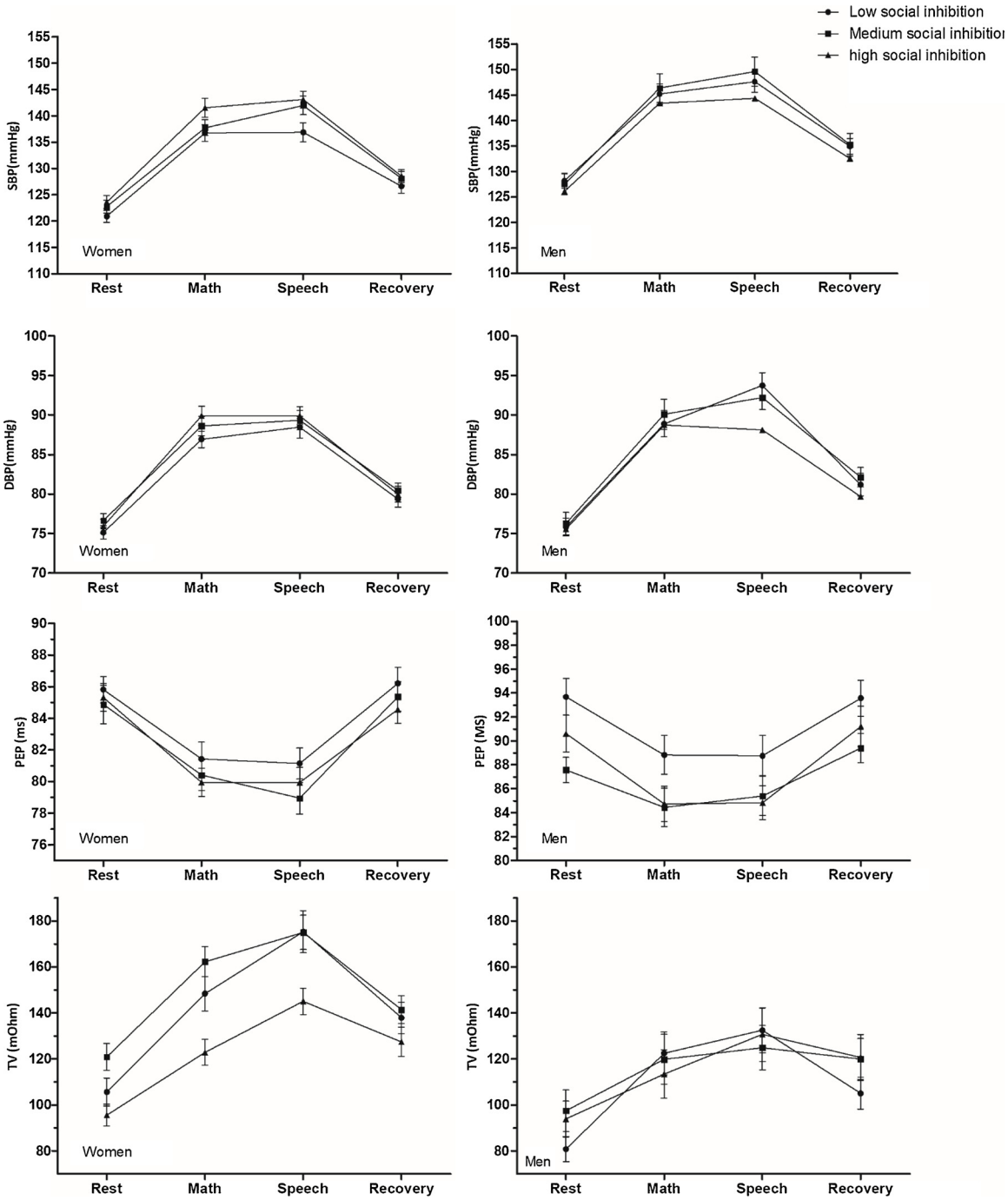

Fig. 3. Mean and Standard Error of Mean (SEM) of physiological reactivity to and recovery from acute social evaluative stress, stratified by social inhibition tertiles.

associated with PEP reactivity in men only.

Examining the heart's contractility function in response to stress, we looked at LVET. While the total score of social inhibition and the facets were unrelated to LVET reactivity and recovery patterns, there was a significant cross-over interaction for interpersonal sensitivity with sex in the within-subjects effect (Fig. 3, Table 4), that was less visible in the sex-split RM-ANOVAs (Women: F (2.31, 362.72) = 1.07, p = .352, partial η^2 = .007); Men: F (2.07, 156.21) = 2.75, p = .065, partial η^2 = .04). Contrast analysis showed that in men, the level of interpersonal sensitivity was related to reduced LVET in response to stress (i.e., stronger contractility), while in women, LVET was positively related in response to stress (F (1, 226) = 4.52, p = .035, partial η^2 = .020; reactivity correlations: r_{women} = .08, r_{men} = -.15). No differences in recovery were found.

3.7. Social inhibition & parasympathetic cardiac control and heart period

There was no relationship between changes in IBI across the experiment measurement occasions and social inhibition (Fig. 3, Table 4, analysis A), nor were there any between subjects effects. Sex and task order were significant within-subjects covariates. When examining the three facets, none of the facets related significantly to IBI (Table 4, analysis B).

There was no main within-subject effect of social inhibition on the course of RMSSD across the experiment (Fig. 3, Table 4, analysis A). There were no between subjects effect for RMSSD. No significant findings were found when analyzing the facets.

3.8. Social inhibition & breathing pattern responses

Across the experiment, within-subjects effects showed tidal volume to be significantly affected by social inhibition (Fig. 3, Table 4, Analysis A). Contrast analysis revealed that particularly TV reactivity (F (1, 232) = 3.09, p = .080, partial η^2 = .013; $r_{\text{social inhibition with TV reactivity}}$ = -.14, p = .027) and recovery (F (1, 232) = 4.62, p = .030, partial η^2 = .020) were smaller (i.e. shallower breathing) with higher levels of social inhibition. There was no significant interaction with sex. There was a significant between-subjects effect of sex, with men having overall higher tidal volumes than women (F (1, 232) = 19.04, p < .001, partial η^2 = .076).

Looking at the facet analysis, results showed that the behavioral inhibition facet was responsible for the above observation (Fig. 3, Table 4, Analysis B). Contrasts showed that behavioral inhibition was associated with TV reactivity (F (1, 230) = 10.38, p = .001, partial η^2 = .043). While interpersonal sensitivity failed to show main within-subjects effects, it was associated with large differences in TV from math to speech task (F (1, 230) = 5.16, p = .024, partial η^2 = .022), with larger reductions in TV during speech with higher levels of interpersonal sensitivity. Moreover, there were significant between-subjects effects for behavioral inhibition (F (1, 230) = 5.43, p = .021, partial η^2 = .023), and social withdrawal (F (1, 230) = 5.53, p = .020, partial η^2 = .023). Respiration rate was unrelated to social inhibition and its facets.

4. Discussion

Social inhibition was associated with increased cardiovascular reactivity, an altered breathing pattern during (and in recovery of) social evaluative stress, and increased negative mood reactivity. We also found differences in physiological and emotional stress reactivity and recovery related to sex, and to different facets of social inhibition.

Regarding the physiological stress response, there was a heightened sympathetic cardiovascular activation (SBP, PEP) in socially inhibited individuals during social evaluative stress. Socially inhibited individuals tend to suppress their emotions during social interaction (Denollet, 2005), and suppression of negative emotions increases sympathetic activation (Gross & Levenson, 1993, 1997). Other, anxiety-related, processes may play a role as well, boosting adrenergic activation (Hoehnsaric & McLeod, 1988). Hence, socially inhibited individuals tend to experience an enhanced stress response and delayed recovery (Bibbey et al., 2015; Habra et al., 2003), which may in time be harmful for their cardiovascular health (Grande, Romppel, & Barth, 2012; Li et al., 2018; Svansdottir et al., 2013). For example, the delayed recovery of SBP we found in socially inhibited individuals, is related to an autonomic dysfunction, including reduced baroreflex sensitivity and increased systemic vascular resistance (Raven, Potts, & Shi, 1997). This activation pattern is associated with an increased risk of hypertension, coronary artery disease, and stroke (Laukkanen et al., 2004; Raven et al., 1997).

The shallow breathing pattern we found in socially inhibited individuals is part of the fight-or-flight response of stress (Wilhelm, Gevirtz et al., 2001), and may affect sympathetic activation of the skeletal muscles (Seals et al., 1993). As many complex events occur simultaneously during breathing, all of which might contribute to respiratory related variations in sympathetic outflow (Seals et al., 1993), more research needs to be performed to find out the exact role of individual differences in the breathing pattern response to acute stress, and its physiological consequences.

For several variables, i.e., DBP, PEP and LVET, we found a cross-over interaction, in which the effect of social inhibition or its facets was opposite for men and women. These differences may have their origin in sex differences in physiological response patterns, as we saw that with higher social inhibition, lower DBP and LVET reactivity was combined with higher PEP reactivity in men. In women, however, we saw that with higher social inhibition, there was higher DBP reactivity and lower or absent PEP and LVET reactivity. A recent paper that used latent class analysis to discover cross-system physiological stress reactivity patterns showing similar sex differences (Kupper et al., Under Review).

In order to improve our understanding of individual differences in stress reactivity, it is important to include a wide range of markers to cover all relevant aspects of the physiological stress response. The psychological and health significance of psychophysiological states derives from the profile of activity across response domains, rather than from only one response domain (Wilhelm, Gevirtz et al., 2001). In fact, sympathetic activation can be seen as a heterogeneous arousal mechanism, which regulates several physiological changes during stress. On the one hand cardiovascular sympathetic activation is operationalized in the blood vessels by α-adrenergic receptors to modulate vessel diameter (as measured indirectly by SBP), and on the other hand it is operationalized in the heart through β-adrenergic receptors with influences on heart rate and myocardial contractility (as measured by PEP and LVET; (Papillo & Shapiro, 1990), to increase blood flow to the muscles during the fight-flight response. Simultaneously, breathing patterns, and in particular tidal volume, affect efferent sympathetic modulation of skeletal muscle, explaining an additional portion of variance in sympathetic activation. Including the activity of multiple response domains is therefore essential, in order to improve our understanding of individual differences in responses to stress.

Social inhibition was also related to a pattern of experiencing negative emotions both in anticipation of, and during social evaluative stress. Similarly, previous research showed that social inhibition was associated with increased sadness and disgust during stress (Habra et al., 2003), increased anxiety during social interaction (Kupper & Denollet, 2014), and more suppressed hostility and anger rumination (Lin et al., 2017; Timmermans et al., 2019). Socially inhibited individuals tend to suppress the expression of their emotions during social interaction (Denollet, 2005), which generally leads to an increased emotional experience, resulting in negative emotions to be unresolved and linger on after stress (Gross & Levenson, 1993, 1997).

We found sex differences in sympathetic arousal, which is more α-adrenergic driven in women and also β-adrenergic driven in men (Hart et al., 2011; Luzier, Nawarskas, Anonuevo, Wilson, & Kazierad, 1998). Interestingly, social inhibition was associated with changes in SBP (α-adrenergic driven) in women and men, while changes in PEP (β-adrenergic driven) were only associated with social inhibition in men. We therefore speculate that the known sex differences in sympathetic drive may be magnified by the trait of social inhibition.

High social inhibition in women was most strongly associated with the low arousal negative emotional response (e.g. sadness), confirming that women typically report more low arousal negative emotions during stress, compared to men (Thomsen, Mehlsen, Viidik, Sommerlund, & Zachariae, 2005). In men, social inhibition was associated with high arousal negative emotional responses during stress, and additionally for the emotions to linger on after stress. Maladaptive emotion regulation (e.g. rumination and worry), may lead to a delayed recovery in socially inhibited individuals compared to non-inhibited individuals (Capobianco, Morris, & Wells, 2018). This delay effect was larger in men than in women. While women ruminate more than men when feeling sad and depressed (Nolen-Hoeksema & Jackson, 2001), men tend to ruminate more about feelings of anger (Maxwell, 2004). The delayed emotional recovery was stronger in men than women, which may be attributed to the association of social inhibition with anger rumination found in a male dominated sample (Timmermans et al., 2019).

The current study also investigated how different facets of social inhibition are related to physiological stress reactivity. First, behavioral inhibition contributed mostly to the altered breathing pattern during stress. This may reflect the close link between behavioral inhibition and anxiety (Clauss, Avery, & Blackford, 2015), of which shallow breathing

is a hallmark characteristic. Neurobiologically, individuals high in behavioral inhibition have a low threshold to activate a hypervigilant state, involving the respiratory control center (Henderson, Pine, & Fox, 2015). Second, interpersonal sensitivity was associated with increased sympathetic activation and a higher heart rate during rest, and higher overall levels of SBP, and to reduced LVET (in men) suggesting stronger contractility per beat. Hence, interpersonal sensitivity is an important factor in the relation between stress and health, as it seems to be associated with elevated stress reactivity, which is in accordance with our hypothesis. This may be due to the increased feelings of anxiety and worry about the potential threat of negative reactions from others (Denollet, 2013). Third, social withdrawal in women was associated with higher DBP reactivity and in men with PEP reactivity, indicating higher sympathetic nervous system activity, which plays a key role in withdrawal behaviors (e.g., Fox, Henderson, Marshall, Nichols, & Ghera, 2005). High scorers on withdrawal tend to avoid social situations (Denollet & Duijndam, 2019), but during the experiment they were unable to avoid the situation.

All facets of social inhibition contributed to the association with low arousal emotional responding, while behavioral inhibition (but not interpersonal sensitivity and social withdrawal) contributed to the association with high arousal negative emotional responding. The challenges faced during the TSST may be especially difficult for people high in behavioral inhibition, due to the difficulty they experience in communicating and performing in public (Denollet & Duijndam, 2019).

Given the interpersonal nature of the TSST, we hypothesized the facet interpersonal sensitivity to be mostly related to increased emotional and larger physiological arousal in response to stress. However, the results of the current study actually show that each underlying facet is related to different (emotional or physiological) responses to social evaluative stress. These results emphasize that the underlying facets are related but distinct facets of social inhibition, thereby supporting our multi-facet model of social inhibition (Denollet & Duijndam, 2019; Duijndam & Denollet, 2019). We therefore suggest that future studies on interpersonal stress should investigate different facets of social inhibition. Whether the higher-order social inhibition trait or (one of) the lower-order facets contribute to a specific health-related outcome is still unclear, and the psychological mechanisms which underlie the hypothesized link between social inhibition and health should be further investigated.

4.1. Limitations and implications

The results of this study should be viewed in light of its limitations and strengths. Because the sample was female-dominated (68 %), and all of the participants were first-year psychology students, results may not generalize to other populations. Higher social inhibition scores are found to be associated with younger age in different samples (Denollet & Duijndam, 2019), and results may be different in an older adult population. Of note, as could be expected from research on individual differences in physiological outcomes (Gignac & Szodorai, 2016), the effect sizes varied from small to medium (Miles & Shevlin, 2001), indicating that our results should be interpreted with caution. Further, non-adherence to health behavior guidelines (e.g., smoking within 2 h of testing) may have contributed to individual differences in the physiological responses (Jaquet, Shapiro, & Uijtdehaage, 1994). We did not include this in our analysis, due to the small number of participants it concerns (n = 15) and because removing these participants did not affect our results, but it is a limitation of the current study. A strength of this study is that both emotional and physiological stress reactivity were assessed. Multiple regulatory subsystems were investigated for a more complete illustration of the individual differences in physiological responses to stress, although we were not able to assess cortisol.

Future research for assessing emotional and physiological stress reactivity in social inhibition should focus on the effects on daily stressors. Research thus far has focused on lab-based stressors only. However, experience sampling methods and ambulant physiological measurements (e.g., VUAMS), should be used to gain more understanding of the effects social inhibition and its facets have on psychological and physiological health. Additionally, insight in total peripheral resistance (TPR) and cardiac output (CO) will help in understanding individual differences in cardiovascular responses to threat related to social inhibition (Blascovich, Mendes, Hunter, & Salomon, 1999).

5. Conclusion

Social inhibition was associated with an increased sympathetic activation, and a delayed recovery of the stress response. The association with sympathetic activation was mostly α-adrenergic in women but also β-adrenergic in men. Socially inhibited women report both low (e.g. sadness) and high (e.g. anger) cortical arousal negative emotions, while socially inhibited men only report high cortical arousal negative emotions in response to social evaluative stress. Different stress effects were found for the three facets of social inhibition, indicating that subtle individual differences in stress reactivity exist within the broad personality construct of social inhibition. These findings emphasize the importance of the relationship between personality and stress responses. Identifying the association between social inhibition and acute stress responses may advance our understanding of the mechanisms which underlie the relations between social stress and health.

Declarations of interest

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Appendix A. Supplementary data

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