have experienced during the TSST– and also compare them to actual physiological data obtained during the task.

Results

In our analyses we addressed the role of peripheral physiological responses and interoceptive ability on the subjective intensity of emotional self-reports. Prior research suggests that more intense physiological reactions predict greater emotional intensity (Levenson, 2014; Kassam & Mendes, 2013; Mendes, 2016). However, we hypothesized that interoceptive ability would interact with physiological reactivity to predict emotional intensity, and also that interoception would account for some of the variability in emotional intensity even beyond this interaction alone.

First, we calculated descriptive statistics for all variables to ensure that our measures were normally distributed and did not exhibit skew or kurtosis. Next, we conducted hypothesis testing using hierarchical regressions to assess the relative contributions of interoceptive ability and physiological reactivity on the intensity of all emotion items, as well as on the intensity of the emotions marked high arousal and negative according to Table 1. Finally, as exploratory analyses, we examined the relationship between the other individual differences (e.g., self-reported interoceptive ability, somatization tendencies, etc.) and interoceptive ability and physiological reactivity. We then ran hierarchical regressions replicating the primary hypothesis-testing models, but with overall somatic intensity as the outcome of interest.

Descriptive Statistics

Means, standard deviations, ranges, and frequencies for each emotion and somatic sensation are presented in Tables 1 and 2, respectively. In general, participants reported relatively high levels of high arousal, negative emotions, like “stressed,” “anxious,” and “frustrated” (*M*s =

4.02, 3.91, 3.64). In contrast, participants indicated that they felt low arousal emotions, including "sad", "quiet", and "sleepy", with much less intensity (*M*s = 1.24, 1.60, 1.89). This suggests that the TSST was effective at inducing the intended high arousal, negative state. In terms of somatic intensity, participants more strongly felt sensations like "heart rate increased," "fidgety," and "wide awake" (*M*s = 3.84, 3.47, 3.42) than sensations like "faint," "pale," or "weak" (*M*s = 1.22, 1.27, 1.38). These data show that high arousal somatic sensations were more characteristic of participant experience during the TSST than were low arousal somatic sensations. Also notably, somatic intensity (*M* = 1.89) was on average lower than emotional intensity (*M* = 2.52). Further, participants reported greater intensity of high arousal, negative emotions (*M* = 2.78) than of emotions in general (*M* = 2.52), as shown in Table 3, which may mean the TSST was likely construed more in terms of emotion than mere somatic changes.

With regards to average physiological reactions during the TSST, participants tended to experience lowest physiological arousal during baseline and peak changes during the prep and math periods of the TSST (e.g., heart rate change from baseline M_{speech} = 14.79 increased beats per minute, SD_{speech} = 10.19). See Table 4 for mean change descriptives from baseline of all peripheral physiological indices at each of the other four time points (prep, speech, math, and recovery), as well as mean reactivity across the TSST as a whole.

Additionally, the distribution of heartbeat detection task scores demonstrated that most (66.67%) of participants performed at a better-than-chance accuracy rate. On average, participants were 57.8% accurate (*SD* = 13.2), though scores included a wide range of poor (min = 36.7) to good (max = 91.7) performance. See Table 5 for a more specific breakdown of the distribution of participant heartbeat detection task scores.

Hypothesis Testing

We ran two overarching hierarchical regression models to test our hypotheses on the roles played by interoceptive ability and physiological reactivity in predicting emotional intensity during the TSST. Each physiological index was run in its own model as a predictor, alongside interoceptive ability and the interaction effect between the two. Table 6 lists results for both steps of the analysis for each outcome variable predicting overall emotional intensity; Table 7 lists results for high arousal, negative emotion intensity models.

Model A: Interoceptive ability + Physiological reactivity + (Interoceptive ability X Physiological reactivity), on Overall emotional intensity. This model is summarized in Table 6. In general, when interoceptive ability was run in Step A1 as the only predictor, it was significant (*p*s < .01). In the Step A2 models, it remained the only significant predictor (*p*s < .05), despite the addition of each physiological reactivity index (e.g., HR) and the interaction between that index and interoceptive ability (*p*s > .25). Changes in R^2 between A1 and A2 were minimal, as well. That is, the A2 models including each physiological reactivity index did not predict the variance in overall emotional intensity during the TSST better than the A1 model with interoceptive ability alone as a predictor. The only exceptions to this pattern were two indices, HR and IBI, for which interoceptive ability became nonsignificant in Step A2 (*p* = .190, .197).

Model B: Interoceptive ability + Physiological reactivity + (Interoceptive ability X Physiological reactivity), on High arousal, negative emotional intensity. The results for Model B, shown in Table 7, were similar to those seen in Model A. In Step B1, interoceptive ability was a significant predictor of high arousal, negative emotional intensity (*p*s < .01). In Step B2, interoceptive ability was still a significant but sometimes marginal predictor (*p*s < 0.10), while the main effect of each physiological reactivity index and the interaction between the two were

nonsignificant (*p*s > .50). Again, entering a given physiological reactivity index and the interaction effect between physiological reactivity and interoceptive ability did not produce a better model of high arousal, negative emotion intensity than the model using interoceptive ability alone.

Exploratory Analyses

Additionally, two sets of exploratory analyses were conducted. Questionnaire descriptive statistics are in Table 8. In Table 9, we present bivariate correlations between all study variables: interoceptive ability; questionnaire measures; physiological reactivity indices; overall emotional intensity; high arousal, negative emotional intensity; somatic intensity.

Questionnaires. There was a significant, moderately strong positive relationship between scores on the MAIA and BAQ, likely since both questionnaires measure similar constructs (r = .459; $p < 0.001$). We also observed significant positive relationships between CMD-SQ score and self-report of overall emotional (r = .417, p = .004), high arousal, negative emotional (r = .298, p = .047), and somatic intensity (r = .384, p = .009) during the TSST; this could indicate that individuals with greater somatization tendencies were also more likely to experience greater intensity emotions and somatic sensations. However, the mean score on the CMD-SQ fails to meet the cut-off values for likelihood of psychopathological symptom reporting or illness worry (Christensen et al., 2005), suggesting our sample in general did not show clinical levels of these symptoms. Interestingly, the heartbeat detection score did not significantly correlate with either measure of self-reported interoceptive ability (MAIA: r = -.194, p = .160; BAQ: r = -.204, p = .139). These findings suggest that a person's subjective report that he or she is highly aware of and sensitive to bodily changes does not necessarily mean that person will be objectively accurate at detecting those changes.

Somatic intensity. We were also interested in how interoceptive ability and physiological reactivity might impact mean reports of overall somatic intensity. To investigate this, we ran hierarchical regressions replicating our primary models of interest with somatic intensity as the outcome. However, no models proved significant. These findings are displayed in Table 10.

Discussion

Hierarchical regression analysis revealed that interoceptive ability is a significant predictor of subjective emotional intensity, regardless of actual physiological reactivity in the autonomic nervous system. The relationship between interoceptive ability, as measured in a heartbeat detection task, and emotional intensity, as self-reported, remained significant even after accounting for actual physiological response in the cardiovascular system and the interaction between this response and interoceptive ability. This evidence suggests that interoceptive ability as an individual difference may be an even more important mechanism driving perceived emotional intensity than how strongly the autonomic nervous system responds.

The non-significance of the relationship between physiological reactivity and emotional intensity demonstrates that there is not a one-to-one relationship between a given physiological reaction and an emotional response, considering that the majority of the variance in emotional intensity was not explained by cardiovascular activity alone. In each physiological index's hierarchical regression, the model with physiological reactivity alongside interoceptive ability was only slightly better at predicting changes in emotional intensity than the model with interoceptive ability by itself, indicating that interoceptive ability was much more central to emotion than was physiological reactivity. Interoceptive ability likely represents how much peripheral bodily signals are being received and refined by the brain, so individuals with greater interoceptive ability are afforded more opportunity to make meaning of those bodily signals as, say, an emotion.

Table 1. Self-reported emotional intensity descriptive statistics. This table contains data from 45 participants.

Emotion	Affect		*M*	*SD*	Range
	Valence	Arousal			
Afraid	–	+	2.20	1.53	1–6
Angry	–	+	1.87	1.49	1–7
Annoyed	–	+	3.44	2.08	1–7
Anxious	–	+	3.91	1.83	1–7
Disgusted	–	+	3.04	1.61	1–6
Distressed	–	+	3.04	1.61	1–6
Embarrassed	–	+	2.98	1.88	1–7
Frustrated	–	+	3.64	1.76	1–7
Guilty	–	+	1.56	1.16	1–5
Hyperactive	–	+	2.33	1.55	1–6
Irritable	–	+	2.60	1.83	1–6
Panicky	–	+	2.96	1.61	1–7
Stressed	–	+	4.02	1.78	1–7
Bored	–	–	2.36	1.86	1–7
Sad	–	–	1.24	0.65	1–6
Unhappy	–	–	2.33	1.85	1–7
Weary	–	–	2.29	1.39	1–5
Activated		+	3.71	1.70	1–7
Alert		+	3.91	1.70	1–7
Calm		–	2.58	1.25	1–5
Quiet		–	1.60	1.25	1–6
Sleepy		–	1.89	1.30	1–6
Excited	+	+	2.22	1.24	1–5
Proud	+	+	2.22	1.28	1–6
Content	+	–	2.02	1.14	1–5
Relaxed	+	–	2.22	1.24	1–5
Amused	+		2.38	1.50	1–6
Happy	+		1.98	1.22	1–6
Interested	+		2.78	1.52	1–6
Pleased	+		1.89	1.13	1–5

Note: For valence, + indicates “positive” and – indicates “negative.” For arousal, + indicates “high” and – indicates “low.” No symbol indicates “neutral” for both dimensions. For all emotions, potential range was from 1 to 7.

Table 2. Self-reported somatic intensity descriptive statistics. This table contains data from 45 participants.

Sensation	*M*	*SD*	Range
Cardiac Sensations			
Blood pumping	3.18	1.81	1–6
Heart palpitations	1.56	1.22	1–6
Heart pounding in chest	2.49	1.78	1–7
Heart rate increased	3.84	1.88	1–7
Throbbing	1.53	1.20	1–7
Gastric Sensations			
Butterflies in stomach	2.33	1.55	1–6
Feeling empty or hollow	1.24	0.71	1–4
Nausea or queasiness	1.13	0.63	1–5
Pit in your stomach	1.76	1.38	1–7
Sick	1.13	0.34	1–2
Stomach tense	1.84	1.48	1–7
Kinesthetic Sensations			
Body or limbs feeling heavy	1.36	0.77	1–5
Dizzy or light-headed	1.47	1.01	1–6
Feeling fidgety	3.47	1.90	1–7
Feeling still or frozen	1.87	1.31	1–7
Head aching	1.07	0.33	1–3
Jittery	3.02	1.69	1–7
Knots / tension	1.96	1.41	1–6
Numbness	1.31	0.73	1–4
Pain	1.04	0.21	1–2
Shakiness or trembling	2.40	1.72	1–7
Shivering	1.29	0.76	1–5
Spine tingling	1.07	0.33	1–3
Tingling in your limbs or fingers	1.64	1.00	1–5
Respiratory Sensations			
Rapid or difficulty breathing	1.24	0.91	1–6
Tightness in chest	1.73	1.34	1–7
Temperature Sensations			
Blood draining out of your face (turning pale)	1.27	0.62	1–4
Face or neck turned red	1.69	1.28	1–7
Feeling cold or clammy	2.00	1.62	1–7
Flushed or hot	1.96	1.36	1–7
Skin or scalp prickling (goosebumps)	1.33	0.85	1–4
Sweating increased	2.64	2.07	1–7

Arousal Sensations			
Drained	1.91	1.18	1–5
Energized	2.64	1.65	1–6
Exhausted	1.87	1.18	1–5
Feeling faint	1.22	0.88	1–6
Feeling physically strong / powerful	1.78	1.15	1–5
Feeling physically weak	1.38	0.96	1–5
Restless	2.87	1.82	1–7
Sluggish	1.58	0.94	1–5
Weariness	1.98	1.34	1–7
Wide awake	3.42	1.76	1–7

Note: For all somatic sensations, potential range was from 1 to 7.

Table 3. Self-reported intensity descriptive statistics. This table contains data from 45 participants.

Measure	M	SD	Range
Overall emotion intensity	2.52	0.59	1.50–3.77
High arousal, negative emotion intensity	2.78	1.04	1.23–5.15
Somatic intensity	1.89	0.58	1.00–3.40

Note: For all emotions, potential range was from 1 to 7.

Table 4. Physiological reactivity descriptive statistics. The mean difference from baseline state for each physiological index is shown in this table. Standard deviations are in parentheses. The measures in this table are calculated from between 34 to 37 participants, depending on data missing at random.

Index	Trier Social Stress Test				Recovery
	Mean	Prep	Speech	Math	
HR	9.54 (7.29)	10.35 (8.82)	14.79 (10.19)	11.24 (10.01)	1.78 (5.61)
IBI	-96.99 (68.22)	-105.75 (82.02)	-144.38 (90.90)	-112.32 (87.11)	-25.52 (67.14)
RSA	0.19 (0.71)	0.36 (0.96)	0.10 (0.88)	0.31 (1.03)	-0.01 (0.54)
CO	2.37 (3.64)	3.47 (8.40)	3.05 (3.53)	2.70 (3.43)	-0.35 (2.84)
LVET	4.76 (22.02)	3.47 (27.35)	6.84 (28.61)	3.46 (25.45)	5.52 (26.17)
PEP	-16.60 (17.19)	-19.36 (22.49)	-18.77 (19.69)	-18.78 (19.41)	-7.70 (15.12)
SV	6.66 (36.70)	16.64 (89.86)	5.94 (49.09)	7.49 (34.81)	-6.61 (38.40)

Note: All measures are per minute. HR is heart rate; IBI is inter-beat interval; RSA is respiratory sinus arrhythmia; CO is cardiac output; LVET is left ventricular ejection time; PEP is pre-ejection period; SV is stroke volume.

Table 5. Heartbeat detection task score frequencies. This table contains data from 54 participants.

Measure	*n*	Percentage
25.1%–50% accuracy	18	33.33%
50.1%–75% accuracy	30	55.56%
75.1%–100% accuracy	6	11.11%

Note: Actual range was 36.7% to 91.7%. Potential range was 0% to 100%.

Table 6. Model A: Hypothesis testing of physiological reactivity and interoceptive ability as predictors of overall emotional intensity, using hierarchical regression analyses.

	Physiological reactivity index													
	HR		IBI		RSA		CO		LVET		PEP		SV	
Predictor	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Step 1														
HBD	1.954*	0.641	1.365*	0.641	1.954*	0.641	2.152*	0.642	2.152*	0.642	2.152*	0.642	2.152*	0.642
Step 2														
HBD	1.442	1.073	1.527	1.152	1.935*	0.651	1.762†	0.759	2.233*	0.665	1.922†	0.903	2.104*	0.689
Physio reactivity	-0.012	0.056	0.000	0.006	-0.317	0.680	-0.188	0.191	-0.001	0.020	-0.003	0.022	0.005	0.024
HBD x Physio	0.049	0.089	-0.004	0.010	0.187	1.026	0.351	0.330	-0.004	0.030	-0.004	0.035	-0.010	0.043
ΔR^2	.069		.078		.059		.037		.021		.034		.004	

Note: For interoceptive ability measurement, HBD is heartbeat detection task score. For physiological reactivity indices, HR is heart rate; IBI is inter-beat interval; RSA is respiratory sinus arrhythmia; CO is cardiac output; LVET is left ventricular ejection time; PEP is pre-ejection period; SV is stroke volume.

* $p < 0.01$ † $p < 0.05$ ‡ $p < 0.10$

Table 7. Model B: Hypothesis testing of physiological reactivity and interoceptive ability as predictors of high arousal, negative emotional intensity, using hierarchical regression analyses.

	Physiological reactivity index													
	HR		IBI		RSA		CO		LVET		PEP		SV	
Predictor	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Step 1														
HBD	3.969*	1.138	3.969*	1.138	3.969*	1.138	4.100*	1.179	4.100*	1.179	4.100*	1.179	4.100*	1.179
Step 2														
HBD	3.466‡	1.979	3.923‡	2.126	3.841*	1.195	3.621†	1.421	4.097*	1.240	3.580†	1.674	4.147*	1.261
Physio reactivity	-0.016	0.103	-0.002	0.011	-0.755	1.249	-0.232	0.357	0.005	0.038	0.002	0.041	-0.011	0.044
HBD x Physio	0.049	0.163	-0.001	0.019	1.052	1.882	0.400	0.617	-0.006	0.056	-0.017	0.064	0.016	0.080
ΔR^2	.014		.023		.010		.011		.001		.020		.008	

Note: For interoceptive ability measurement, HBD is heartbeat detection task score. For physiological reactivity indices, HR is heart rate; IBI is inter-beat interval; RSA is respiratory sinus arrhythmia; CO is cardiac output; LVET is left ventricular ejection time; PEP is pre-ejection period; SV is stroke volume.

* $p < 0.01$ † $p < 0.05$ ‡ $p < 0.10$

Table 8. Questionnaire descriptive statistics. This table contains data from 61 participants.

Measure	*M*	*SD*	Range
MAIA			
Overall	3.69	0.55	2.03–5.16
Noticing	3.83	0.93	1.25–6.00
Not distracting	3.07	0.97	1.00–5.33
Not worrying	3.84	0.88	1.33–5.67
Attention regulation	3.55	0.79	1.43–5.86
Emotional awareness	3.98	0.94	1.80–6.00
Self-regulation	3.54	0.94	1.25–5.75
Body listening	3.01	1.02	1.00–5.67
Trusting	4.52	0.91	2.00–6.00
BAQ	3.97	0.85	2.39–5.67
CMD-SQ	1.45	0.46	1.00–3.53

Note: For the MAIA, potential range was from 1 to 6. For the BAQ, potential range was from 1 to 7. For the CMD-SQ, potential range was from 1 to 5.

Table 9. Bivariate correlations of study variables.

	Interoceptive ability				Physiological reactivity						TSST self-report		
Measure	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Interoceptive ability													
1. HBD	-.194	-.204	-.012	.033	-.031	.008	-.077	.123	-.212	-.030	.373†	.385†	.253
2. MAIA	–	.459*	.052	-.032	-.135	-.257	.076	.230	-.202	-.162	-.135	-.229	-.222
3. BAQ		–	.150	.135	-.104	-.339†	.064	.122	-.241	-.143	-.134	-.323†	-.116
4. CMD-SQ			–	.018	-.131	-.278	-.071	-.178	.066	-.126	.417*	.298†	.384*
Physiological reactivity													
5. HR				–	-.915*	-.521*	.464*	-.529*	-.314	.006	.235	.084	.310
6. IBI					–	.517*	-.348†	.421†	.316	.064	-.193	-.076	-0.259
7. RSA						–	-.348†	.000	.260	.067	-.249	-.032	-.070
8. CO							–	-.054	-.323	.798*	.003	-.076	.297
9. LVET								–	-.201	.079	-.064	.089	-.168
10. PEP									–	-.136	-.227	-.219	-.067
11. SV										–	-.116	-.092	.235
TSST self-report													
12. Emo intensity											–	.879*	.696*
13. HANE intensity												–	.700*
14. Somatic intensity													–

Note: For interoceptive ability measurement, HBD is heartbeat detection task score; MAIA is Multidimensional Assessment of Interoceptive Awareness; BAQ is Body Awareness Questionnaire; CMD-SQ is Common Mental Disorders – Screening Questionnaire. For physiological reactivity indices, HR is heart rate; IBI is inter-beat interval; RSA is respiratory sinus arrhythmia; CO is cardiac output; LVET is left ventricular ejection time; PEP is pre-ejection period; SV is stroke volume. For TSST self-report measures, emo intensity is emotional intensity; HANE intensity is high arousal, negative emotion intensity.

* $p < 0.01$ † $p < 0.05$

Table 10. Hypothesis testing of physiological reactivity and interoceptive ability as predictors of somatic intensity, using hierarchical regression analyses.

	Physiological reactivity index													
	HR		IBI		RSA		CO		LVET		PEP		SV	
Predictor	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Step 1														
HBD	1.262	0.798	1.262	0.798	1.262	0.798	1.454‡	0.812	1.454‡	0.812	1.454‡	0.812	1.454‡	0.812
Step 2														
HBD	0.152	1.313	0.194	1.429	1.149	0.834	1.191	0.928	1.630‡	0.822	1.910	1.163	1.548‡	0.844
Physio reactivity	-0.044	0.069	0.004	0.008	-0.673	0.871	-0.127	0.233	0.008	0.025	-0.015	0.028	-0.004	0.030
HBD x Physio	0.109	0.108	-0.011	0.012	0.934	1.313	0.307	0.403	-0.022	0.037	0.025	0.045	0.015	0.053
ΔR^2	.113		.102		.023		.103		.066		.011		.059	

Note: For interoceptive ability measurement, HBD is heartbeat detection task score. For physiological reactivity indices, HR is heart rate; IBI is inter-beat interval; RSA is respiratory sinus arrhythmia; CO is cardiac output; LVET is left ventricular ejection time; PEP is pre-ejection period; SV is stroke volume.

* $p < 0.01$ † $p < 0.05$ ‡ $p < 0.10$