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Parasympathetic cardio-regulation during social interactions in individuals with obesity—The influence of negative body image

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Abstract Individuals with obesity in Western societies often face weight-related stigmatization and social exclusion. Recurrent exposure to prejudice and negative social feedback alters one's behavior in future social interactions. In this study, we aimed to investigate autonomic nervous system and affective responses to social interactions in individuals with obesity. Women and men with ($n = 56$) and without ($n = 56$) obesity participated in episodes of social inclusion and social exclusion using a virtual ball-tossing game. During the experiment, heart rate was measured and parasympathetic activity (overall high-frequency power and event-related cardiac slowing) was analyzed. Our results show that in novel social interactions, women with obesity, relative to the other groups, exhibited the strongest increase in parasympathetic activity. Furthermore, parasympathetic activity was related to a more negative body image in individuals with obesity, but not in lean individuals. Additionally, women with obesity reported a stronger decrease in mood after social exclusion than did the other participants. Our results demonstrate influences of objective and subjective bodily characteristics on parasympathetic cardio-regulation during social interactions. In particular, they show behavioral and physiological alterations during social interactions in women with obesity.

Keywords Obesity · Social information processing · Heart rate variability · Body image · Social exclusion

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Human beings are a distinctly social species and strongly dependent on social relationships (Baumeister & Leary, 1995). However, throughout history and around the world, humans are also engaged in socially excluding and discriminating against other groups, subgroups, or individuals that are deviating from group-specific norms, values, or physical appearance (Kurzban & Leary, 2001). Individuals of those groups possess an attribute that does not meet society's normative expectations, which can result in a stereotypical classification, and further in social exclusion and stigmatization (Goffman, 1963). Moreover, the visibility and preventability of this attribute enhances stigmatizing behavior (Kurzban & Leary, 2001; Weiner, Perry, & Magnusson, 1988).

Being obese in a present Western society is often accompanied by weight-related stigmatization, discrimination, and social exclusion in multiple daily contexts: Individuals with excess weight are judged more negatively, have fewer opportunities on the labor market (Puhl & Brownell, 2001), and are frequently exposed to teasing and stigmatization in significant interpersonal relationships (Puhl, Moss-Racusin, Schwartz, & Brownell, 2008). These effects are more prominent in women than in men with obesity (Puhl, Moss-Racusin, & Schwartz, 2007). Excess body weight is perceived to be under the

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individual's control (DeJong, 1980) and is associated with laziness, irresponsibility, lack of intelligence, or self-control (Crandall, 1994; Puhl & Brownell, 2001)—which are highly undesirable traits in modern, performance-oriented societies. Additionally, Andreyeva, Puhl, and Brownell (2008) showed that weight stigmatization is rising disproportionally with obesity rates, indicating a further growing negative bias against individuals with obesity.

It has been hypothesized that recurrent negative social experiences change one's behavior in future social interactions. Swim, Cohen, and Hyers (1998) argued that stigmatized individuals are able to anticipate potentially stigmatizing situations. The targets of peer victimization show increased vigilance toward even subtle cues of prejudice. The pure anticipation of being the target of prejudice increases attention to the signs of devaluation (Kaiser, Vick, & Major, 2006), and fear of negative evaluation enhances attention to threat cues after social exclusion (Tanaka & Ikegami, 2015). Improved detection accuracy of prejudice enables individuals to apply strategies that prevent or reduce its negative impact on psychological well-being (Barreto & Ellemers, 2015). Such strategies comprise psychological disengagement (Crocker & Major, 1989), avoidance (Puhl & Brownell, 2003), and assertion or aggression (Joanisse & Synnott, 1999), as well as compensation with increased prosocial behavior (Miller, Rothblum, Felicio, & Brand, 1995). Furthermore, it has been shown that, in the presence of negative stereotypical statements, individuals are more likely to show disengagement after negative feedback (Leitner, Jones, & Hehman, 2013). These studies have indicated two, complementary mechanisms of behavioral adaption to social exclusion: (1) heightened vigilance to social cues in situations in which an individual has previously experienced negative feedback (Kaiser et al., 2006; Tanaka & Ikegami, 2015), and (2) the application of coping mechanisms like disengagement in an actual discriminatory situation (Leitner et al., 2013).

Blackhart, Nelson, Knowles, and Baumeister (2009) found that experimentally excluded participants not only showed altered vigilance for social cues but also reported more negative affect than included participants, indicating the potential detrimental effects of exclusion on well-being. In participants with obesity, social exclusion furthermore increased the feeling of shame (Westermann, Rief, Euteneuer, & Kohlmann, 2015). Shame has been described as a feeling of being worthless and might result in withdrawal or maladaptive coping in stressful situations (Conradt et al., 2008). Body shame has been found to be related to disordered eating and depressive symptoms (Tiggemann & Kuring, 2004). Moreover, body shame mediates the relationship between weight status and self-esteem (Pila, Sabiston, Brunet, Castonguay, & O'Loughlin, 2015). In individuals with obesity, increased shame after social exclusion might contribute to a higher prevalence of psychological disorders described in the literature (Carpenter, Hasin, Allison, & Faith, 2000).

Psychophysiological and neuroimaging studies on social exclusion support the psychological processes involved—such as attention, regulation, or negative affect: Functional MRI studies have shown brain activation associated with social exclusion in the anterior cingulate cortex and the ventrolateral prefrontal cortex—areas associated with distress and conflict monitoring (Botvinick, Cohen, & Carter, 2004; Eisenberger, Lieberman, & Williams, 2003). This effect was more pronounced in individuals with more experiences of childhood peer rejection (Will, van Lier, Crone, & Güroğlu, 2015). Psychophysiological studies on social interactions have examined the arousal and activation of the autonomic nervous system (ANS), for example by using heart rate (HR) recordings. The ANS influences heart activity by input to the sinoatrial node. A particular focus thereby lies on the interplay of the fast-responding inhibitory parasympathetic nervous system (PNS) and the slow-responding excitatory sympathetic nervous system (SNS). PNS activation is typically measured as rapid changes in HR and increased heart rate variability (HRV). According to the "neurovisceral integration model," higher PNS activity indexes physiological and behavioral flexibility to changing environmental demands (Thayer & Lane, 2000, 2009). This framework thus connects affective and attentional processes to the ANS. Of particular interest for this study are social factors influencing HRV or PNS activation: Patients with social anxiety disorder show decreased HRV—an index of decreased PNS activity—at rest (Alvares et al., 2013) and during implicit emotional face processing (Gaebler, Daniels, Lamke, Fydrich, & Walter, 2013). In healthy participants, HRV has been shown to decrease during psychosocial stress and other negative social interactions (Shahrestani, Stewart, Quintana, Hickie, & Guastella, 2015).

On the other hand, Gunther Moor, Crone, and van der Molen (2010) showed that when participants received unexpected social rejection, the heart period decelerated, indicating increased PNS activity. A similar effect was found in adolescents (Gunther Moor, Bos, Crone, & van der Molen, 2014) as well as after laughter stimuli in individuals that perceived laughter as a cue of social rejection (Papousek et al., 2014). Conversely, during an episode of exclusion relative to an episode of inclusion, an increase in tonic HR (Iffland, Sansen, Catani, & Neuner, 2014a; Murray-Close, 2011) and a reduction of PNS-driven respiratory sinus arrhythmia (Murray-Close, 2011) have been observed. Since HR is controlled by a complex interplay between the PNS and SNS, the relative impact of PNS and SNS activity on HR changes cannot be fully disentangled. Similarly, Newman (2014) showed that social exclusion correlates with increased sympathetic activity measured through pre-ejection period, an association that was blunted in individuals with previous victimization. In summary, social, attentional, and affective processes have been associated with changes in PNS activity. Although negative or stressful information processing was associated with decreases in HRV, regulatory processes have been related to increased HRV.

As we mentioned above, studies have suggested that targets of victimization adaptively respond to potentially threatening social situations with higher vigilance and, when receiving negative feedback, with psychological disengagement. However, there has been little research into how people with obesity or stigmatizing experiences process and respond to new social situations or social exclusion. In a previous study, we found that women with obesity showed slower response times than did lean women during the anticipation of social as compared to monetary feedback, as well as blunted cardiac responses to negative social stimuli. This differential response was more pronounced in women with obesity with higher body mass indexes (BMIs) and more intense weight-related teasing experiences (Kube, Schrimpf, et al., 2016).

In the present study, we aimed to investigate the ANS and affective responses to social interaction in individuals with obesity. We applied the well-established Cyberball paradigm (Williams, Cheung, & Choi, 2000), a virtual ball-tossing game, to induce standardized episodes of social inclusion and exclusion. To establish a potentially threatening or stigmatizing social situation, the participant's full-body picture was visible throughout the experiment. During the entire experiment, each participant's electrocardiogram (ECG) was recorded, and changes in heart periods as well as HRV were analyzed. Since the heart is under constant inhibitory control by the PNS, fast phasic changes in heart periods and measures of HRV mainly reflect parasympathetic (or vagal) cardio-regulation (e.g., Thayer & Lane, 2000). For phasic heart period changes, it has been shown that motivationally relevant stimuli—in particular, negatively valenced stimuli—elicit an immediate cardiac deceleration followed by a delayed acceleratory recovery (Somsen, Van der Molen, Jennings, & van Beek, 2000; van der Veen, van der Molen, Crone, & Jennings, 2004). The analysis of HRV in the frequency domain allows the extraction of PNS or vagal activity through the quantification of power in the high-frequency (HF) band between 0.15 and 0.40 Hz (HF power). Increased HRV during experimental conditions, indexing parasympathetic cardio-regulation, has been associated with attentional engagement, emotional self-regulation, or—more generally—behavioral flexibility (Porges, 2007; Thayer & Lane, 2000, 2009).

On the basis of the existing literature, we hypothesized that individuals with obesity, as compared to lean individuals, would show a higher vigilance to potentially threatening social cues and exhibit stronger parasympathetic activation when engaging in a novel social interaction, in which they are included but their weight status is visible. However, when confronted with social exclusion by others, we assumed that individuals with obesity and with a history of weight-related stigmatization would show parasympathetic withdrawal, indicated by a blunted phasic heart period response and lower HRV. Additionally, we hypothesized that social exclusion would affect individuals with obesity more negatively than lean individuals, as indicated through worse mood, happiness, or a lower feeling of being accepted. Finally, we examined possible influencing factors such as sex, negative body image, and social insecurity, which we expected to alter the responses to social interactions. We hypothesized that the effects of inclusive and exclusive social interactions would be more pronounced in women than in men with obesity and that negative body image as well as social insecurity would modulate the weight-related influence on social information processing.

Method

Participants

Participants were recruited from the database of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany. Volunteers either entered their details into the database via the Institute's website or were recruited for previous studies via advertisement in public spaces. A total of 120 healthy individuals, matched for educational background and age, participated in this study. The inclusion criteria were that participants be between 18 and 35 years of age and have BMIs >30.0 kg/m^2 for obese or between 18.5 kg/m^2 and 24.9 kg/m^2 for lean control participants, respectively. All participants underwent a telephone screening and were excluded when meeting any of the following exclusion criteria: history of neuropsychiatric disorders, hypertension, respiratory or thyroid diseases, smoking, and regular substance or medication use. Eight individuals were excluded after participation: three due to a total score above 18 on the Beck Depression Inventory (BDI; Beck, Steer, & Carbin, 1988), one due to previously unreported occasional smoking, two due to data-recording failure, and two due to deviating HR responses (more than three interquartile ranges from the nearer edge of the boxplots). Thus, 112 participants entered the final analyses: 29 lean women (age = 26.5 ± 3.8 years, BMI = 21.6 ± 2.0), 29 women with obesity (age = 26.2 ± 3.7 years, BMI = 36.1 ± 4.9), 27 lean men (age = 27.2 ± 3.3 years, BMI = 22.1 ± 1.5), and 27 men with obesity (age = 27.9 ± 3.1 years, BMI = 35.1 ± 3.8).

All participants gave written informed consent and received a reimbursement for their participation (€7/h). The study duration was a total of 3–4 h on two separate days. The study was carried out in accordance with the Declaration of Helsinki and was approved by the ethics committee of the Leipzig University.

Procedure

All participants were invited on two separate days within one week. During the first appointment, participants completed questionnaires assessing their demographic information, body image, stress, depression, and rejection sensitivity. Then weight, height, and waist and hip circumference were measured before a full-body photo was taken of each participant. Here, participants were asked to wear a slim-fitting black shirt and leggings provided by us to take a portrait in front of a white background. On the second day, participants took part in the Cyberball paradigm, a virtual ball-tossing game to induce a standardized social exclusion experience (Williams et al., 2000). Participants were randomly assigned to either the inclusion or the exclusion condition. They were instructed by the experimenter that two other invited participants were sitting in nearby rooms and would play an online game with the participant. In reality, the two players were computer generated. All players were represented on the computer screen by drawings and a full-body picture. The participant's character and picture were located at the bottom center of the screen (see Fig. 1). The two confederates had the same sex as the participant. To induce a potentially stigmatizing situation, the pictures of the computer-generated players had lean body shapes. Photographs of the two female and two male lean players were taken of coworkers at the institute.

Before the start of the experiment, participants completed initial visual analogue scales (VASs) to assess their baseline mood, happiness, and feelings of being accepted (see Table 1). Afterward, the ECG electrodes were attached (see below for details). Before the start of the experiment, a 4-min

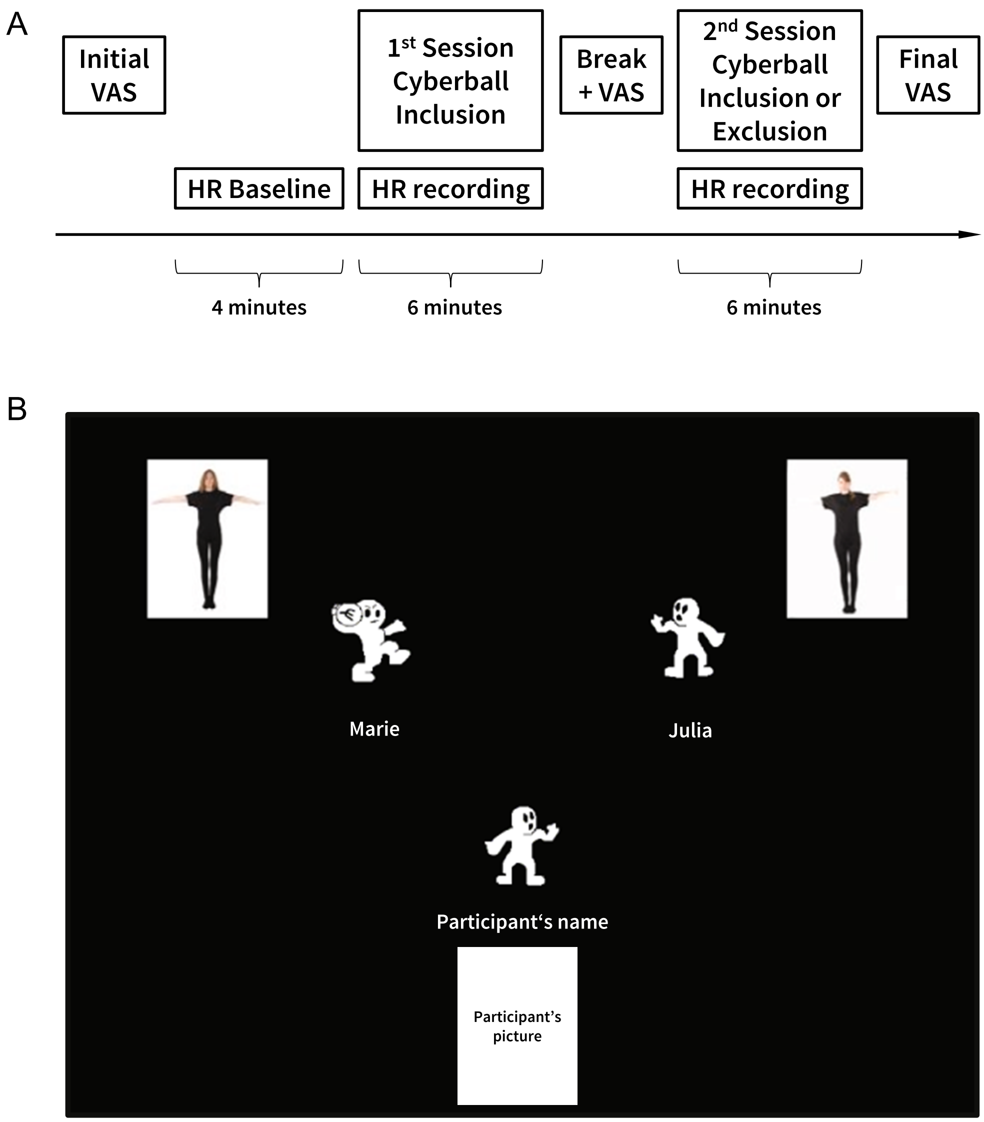

Fig. 1 Paradigm. (**A**) Overall experimental timeline. (**B**) The participant and the two confederates were represented on the computer screen by drawings, a full-body picture and their names, with the participant's character, picture, and name located at the bottom center

Table 1 Sample characteristics

	Lean Women $n = 29$	Women With Obesity $n = 29$	Lean Men $n = 27$	Men With Obesity $n = 27$	Weight		Weight × Sex	
n Incl./Excl.	15/14	15/14	14/13	13/14	*F*	*p*	*F*	*p*
Anthropometrics								
Age	26.45 ± 3.8	26.17 ± 3.7	27.15 ± 3.3	27.89 ± 3.1	0.145	.704	0.578	.449
Education in years	15.62 ± 1.6	15.28 ± 1.5	15.85 ± 1.8	14.96 ± 1.2	0.113	.738	0.113	.738
BMI	21.64 ± 2.0	36.11 ± 4.9	22.06 ± 1.5	35.09 ± 3.8	465.811	**.001**	1.252	.266
WHR	.73 ± 0.05	.82 ± 0.07	.81 ± 0.04	.97 ± 0.07	126.855	**.001**	10.185	**.002**
Sports h/week	3.59 ± 3.5	2.84 ± 3.5	4.14 ± 3.7	4.02 ± 3.2	0.397	.530	0.249	.619
Components derived from questionnaires								
Insecurity	–.07 ± 0.9	.03 ± 1.1	.31 ± 1.1	–.26 ± 0.9	1.685	.197	3.365	.069
Negative body image	–0.33 ± 0.5	**1.08 ± 0.6**	–1.17 ± 0.3	0.37 ± 0.8	214.562	**.001**	0.251	.618
Perceived overload	.32 ± 1.2	–.10 ± 1.0	–.04 ± 0.7	–.19 ± 1.0	2.159	.145	0.497	.483
Visual analogue scales baseline								
Mood (mm)	7.53 ± 1.3	7.47 ± 1.4	7.17 ± 1.5	7.67 ± 1.2	0.726	.396	1.144	.287
Happiness (mm)	6.85 ± 1.4	6.63 ± 1.2	6.71 ± 1.5	6.87 ± 1.1	0.009	.926	0.628	.430
Feeling of acceptance (mm)	8.14 ± 1.4	7.72 ± 1.5	7.15 ± 1.3	7.83 ± 1.2	0.245	.621	4.712	**.032**
Heart rate variability baseline								
Mean HR (bpm)	79.45 ± 10.4	79.39 ± 8.6	79.18 ± 11.2	77.63 ± 8.8	0.287	.593	0.194	.661
LF power (ms^2)	959 ± 728	1,418 ± 1,129	1,583 ± 1,262	1,347 ± 1,343	0.282	.597	2.644	.107
HF power (ms^2)	631 ± 826	1,447 ± 4,432	589 ± 985	747 ± 1081	1.097	.297	0.473	.493
HF power n.u.	35.37 ± 21.8	32.95 ± 21.1	22.64 ± 13.0	31.45 ± 18.1	0.874	.352	2.440	.121
LF/HF power (log_{10})	.31 ± 0.5	.37 ± 0.5	.59 ± 0.3	.41 ± 0.4	0.685	.410	1.993	.161

Univariate ANCOVAs: BMI = body mass index, WHR = Waist-to-hip-ratio, HR = heart rate, LF = low-frequency power, HF = high-frequency power, HF power n.u. = normalized units, LF/HF = ratio between LF and HF power. Values represent means ± *SD*s, and boldface indicates results significant at $p < .05$

HR measurement at rest was acquired. This was followed by two 6-min sessions of the Cyberball game. In the first session, all participants were included in the game, whereas in the second session, 50% were included as before, and 50% were excluded. With a computer mouse, participants were able to throw the ball to the confederates. The first session consisted of approximately 150 ball throws, of which the participant received one third—that is, every player received the ball equally often throughout the game. Each trial of the computer-generated players lasted between 1,600 and 4,600 ms, consisting of a randomized waiting period (1,000 to 4,000 ms) and a "throw and flight" period (600 ms).

The first session ended with a short break, during which participants completed a second set of VASs to assess their mood, happiness, and feelings of being accepted. In the second session of the game, one group of participants continued to be included in the game, as before. A second group of participants underwent the exclusion condition, in which they received just one ball per minute after the first three throws. This resulted in approximately seven ball tosses during the 6 min (as compared to ~50 min in the inclusion condition). At the end, participants completed a final set of VASs to one again measure mood, happiness, and feelings of being accepted. All participants were debriefed at the end of the experiment.

Psychometric measures and factor analysis

On the first day of the experiment, all participants completed a battery of questionnaires to assess study-relevant information about the individuals' personality traits, body image, stress, and depression: the BDI (Beck et al., 1988), Body Image Avoidance Questionnaire (BIAQ; Legenbauer, Vocks, & Schütt-Strömel, 2007), Body Shape Questionnaire (BSQ; Cooper, Taylor, Cooper, & Fairbum, 1987), Eating Disorder Inventory (EDI-2; Garner, 1991), Fear of Negative Evaluation Scale (SANB-5; Kemper, Lutz, & Neuser, 2012), Figure Rating Scales (FRS; Stunkard, Sorensen, & Schulsinger, 1983), NEO Five-Factor Inventory (NEO-FFI; Borkenau & Ostendorf, 1993), Perceived Stress Questionnaire (PSQ-20; Fliege, Rose, Arck, Levenstein, & Klapp, 2001), Perceived Stress Scale (PSS-10; Cohen, Kamarck, & Mermelstein, 1983), Perception of Teasing Scale (POTS; Thompson, Fabian, Moulton, Dunn, & Altabe, 1991), Rejection Sensitivity Questionnaire (RSQ; Staebler, Helbing, Rosenbach, & Renneberg, 2011), Rosenberg Self-esteem Scale (RSES; Rosenberg, 1965), and Trier Inventory for Chronic Stress (TICS; Schulz & Schlotz, 1999).

A principal component analysis (PCA) with orthogonal rotation (varimax) was conducted using IBM SPSS Statistics

23 (Armonk, NY, USA) to reduce the number of variables and extract convergent latent factors across different measures of self-related social experiences. Only the total scores of the questionnaires or specific subscales that assessed social contexts and fulfilled the criteria for PCA were included. The Kaiser–Meyer–Olkin (KMO) measure of .86 (with all KMO values for individual scales > .62 and thus above the threshold of .5) confirmed the sampling adequacy for the analysis. The correlations between scales were sufficiently large for a PCA [Bartlett's test of sphericity: $\chi^2(406) = 2296.256$, $p < .001$]. In the initial analysis, six components had eigenvalues over 1 (Kaiser's criterion) and explained 69.08% of the variance. The scree plot was showing inflexions that justified retaining three components (explaining 57.06% of the variance). After evaluation of the scales that clustered on the same component, Component 1 was summarized as *social insecurity*, Component 2 as *negative body image*, and Component 3 as *perceived overload* (see Table S1 in the supplements).

HR data recordings and analysis

A three-lead ECG was continuously recorded during both parts of the experiment, each lasting for 6 min, and during the 4-min resting period before the start. The ECG data were recorded at 500 Hz using a BrainAmp ExG amplifier and BrainVision Recorder software (Version 1.20.0506, Brain Products, München, Germany). Three Ag/AgCl electrodes (MES Forschungssysteme GmbH, Gilching, Germany) were placed between the right clavicle and sternum, on the left side between the two lower rips, and on the right lower abdomen.

The ECG data were imported into Kubios (Version 2.2; Biosignal Analysis and Medical Imaging Group, University of Eastern Finland, http://kubios.uef.fi/) and visually inspected. For unclear peaks, the Kubios artifact correction level "very low" was applied that identifies and (cubic spline) interpolates RR intervals that are differing more than 0.45 s from the local mean RR interval. The amount of corrected peaks did not exceed 0.5% of the total analyzed data and artifact correction was equally distributed in subsamples; that is, there was no significant difference between groups in number of corrected peaks [interaction of Weight × Sex, $F(3, 108) = 1.38$, $p = .252$]. We analyzed mean HR and HRV in the frequency domain, the latter by means of fast Fourier transformation using Welch's periodogram method with a sliding window of 256 s and 50% overlap. In particular, we extracted low-frequency (LF; 0.04–0.15 Hz) and HF (0.15–0.4 Hz) power. LF and HF power were analyzed in normalized units (n.u.) by dividing the values through the total LF and HF power. Normalization removes unequal distribution of the raw data and increases comparability between individuals and studies (Burr, 2007). Because of the linear redundancy between LF n.u. and HF n.u. (Burr, 2007), and because HF power is more clearly interpretable as parasympathetic activation (Billman, 2013; Thayer & Lane, 2000), we will only report HF power n.u. in the following results section. All raw HRV values for baseline and experimental sessions can be found in supplements (Table S2 in the supplements).

For our event-related heart period analyses, in-house MATLAB scripts (MATLAB R2016a; The MathWorks, Sherborn, MA, USA) extracted event-related interbeat intervals (IBIs) from the files that were previously corrected with Kubios. Five consecutive IBIs around event onset were extracted. The events were ball tosses between computer-generated players, tosses to the participant, and participant's tosses. To avoid an interference with the participant's motor response (Jennings & van der Molen, 2002), only the ball tosses between the computer-generated players were included in the analysis. To account for a few deviant trials and to increase robustness of analysis, the median of each participant's IBIs was used for further analysis. IBI0 was measured at the time of the ball throw. In addition, one IBI prior to the ball-tossing (IBI-1), and two IBIs following the ball-tossing (IBI+1, IBI+2) were included in the analysis. All IBIs were referenced to the baseline IBI (IBI-2), at which no significant effects of time, sex, weight, or condition emerged [Time × Weight × Sex, $F(1, 104) = 0.464$, $p = .497$; Time × Weight × Sex × Condition, $F(1, 104) = 0.992$, $p = .321$]. Furthermore, there were no significant effects of time, sex, weight, or condition on IBI-1 [Time × Weight × Sex, $F(1, 104) = 1.297$, $p = .257$; Time × Weight × Sex × Condition, $F(1, 104) = 0.359$, $p = .550$].

Statistical analysis

All statistical analyses were carried out using IBM SPSS Statistics 23 (Armonk, NY, USA) with a two-sided α level of .05. Greenhouse–Geisser corrections were used to adjust the degrees of freedom in mixed-design analyses of variance (ANOVAs) in case the assumption of sphericity was violated according to the Mauchly test. In this case, we report uncorrected degrees of freedom, corrected p values, and epsilon (ε). Estimated effect sizes are reported using partial eta squared (η_p^2). The mean-centered covariate "age" was included in all mixed-design analyses of covariance (ANCOVAs). All reported post-hoc results were least significant difference corrected.

Group differences in the participant characteristics and baseline HRV data were analyzed using univariate ANCOVAs, employing between-subjects factors "weight" (lean, obese), "condition" (inclusion, exclusion), and "sex" (women, men). VAS changes over time were analyzed using separate mixed-design ANCOVAs for all time points, employing the within-subjects factor Time (baseline, 1st session, 2nd session) and the between-subjects factors Condition (inclusion, exclusion), Weight (lean, obese), and Sex (women, men). HRV changes from baseline to the first session and HRV changes from the first to the second experimental session were examined separately in order to disentangle general effects of social interaction from social exclusion. Mixed-design ANCOVAs for all time points were used, employing the within-subjects factor Time and the between-subjects factors Weight (lean, obese), Sex (women, men), and, for the analysis between the first and second session, Condition (inclusion, exclusion).

Phasic heart period changes between the two experimental sessions were analyzed using a mixed-design ANCOVA with the within-subjects factors Time and IBI, as well as between-subjects factors Weight (lean, obese), Sex (women, men), and Condition (inclusion, exclusion).

Furthermore, two-sided bivariate correlations were calculated to analyze the associations of HRV and phasic heart period responses with the state and trait variables (VAS and principle components). A Fisher's *r*-to-*z* transformation was performed to assess group differences between the correlations.

Results

Group characteristics

The means and standard deviations for all group characteristics can be found in Table 1. Lean women, lean men, and women and men with obesity did not significantly differ in age, education, and hours of sports per week. In line with our inclusion criteria, the groups significantly differed in BMI [main effect of weight, $F(1, 104) = 465.811$, $p < .001$, $\eta_p^2 = .817$] and waist-to-hip-ratio [main effect of sex, $F(1, 104) = 102.601$, $p < .001$, $\eta_p^2 = .497$; main effect of weight, $F(1, 104) = 126.855$, $p < .001$, $\eta_p^2 = .549$; interaction of Sex × Weight, $F(1, 104) = 10.185$, $p = .002$, $\eta_p^2 = .089$]. Regarding the components derived from questionnaires, we found no difference between the groups in social insecurity and perceived overload. However, the groups differed significantly in negative body image [main effect of sex, $F(1, 104) = 61.113$, $p < .001$, $\eta_p^2 = .370$; main effect of weight, $F(1, 104) = 214.562$, $p < .001$, $\eta_p^2 = .674$], with women with obesity having the highest and lean men having the lowest negative body image (lean women, $M = –0.33$, $SD = 0.46$; lean men, $M = –1.17$, $SD = 0.32$; women with obesity, $M = 1.08$, $SD = 0.56$; men with obesity, $M = 0.37$, $SD = 0.79$). Although we did not find a correlation between social insecurity, negative body image, and perceived overload in the lean group; social insecurity and negative body image showed a significant positive correlation [$r(56) = .34$, $p = .010$] in the group with obesity (Table 2). The baseline HRV parameters did not differ significantly between groups, except for HF power n.u. [main effect of sex, $F(1, 104) = 4.083$, $p = .046$, $\eta_p^2 = .038$], with lower values in men ($M = 27.05$, $SD = 16.25$) than in women ($M = 34.16$, $SD = 21.28$).

Visual analogue scales

The analyses over all three measurement times for *mood* revealed a significant main effect of time [$F(2, 206) = 5.625$, $\varepsilon = .931$, $p = .005$, $\eta_p^2 = .052$] and a Time × Condition interaction [$F(2, 206) = 4.029$, $\varepsilon = .931$, $p = .022$, $\eta_p^2 = .038$]. Mood was significantly lower in the second session after exclusion than after inclusion (exclusion $M = 6.78$, $SD = 1.7$, inclusion $M = 7.43$, $SD = 1.3$, $p = .019$). A Time × Condition × Sex × Weight interaction [$F(2, 206) = 3.166$, $\varepsilon = .931$, $p = .048$, $\eta_p^2 = .030$] showed that only women with obesity exhibited a significant difference in mood after the second session inclusion and the second session exclusion. Women with obesity that were excluded from the ball-tossing game showed more negative mood ($M = 6.28$, $SD = 1.7$), whereas women with obesity that were further included showed more positive mood ($M = 7.84$,

Table 2 Correlations between principal components in individuals with obesity (upper diagonal) and lean individuals (gray, lower diagonal)

	Social insecurity	Negative body image	Perceived overload
Social insecurity		**.342****	-.040
Negative body image	-,144		.141
Perceived overload	.006	.189	

** Correlation significant at the .01 level (two-tailed)

SD = 1.0, p = .005). Furthermore, only excluded women with obesity showed a significant decrease in mood from the first to the second experimental condition (mood after first session, M = 7.03, SD = 1.6; mood after second session, M = 6.28, SD = 1.7, p = .019; Fig. 2).

For *happiness*, we found a significant main effect of condition [$F(1, 103) = 5.029$, $\varepsilon = .917$, $p = .027$, $\eta_p^2 = .047$]. A Time × Condition × Sex × Weight interaction [$F(2, 206) = 3.689$, $\varepsilon = .917$, $p = .030$, $\eta_p^2 = .035$] indicated that women with obesity and lean men reported a significantly lower level of happiness after the second-session exclusion (women with obesity, M = 5.73, SD = 1.5; lean men, M = 6.19, SD = 1.3), relative to women with obesity and lean men after the second-session inclusion (women with obesity, M = 7.23, SD = 1.0, p = .006; lean men, M = 7.52, SD = 1.5, p = .017). Furthermore, women with obesity had lower levels of happiness (M = 5.73, SD = 1.5) than did men with obesity when they were excluded in the second session (M = 7.17, SD = 1.7, p = .009; Fig. 2).

For the *feeling of being accepted*, we found a significant main effect of time [$F(2, 206) = 30.193$, $p < .001$, $\eta_p^2 = .227$] and a Time × Condition interaction [$F(2, 206) = 22.047$, $p < .001$, $\eta_p^2 = .176$], showing that excluded participants felt less accepted after the second session (M = 6.04, SD = 1.9) than did included participants (M = 7.45, SD = 1.3, p < .001). A between-subjects interaction of Condition × Sex × Weight [$F(1, 103) = 4.657$, $p = .033$, $\eta_p^2 = .043$] indicated that women with obesity and lean men who were excluded from the

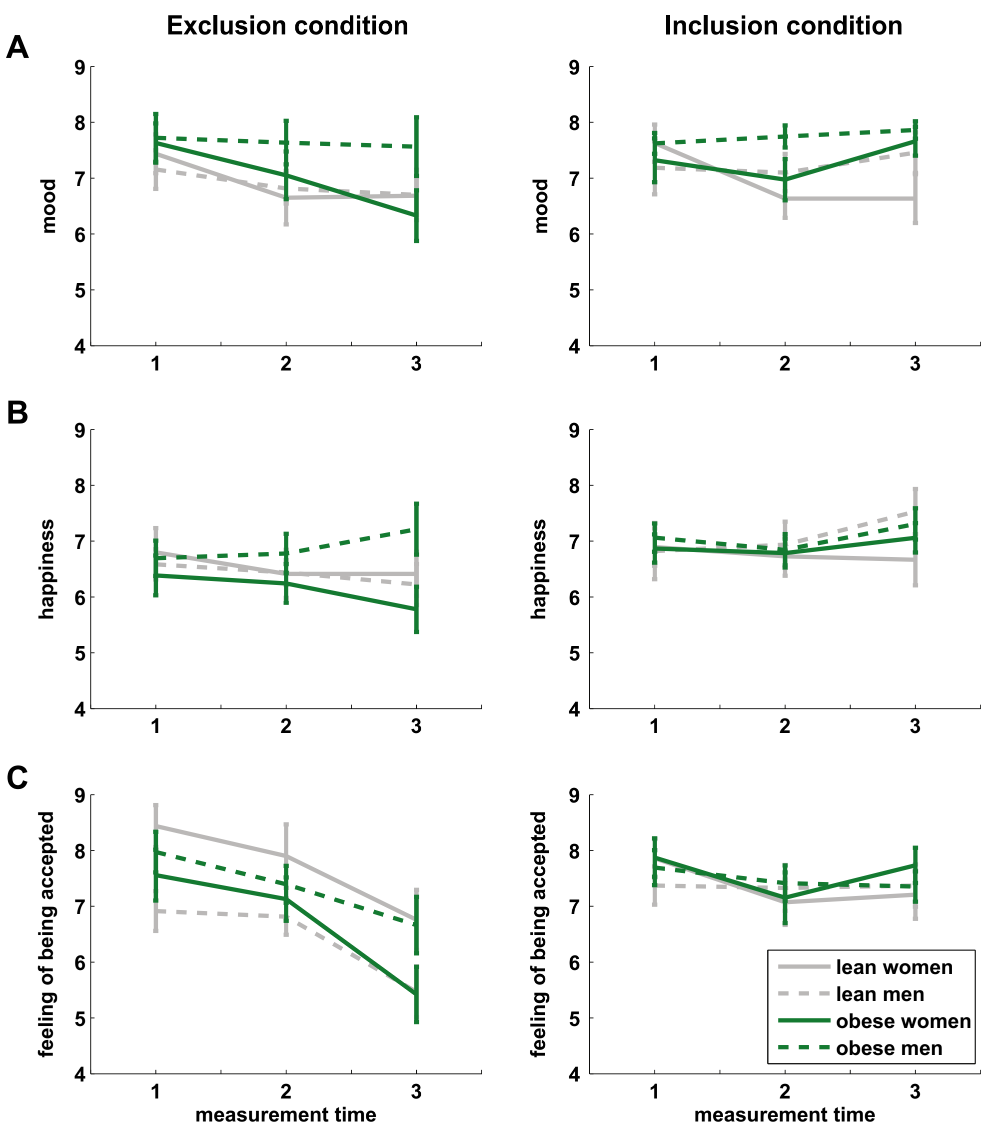

Fig. 2 Visual analogue scales. Values represent means ± *SE*s. The rows show changes in (**A**) mood [Time × Condition × Sex × Weight interaction, $F(2, 206) = 3.166$, $\varepsilon = .931$, $p = .048$, $\eta_p^2 = .030$], (**B**) happiness [Time × Condition × Sex × Weight interaction, $F(2, 206) = 3.689$, $\varepsilon = .917$, $p = .030$, $\eta_p^2 = .035$], and (**C**) feelings of being accepted [Condition × Sex × Weight interaction, $F(1, 103) = 4.657$, $p = .033$, $\eta_p^2 = .043$] over time in the exclusion (left) and inclusion (right) conditions

ball-tossing game felt less accepted than women with obesity and lean men who continued to be included in the game (women with obesity exclusion, $M = 6.68$, $SD = 1.4$; inclusion, $M = 7.67$, $SD = 1.3$, $p = .047$; lean men exclusion, $M = 6.38$, $SD = 1.2$; inclusion, $M = 7.35$, $SD = 1.3$, $p = .055$). Additionally, in the exclusion condition, women with obesity felt less accepted than lean women (women with obesity, $M = 6.68$, $SD = 1.4$; lean women, $M = 7.70$, $SD = 1.6$, $p = .041$; Fig. 2).

Heart rate variability

Social inclusion: Changes from baseline to the first experimental session The analysis of changes from baseline to the first session for *mean HR* showed a significant main effect of time [$F(1, 107) = 43.209$, $p < .001$, $\eta_p^2 = .288$]. All participants had a decrease in mean HR in the first experimental session ($M = 78.93$, $SD = 9.7$) relative to baseline ($M = 76.91$, $SD = 9.5$).

The analysis of the *HF power n.u.* revealed a significant main effect of time [$F(1, 107) = 45.322$, $p < .001$, $\eta_p^2 = .298$]. A Time × Sex × Weight interaction [$F(1, 107) = 8.926$, $p = .003$, $\eta_p^2 = .077$] showed that all groups but men with obesity had a significantly increase from baseline to the first session (lean women baseline, $M = 34.97$, $SD = 21.8$; first session, $M = 43.72$, $SD = 20.4$, $p = .001$; women with obesity baseline, $M = 32.31$, $SD = 21.1$; first session, $M = 50.71$, $SD = 16.6$, $p < .001$; lean men baseline, $M = 22.87$, $SD = 13.0$; first session, $M = 29.53$, $SD = 16.2$, $p = .013$; men with obesity baseline, $M = 32.33$, $SD = 19.5$; first session $M = 33.22$, $SD = 17.5$, $p = .739$). In a second step, differences in HF power n.u. increase between groups were analyzed. The analysis showed a main effect of sex [$F(1, 107) = 14.059$, $p < .001$, $\eta_p^2 = .116$] and a Sex × Weight interaction [$F(1, 107) = 8.926$, $p = .003$, $\eta_p^2 = .077$], indicating a stronger increase in HF power n.u. in women with obesity ($M = 18.40$, $SD = 13.9$) than in men with obesity ($M = 0.89$, $SD = 10.8$, $p < .001$), as well as in lean women ($M = 8.75$, $SD = 15.5$, $p = .008$; Fig. 3). The inclusion of the covariates social insecurity, negative body image, and perceived overload in separate analyses did not change the significance of the main effects nor of the interactions.

Social exclusion: Changes from the first to the second session The analysis of changes from the first to the second session showed for *mean HR* a significant Time × Weight interaction [$F(1, 103) = 11.701$, $p = .001$, $\eta_p^2 = .102$]. Lean participants had a general decrease in mean HR, independent of condition (1st session, $M = 76.93$, $SD = 10.5$; 2nd session, $M = 76.02$, $SD = 10.1$, $p = .014$), and participants with obesity showed an increase in mean HR (1st session, $M = 76.86$, $SD = 8.4$; 2nd session, $M = 77.71$, $SD = 8.8$, $p = .021$).

The analysis of *HF power n.u.* showed a main effect of time [$F(1, 103) = 15.963$, $p < .001$, $\eta_p^2 = .134$] and an interaction of Time × Condition × Sex × Weight [$F(1, 103) = 5.306$, $p = .023$, $\eta_p^2 = .049$]. Women with obesity that were excluded in the second session exhibited a significantly higher response ($M = 55.1$, $SD = 14.3$) than did excluded men with obesity ($M = 29.8$, $SD = 17.3$, $p < .001$), excluded lean women ($M = 41.9$, $SD = 22.3$, $p = .040$), included women with obesity ($M = 37.3$, $SD = 16.5$, $p = .006$), and included lean women ($M = 41.8$, $SD = 18.7$, $p = .040$). In the inclusion condition, all groups but lean women showed a decrease of HF power n.u. over time (lean women 1st session, $M = 40.4$, $SD = 20.1$; 2nd session, $M = 41.8$, $SD = 18.7$, $p = .601$; women with obesity 1st session, $M = 44.8$, $SD = 19.6$; 2nd session, $M = 37.3$, $SD = 16.5$, $p = .008$; lean men 1st session, $M = 34.8$, $SD = 19.6$; 2nd session, $M = 25.0$, $SD = 13.2$, $p = .001$; men with obesity 1st session, $M = 34.5$, $SD = 15.4$; 2nd session, $M = 29.4$, $SD = 18.4$, $p = .089$). The inclusion of the covariates social insecurity, negative body image, and perceived overload in separate analyses did not change the significance of the main effects nor of the interactions.

Phasic heart period changes from the first to the second Cyberball session: Social inclusion versus social exclusion

The analysis of the event-related changes between consecutive IBIs in the first and second sessions showed significant main effects of IBI [$F(3, 309) = 10.030$, $\varepsilon = .857$, $p < .001$, $\eta_p^2 = .089$] and condition [$F(1, 103) = 8.079$, $p = .005$, $\eta_p^2 = .073$], as well as a Time × IBI × Condition × Weight interaction [$F(3, 309) = 2.959$, $p = .033$, $\eta_p^2 = .028$]. In the second session of the experiment, post-hoc tests revealed that participants with obesity exhibited stronger cardiac slowing in IBI0 and IBI+1 in the inclusion condition (IBI0, $M = 9.28$, $SD = 10.9$; IBI+1, $M = 6.91$, $SD = 9.6$) than did participants with obesity in the exclusion condition (IBI0, $M = 4.14$, $SD = 5.0$, $p = .040$; IBI+1, $M = 2.06$, $SD = 4.1$, $p = .082$). Lean participants exhibited stronger cardiac slowing in IBI+1 and IBI+2 in the inclusion condition (IBI+1, $M = 8.36$, $SD = 13.8$; IBI+2, $M = 6.07$, $SD = 12.6$) than did the lean participants in the exclusion condition (IBI+1, $M = 0.79$, $SD = 10.9$, $p = .007$; IBI+2, $M = 0.02$, $SD = 4.3$, $p = .027$). Additionally, all groups but excluded individuals with obesity showed a significant increase in heart period length from IBI-1 to IBI0 in the second part of the experiment (lean individuals inclusion IBI-1, $M = 3.39$, $SD = 10.9$; IBI0, $M = 8.22$, $SD = 14.6$, $p = .013$; lean individuals exclusion IBI-1, $M = 0.68$, $SD = 14.1$; IBI0, $M = 4.97$, $SD = 7.9$, $p = .032$; individuals with obesity inclusion IBI-1, $M = 2.58$, $SD = 8.5$; IBI0, $M = 9.28$, $SD = 11.5$, $p = .001$; individuals with obesity exclusion IBI-1, $M = 2.21$, $SD = 4.9$; IBI0, $M = 4.14$, $SD = 5.0$, $p = .322$; Fig. 4).

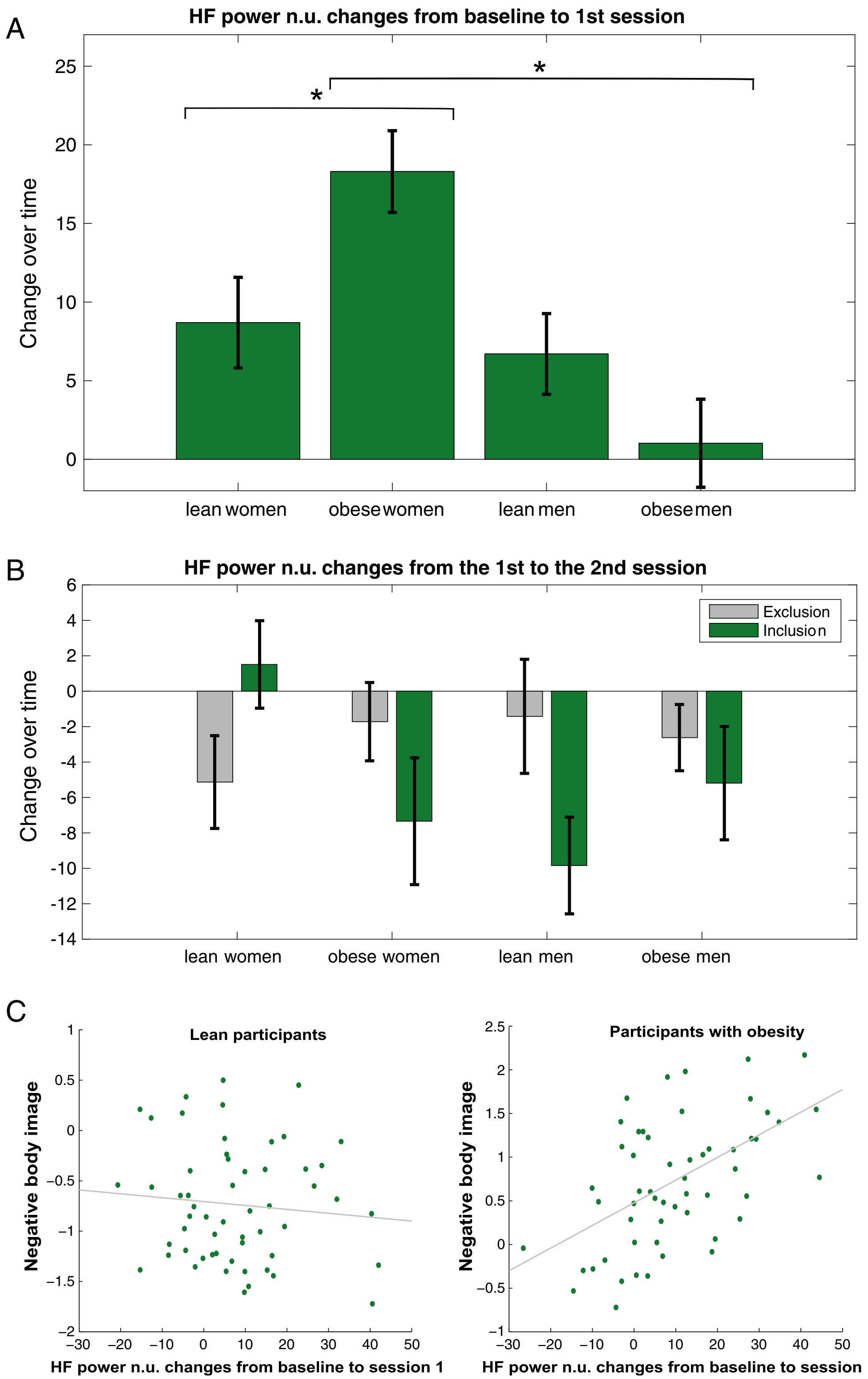

Fig. 3 Parasympathetic activity. Values represent means ± *SE*s. (**A**) Changes in HF power normalized units (n.u.) from baseline to the first experimental session show a significantly stronger increase in women with obesity when confronted with a social interaction [Sex × Weight interaction, $F(4, 107) = 8.926$, $p = .003$, $\eta_p^2 = .077$]. (**B**) Changes in HF power n.u. from the first to the second experimental session, showing that all groups but lean women showed a decrease in HF power n.u. over time in the inclusion condition [Time × Condition × Sex × Group interaction, $F(1, 103) = 5.306$, $p = .023$, $\eta_p^2 = .049$]. (**C**) In participants with obesity, changes in HF power n.u. were correlated with negative body image ($r = .52$, $n = 56$, $p < .01$)

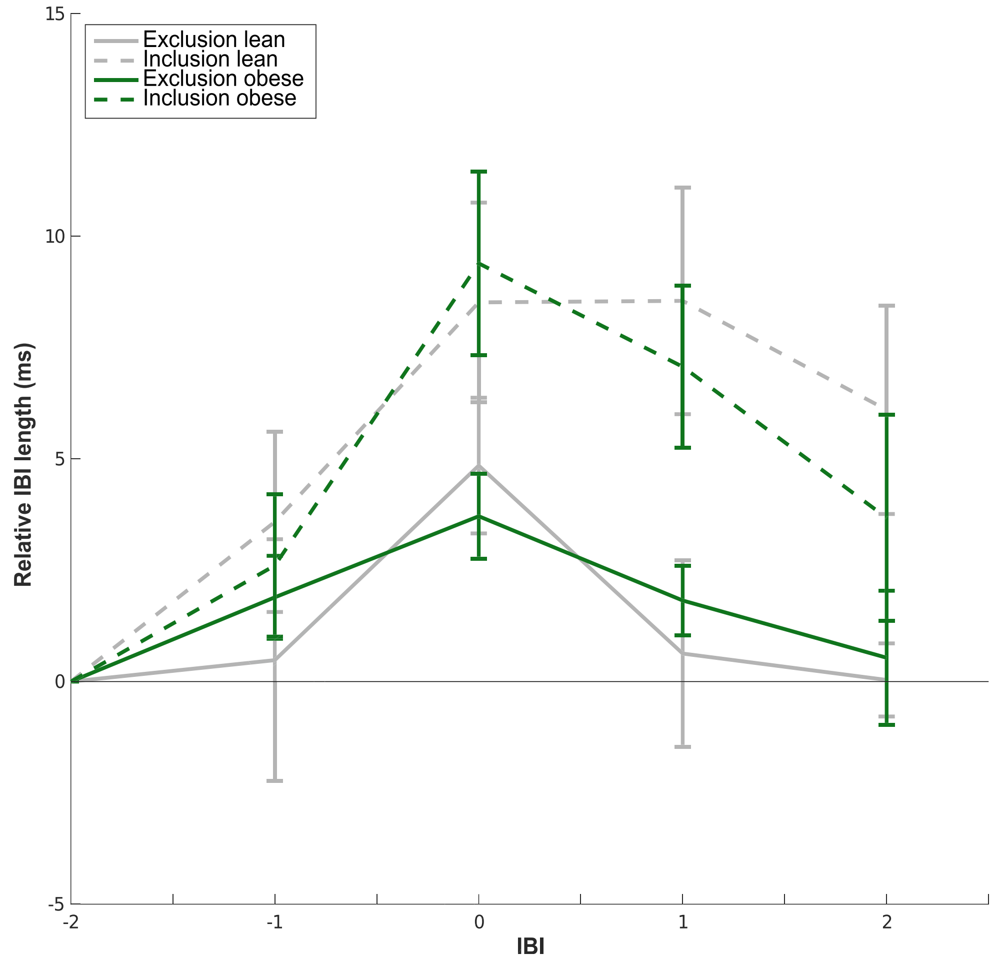

Fig. 4 Phasic heart period changes. Values represent means ± *SE*s. Participants with obesity exhibited significantly stronger cardiac slowing in IBI0 in the inclusion than in the exclusion condition. Furthermore, excluded individuals with obesity are the only group without a significant increase from IBI-1 to IBI0 [Time × IBI × Condition × Group interaction, $F(3, 309) = 2.959$, $p = .033$, $\eta_p^2 = .028$]

Trait influences on affective response and parasympathetic activity

To examine the possible influence of trait variables on affective responses during social interaction, correlation coefficients were calculated for the changes in mood, happiness, and the feeling of being accepted from baseline to the last session, as well as for social insecurity, negative body image, and perceived overload. In the lean group, happiness after exclusion was negatively correlated with social insecurity [$r(27) = -.41$, $p = .032$]. In the excluded group with obesity, negative correlations between mood and social insecurity [$r(28) = -.48$, $p = .009$] and happiness and negative body image [$r(28) = -.38$, $p = .048$] were found. In the included group with obesity, mood was negatively correlated with social insecurity [$r(28) = -.43$, $p = .022$].

To assess the influences of trait variables on parasympathetic activity during social interaction, correlation coefficients were calculated for HF power n.u., social insecurity, negative body image, and perceived overload. The analysis of the changes from baseline to the *first session* showed in the lean group no significant correlations between HRV parameters, state, and trait characteristics. In the group with obesity, however, a significant positive correlation was found between the changes in HF power n.u. and negative body image [$r(56) = .52$, $p < .001$; Fig. 3]. The correlation coefficients of the association of HF power n.u. changes and negative body image were significantly different between the lean group and the group with obesity (Fisher's *r*-to-z transformation, $z = -3.45$, $p < .001$).

The analysis of the changes from the first to the *second session* showed in the excluded lean group, the included lean group, and the excluded group with obesity no significant correlations between HRV parameters and state and trait characteristics. The analysis of the included group with obesity revealed a significant positive correlation between the changes of HF power n.u. and negative body image [$r(28) = .46$, $p = .015$].

We found no associations between the trait variables and phasic heart period changes.

Influence of affective responses on parasympathetic activity

To assess the influences of the affect variables on parasympathetic activity during social interaction, correlation coefficients were calculated for HF power n.u. and changes in mood, happiness, and the feeling of being accepted. The analysis of the changes from baseline to the *first session* in the lean group showed no significant correlations between changes in HF power n.u. and changes in affective responses. In the group with obesity, however, a negative correlation was found between the changes of HF power n.u. and changes in happiness [$r(56) = -.26$, $p = .049$].

The analysis of the changes from the first to the *second session* showed no significant correlations between the HRV parameters and affect in the excluded lean as well as in the included and excluded groups with obesity. In the included lean group, we found a significant positive correlation between changes of HF power n.u. and changes in the feeling of being accepted [$r(29) = .42$, $p = .022$].

There were no associations between affective responses and phasic heart period changes.

Discussion

Using the Cyberball paradigm, we investigated differences in affective and cardiac responses to social inclusion and exclusion in individuals with and without obesity. We hypothesized that individuals with obesity would exhibit stronger parasympathetic activation than lean individuals when engaging in a novel, potentially stigmatizing social situation, in which they are included and their weight status is visible.

In our study, all participants but men with obesity showed an increase in parasympathetic activity when engaged in an inclusive social situation relative to a resting baseline. This increase was significantly more pronounced in women with obesity. Other studies found heightened parasympathetic activity to be associated with attention to negatively valenced stimuli, such as threatening animals (Jönsson & Hansson-Sandsten, 2008) or angry facial expressions (Jönsson & Sonnby-Borgström, 2003), as well as during the reception of negative as compared to positive social feedback (Vanderhasselt, Remue, Ng, Mueller, & De Raedt, 2015). In a mother–infant interaction study, mothers exhibited increased parasympathetic activity when their infants displayed distress (Oppenheimer, Measelle, Laurent, & Ablow, 2013). Interestingly, as the infant's distress increased, the mother's PNS activity decreased over the course of the experiment. Since the mothers were instructed not to respond, the results were interpreted as a regulatory process followed by a response mobilization. Likewise, watching other people suffer evokes an increase in PNS activity (Stellar, Cohen, Oveis, & Keltner, 2015).

Butler, Wilhelm, and Gross (2006) provided further support for the role of parasympathetic responses during emotion regulation. In their study, participants reappraising or suppressing their emotional response to a short negative film showed higher PNS activity than passively viewing participants. It can be assumed that effortful regulation of emotions requires heightened levels of attention—to internal and external stimuli. The neurovisceral integration model proposes that increased parasympathetic activity together with increased attention improves the individual's capacity to make effective and rapid responses (Thayer & Lane, 2000, 2009).

According to the aforementioned research, the strong increase in PNS activity from baseline to the first session in women with obesity and with a visible weight status in our study might indicate higher attention to or engagement with the novel and potentially stigmatizing social interaction. A study by Hartung and Renner (2013) found that participants (mainly women) with higher BMI perceive themselves as less socially included and are more sensitive to their actual social inclusion or exclusion status than participants with lower BMI. In a similar vein, women with obesity that were visible during an interaction with another participant, as compared to women with obesity that were invisible, engaged in more friendly behavior during the social interaction. This has been interpreted as a compensatory mechanism in anticipation of prejudice (Miller et al., 1995).

Interpreting increased PNS activity as heightened attention to a novel social situation in women with obesity can be linked to broader theoretical formulations: Pickett and Gardner (2005) proposed an inherent social monitoring system that regulates the level of sensitivity to social information. This monitoring system is adaptive and can be affected by social context or environment. Since humans are dependent on social affiliations, it might have evolved to detect potential threats to belongingness. Consequently, individuals that have a higher need to belong are assumed to show enhanced sensitivity to social cues in order to affiliate and reconnect.

Although we did not find a direct relationship between previous negative social experiences and PNS reactivity in individuals with obesity, we observed an association between negative body image and the changes of parasympathetic activity from baseline to the first session of the Cyberball game in individuals with obesity but not in lean individuals. Importantly, in individuals with obesity but not in lean individuals, negative body image was also highly correlated with social insecurity. Repeated negative social experiences might accumulate over time and result in negative psychological outcomes, such as higher body dissatisfaction (Schwartz & Brownell, 2004; Stunkard & Mendelson, 1967). This effect is more pronounced in individuals who report frequent weight-related teasing and stigmatization (Eisenberg, Neumark-Sztainer, & Story, 2003; Friedman et al., 2005; Myers & Rosen, 1999). In our sample, women with obesity had the highest negative body image, relative to the other groups. During the experimental session, the participant's weight status was continuously visible, which could have provoked higher attention in individuals with obesity and a more negative body image. In line with this interpretation, it has been shown that women with a negative body image perceived social feedback regarding their own body portrait as more negative in comparison with another woman's body portrait, even though the feedback was equal (Alleva, Lange, Jansen, & Martijn, 2014). Furthermore, women with higher BMI and a visible weight status showed greater rejection expectations by a potential dating partner than did women with higher BMI and an invisible weight status (Blodorn, Major, Hunger, & Miller, 2016). Kaiser and colleagues (2006) showed that individuals high in prejudice expectation are more vigilant for subliminal prejudice-related cues. The expectation of being a target of appearance-related prejudice might therefore enhance attention in social interactions. Additionally, the group with obesity also showed a relationship between affective responses and HRV that might further support our interpretation of prejudice expectation: Changes of parasympathetic activity from baseline to the first session were negatively related to changes in happiness. Studies on inter-ethnic interactions showed that the expectation of being the target of prejudice increased negative affect in ethnic minorities (Shelton, 2005).

Further, we hypothesized that during social exclusion individuals with obesity would show parasympathetic withdrawal and that this might be influenced by previous weight-related negative social experience and body dissatisfaction. In this study, we could not confirm this hypothesis. In the exclusion session, only lean women showed a significant reduction of PNS activity relative to the first (inclusion) session. Nevertheless, excluded women with obesity still had the highest parasympathetic activity, as compared to the other excluded groups. On the basis of the literature mentioned above, this may indicate higher attentional engagement or stronger emotion regulation in women with obesity than in the other groups (Butler et al., 2006; Jönsson & Hansson-Sandsten, 2008; Jönsson & Sonnby-Borgström, 2003; Oppenheimer et al., 2013; Vanderhasselt et al., 2015).

In addition to tonic parasympathetic activity, we looked at phasic cardiac responses by analyzing the participants' heartbeats around the confederates' ball tosses. Stronger stimulus-related cardiac slowing indicates higher PNS activity (Gunther Moor et al., 2010). We found that individuals with obesity who were included in the game showed significantly stronger cardiac slowing around the ball throws than did individuals with obesity who were excluded. We found the same (but not significant) pattern in lean individuals. There is substantial evidence that phasic cardiac slowing is more pronounced for motivationally relevant stimuli (Somsen et al., 2000; van der Veen et al., 2004). Jennings and van der Molen (2002) summarized in their review that at the peak of cardiac slowing, anticipatory attention, motor readiness, cognitive load, and energy accumulation are maximized. Balconi, Brambilla, and Falbo (2009) showed increased cardiac deceleration to highly arousing relative to low-arousing stimuli. Higher responses in the inclusion than in the exclusion condition in our study might therefore indicate a higher attentional engagement in this social interaction game.

We found no significant differences in heart period responses between individuals with obesity and lean individuals in the exclusion condition. However, excluded individuals with obesity were the only group without a typical significant increase in heart period length during stimulus occurrence. Previously, we argued (Kube, Schrimpf, et al., 2016) that individuals with obesity might apply coping mechanisms such as psychological disengagement (Crocker & Major, 1989) or avoidance (Puhl & Brownell, 2003) to prevent the detrimental effects of negative social feedback. In line with this, it has been shown that individuals with a history of victimization exhibited blunted skin conductance (Iffland, Sansen, Catani, & Neuner, 2014b) and cardiovascular responses to social exclusion (Newman, 2014). These studies provide evidence that frequent negative social feedback could result in reduced physiological responses to social exclusion, which might be an adaptive strategy that is complementary to psychological disengagement.

Physiologically, more phasic cardiac deceleration should be associated with higher tonic HRV. In our analysis of phasic heart period changes, we did not include all events but only ball tosses between the computer-generated players to avoid interferences with motor preparation or key presses. Phasic heart period changes on this subset of events were not associated with tonic PNS activity. To our knowledge, only one previous study combined the analysis of HRV over a certain time period and phasic heart rate changes during stimulus occurrence (Abercrombie, Chambers, Greischar, & Monticelli, 2008). In their study, they found a relationship between tonic autonomic arousal (elevated mean HR, interpreted as parasympathetic withdrawal) and stronger heart rate deceleration in response to emotional pictures (a marker of parasympathetic activity), which was interpreted as an increased attentional processing. A greater tonic PNS withdrawal was explained as a preparation of the attentional system, which might foster stronger HR deceleration during stimulus onset. However, independent of a relationship between variables, we found higher tonic and phasic PNS activity in inclusionary situations, which might deviate from Abercrombie and colleague's findings.

Finally, we hypothesized that individuals with obesity are more negatively affected by social exclusion than lean individuals. We measured mood, happiness, and the feeling of being accepted prior, between, and after the two sessions. In our study, all participants felt worse, less accepted, and were less happy after an episode of social exclusion than after an episode of social inclusion. These findings are in line with previous studies using the Cyberball or other social exclusion paradigms (see Blackhart et al., 2009; Gerber & Wheeler, 2009). In addition, we found that women with obesity show on the one hand the greatest *decrease* in mood after exclusion but on the other hand also the greatest *increase* in mood after inclusion, which partially confirms our hypothesis. For happiness and the feeling of being accepted, women with obesity and lean men both exhibit a reduction after an episode of exclusion versus after an episode of inclusion. Furthermore, socially excluded women with obesity felt less accepted than socially excluded lean women. Interestingly, decreases in mood and happiness in individuals with obesity after exclusion were boosted by a more negative body image and higher social insecurity.

Only few studies examined negative affect after social exclusion or rejection in individuals with obesity. Crocker, Cornwell, and Major (1993) found that women with overweight attribute ambiguous negative social feedback to their weight and show a more negative affect than do lean women. Moreover, the more women with overweight attributed the negative social feedback to their weight, the higher was their negative affect. Although this study did not directly measure the influence of negative body image, the association between weight attribution and negative affect might be influenced by negative body image. Taken together, these results suggest that body image or social insecurity might enhance negative emotions after negative social feedback in individuals with overweight or obesity.

Moreover, not only women with obesity but also lean men showed a stronger negative affect after social exclusion. It is not clear why this effect was absent in men with obesity. Previous research reported divergent results concerning sex differences in emotional processing and response to social exclusion or rejection. For example, sex differences have been found in neural correlates of emotional processing (Whittle, Yücel, Yap, & Allen, 2011; but cf. García-García et al., 2016, for a meta-analysis of visual emotional stimuli). Women tend to report stronger positive and negative emotion intensity than men (Fujita, Diener, & Sandvik, 1991). With regard to social exclusion experiences, women have been found to report stronger distress after negative social interactions than men (Birditt & Fingerman, 2003). In another study, women exhibited a stronger increase in cortisol level after social rejection than men, but did not differ in self-reported negative affect (Stroud, Salovey, & Epel, 2002). A lack of sex differences in negative affect after social rejection has also been found by other studies (Blackhart, Eckel, & Tice, 2007; Seidel et al., 2013; Stillman et al., 2009). With respect to weight, obesity status has been related to poorer psychosocial outcomes in females but not in males (Barry, Pietrzak, & Petry, 2008; Merten, Wickrama, & Williams, 2008), whereas other studies did not find a sex difference in the relation between obesity and psychological distress (Friedman, Reichmann, Costanzo, & Musante, 2002). Emotional responses to weight-related stigmatization have been found to differ between sexes, showing that stigmatization is not predicting negative affect in males but in females (Puhl & Luedicke, 2012). Other studies did not find sex differences (Almenara & Ježek, 2015; Friedman et al., 2005). Mixed findings on sex and obesity differences in affective response to social exclusion indicate the need for further work on the interaction of sex and weight status in the context of negative social experiences.

In this study, baseline HF-HRV significantly differed between men and women, which is in line with a current meta-analysis on sex differences in autonomic cardiac control (Koenig & Thayer, 2016), reporting greater dominance of parasympathetic activity in females than in males. Interestingly, we did not find any significant baseline differences in HF-HRV between participants with and without obesity. This deviates from other studies that have reported reduced parasympathetic resting-state activity in individuals with obesity relative to normal-weight individuals (e.g., Birch, Duncan, & Franklin, 2012; Monda et al., 2006; Rodríguez-Colón, Bixler, Li, Vgontzas, & Liao, 2010; Tonhajzerova et al., 2008). However, these studies did not control for potential influencing metabolic or cardiovascular alterations to the extent that we did. Participants with pre-existing alterations were not included in our study. Metabolic factors independent of BMI (Poliakova et al., 2012) as well as insulin resistance and inflammation dependent of visceral fat mass (Kaufman, Kaiser, Steinberger, Kelly, & Dengel, 2007) have been shown to influence HRV. In addition, we included participants with and without obesity that reported a comparable hours of sports per week. Nagai and Moritani (2004) found that physical activity is positively associated with resting-state PNS activity in lean children as well as in children with obesity. It is thus conceivable that the absence of group differences in baseline HF-HRV in our study is due to these inclusion and matching criteria.

The present study has several limitations. We did not account for the potential influence of respiration rate on HF-HRV. In some studies, respiration rate has been found to be a confounder in HF-HRV data (Grossman & Taylor, 2007; Penttilä et al., 2001). However, the analysis of HF-HRV uncorrected for respiration rate is sufficient for tasks with comparable demands and spontaneous breathing (Denver, Reed, & Porges, 2007; Grossman & Taylor, 2007). Nevertheless, a potential influence of different respiration rates between groups on the results of HRV cannot be fully excluded in this study. Furthermore, we cannot completely rule out the possibility of obesity-related cardiovascular or respiratory alterations. In other studies, no differences in respiration rate have been found between children with and without obesity (Tonhajzerova et al., 2008) and between adults with overweight, obesity, and morbid obesity (Laederach-Hofmann, Mussgay, & Ruddel, 2000). However, a direct comparison of lean individuals and individuals with severe and morbid obesity indicated a higher respiratory rate in individuals with obesity (Chlif, Keochkerian, Choquet, Vaidie, & Ahmaidi, 2009). In this study, we did not expect higher or lower breathing frequencies between participants and tasks as participants were instructed to sit calmly and not to speak during ECG measurements. All participants reported no diagnosed respiratory or cardiovascular diseases.

Furthermore, the present task design is not able to disentangle emotion regulation from attentional processes. Both are associated with an increase in parasympathetic activity (Butler et al., 2006; Jönsson & Hansson-Sandsten, 2008; Jönsson & Sonnby-Borgström, 2003; Oppenheimer et al., 2013; Stellar et al., 2015; Vanderhasselt et al., 2015). Conversely, other studies did not find a relationship between heightened parasympathetic activity and attention or emotion regulation (e.g., Demaree et al., 2006; Frazier, Strauss, & Steinhauer, 2004; Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000). However, it has been shown that attention and emotion regulation share common neuronal networks (Pessoa, 2008). Moreover, Todd, Cunningham, Anderson, and Thompson (2012) proposed that an individual's affective memory acquired during past experiences habitually biases attention to salient environmental stimuli. Thus, such biased attention might represent a form of emotion regulation. We therefore assume that the specific group differences in HRV found in this study can be interpreted as emotionally biased attention. Additional eye tracking and analysis of eye movement/fixation and pupil dilation data could support this interpretation.

Although trait stress level (perceived overload) did not influence HRV results in this study, we cannot rule out a potential influence of a group difference in stress regulation on HRV. Future studies on social exclusion or social rejection could explicitly assess stress regulation abilities.

Finally, the Cyberball paradigm is a laboratory instrument with little contextual information in which the group interaction is restricted to tossing a ball. Although the paradigm is widely established, it lacks the generalizability to and the reflection of real-life interactions, which are by nature more significant and more complex. Inferences from behavioral and psychophysiological results obtained with the Cyberball paradigm in the lab to real-life interactions must be carefully considered and ideally complemented with more realistic social interaction scenarios.

The results of this study have implications for future studies. Subjective measures such as body image and previous social experiences should be taken into consideration in future studies on obesity. The association between negative body image and heightened parasympathetic activity during social interactions in individuals with obesity indicate that negative body image might have an influence on social functioning. Behavioral interventions for individuals with obesity with a special focus on body image and social insecurity might therefore be promising for an improvement in well-being. In summary, the present findings add to our understanding of how individuals with obesity process social interactions. We show that women with obesity exhibit higher parasympathetic activity during social interactions, which might indicate a higher vigilance in order to quickly detect signs of prejudice and apply adaptive psychophysiological strategies. This might be especially true for individuals with obesity and with a more negative body image.

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