Does it Help to Feel your Body? Evidence is Inconclusive that Interoceptive Accuracy and Sensibility Help Cope with Negative Experiences

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Abstract

In four studies (total $N = 534$), we examined the moderating impact of Interoceptive Accuracy (i.e., IAcc, as measured with the heartbeat counting task) and Interoceptive Sensibility (IS, assessed via questionnaire) on negative affect, following social exclusion or after receiving negative feedback. Results from an integrative data analysis combining the four studies confirmed that the manipulations were successful at inducing negative affect. However, no significant interaction between mood induction (control versus negative affect induction) and interoception on mood measures was observed, and this was true both for objective (i.e., IAcc) and subjective (i.e., IS) measures of interoception. Hence, previous conclusions on the moderating impact of interoception in the relationship between mood induction and self-reported mood were neither replicated nor generalized to this larger sample. We discuss these findings in light of theories of emotion regulation as well as recent concerns raised about the validity of the heartbeat counting task.

Keywords: Social exclusion; Negative affect; Mood; Interoceptive Accuracy; Heartbeat counting task; Interoceptive Sensibility.

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It is assumed that interoceptive abilities help people regulate their negative emotions (e.g., Kever, Pollatos, Vermeulen, & Grynberg, 2015; Pollatos, Matthias, & Keller, 2015). The present research investigated this regulation advantage assumption across four studies by using (1) a large aggregated sample, (2) two inductions of negative mood (i.e., social exclusion and negative feedback), (3) objective and subjective measures of interoceptive capacities, and (4) two affective measures. Below, we provide a short description of interoception and review how it is thought to relate to emotion regulation before testing the 'interoception-as-moderator' hypothesis.

Interoception and its relation to emotion regulation

Definitions of interoception vary in their inclusiveness. The first occurrence of the term can be retrieved in Sherrington's book (1906) where the term "interoception" was first used to refer to the internal area of the body as opposed to the external one called exteroception. As outlined in a recent review of the concept (Ceunen, Vlaeyen, & Van Diest, 2016), the definition of Sherrington excludes temperature and nociception, which are part of a more updated definition (Craig, 2002). In the latter, more inclusive, interpretation of the term, interoception is defined as the "sense of physiological status of all tissues of the body", which is represented at the central nervous system level (Ceunen et al., 2016, p. 10). In particular, the mid-insula is proposed to be the center of interoception, where all the information coming from the receptors are integrated and represented.

Interoception has been considered a critical psychological variable since early theories of emotions (James, 1884). Studies have suggested that interoception is involved in a variety of typical and disordered psychological phenomena ranging from emotion recognition (Pollatos, Kirsch, & Schandry, 2005), emotion regulation (Füstös, Gramann, Herbert, & Pollatos, 2013), and decision making (Werner, Jung, Duschek, & Schandry, 2009) to disorders and diseases such as anxiety (Domschke, Stevens, Pfleiderer, & Gerlach, 2010), pain (Cramer et al., 2018), and eating disorders (Pollatos et al., 2008).

Three central dimensions of interoception have been identified: Interoceptive Accuracy (IAcc), Interoceptive Sensibility (IS), and Interoceptive Awareness (IA) (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015). The present research focuses only on the first two. In Garfinkel's model, while IAcc speaks to objective interoceptive performance, IS refers to a subjective component of interoception. More specifically, IAcc consists in people's ability to perceive their internal (bodily) signals and states, such as heartbeats, hunger and satiety. IA was not considered (nor even known by us) as a variable of interest at the time the present studies were designed, and so no measure was collected allowing to address this third interoceptive dimension.

The most frequently used measure of IAcc is the heartbeat counting task (Dale & Anderson, 1978; Schandry, 1981). In this task, individuals are asked to silently count their heartbeats in their mind, without relying on external cues. They are asked to do so for different time intervals (usually of 25, 35, and 45 seconds) and to report the number of counted heartbeats. Throughout the task, the actual number of heartbeats is recorded, allowing comparisons between the self-reported and objective measures. Interoceptive sensibility is usually assessed using questionnaires that ask individuals to what extent they perceive their internal sensations, such as their heartbeats, hunger, or respiration. The third and last component is interoceptive awareness (IA), which relates to the correspondence between objective and the self-reported ability in perceiving internal sensations. The latter dimension was not considered in the present research.

Past research has concluded that awareness of one's emotional states is necessary for emotion regulation. Izard (2011) stated that emotion knowledge and emotion regulation are two successive steps in the cognitive processing of emotion. These authors propose that an increase in emotion knowledge through normal development or with training improves ability in regulating emotions. A study by Füstös et al. (2013) suggested that people who can better perceive their bodily states rely to a greater extent on a reappraisal strategy that was taught to them instead of relying on less functional coping strategies such as expressive suppression. Another study by Weiss, Sack, Henningsen, and Pollatos (2014) found a positive correlation between IAcc and emotion regulation skills, as measured using the Hannover Self-Regulation Inventory (HSRI; Jäger, Schmid-Ott, Ernst, Dölle-Lange, & Sack, 2012), which evaluates interpersonal disturbances, frustration tolerance and impulse control, identity disturbances, affect differentiation and affect tolerance, and self-esteem. Relatedly, Kever et al. (2015) found a positive relationship between IAcc and self-reported use of reappraisal and suppression as regulatory strategies, as assessed using the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003). The latter authors proposed that individuals with higher IAcc are better able to identify which strategy is likely to be effective in specific contexts. This can include the selection of suppression as a more adaptive strategy when dealing with traumatic events in the short-term.

Interoception as a buffer of social exclusion effects

While the correlational studies discussed above point to a positive association between interoception and emotion regulation strategies, only two experimental studies have examined how interoception moderates the impact of a negative mood induction on people's mood states. Both studies manipulated mood by using a social exclusion induction. First, Werner, Kerschreiter, Kindermann, and Duschek (2013) showed that, relative to individuals with lower interoceptive capacities, individuals scoring higher in IAcc report less negative affect after being socially excluded from a conversation with confederates. Second, Pollatos et al.

(2015) found that, relative to lower IAcc participants, those higher in IAcc report less distress (as measured by the Needs Threat Scale) after being excluded in a Cyberball paradigm. The authors interpreted these findings as revealing a higher ability to cope with stress induced by the experience of ostracism in people scoring higher in IAcc.

The present experiments

The positive influence of interoceptive abilities on emotion regulation is widely assumed. However, as just discussed, only two studies have explored this regulatory role by controlling experimentally the mood induction. As a further concern, these two studies face limitations. First, they only considered social exclusion as a mood induction. Second, they relied on small samples. Third, they did not examine the role of the subjective component of interoception (i.e., IS). Fourth, they assessed IAcc using the heartbeat counting task, whose validity has been questioned in recent studies. In particular, scores derived from this measure have been shown to have low psychometric value (Zamariola, Maurage, Luminet, & Corneille, 2018), and several studies suggest that this task is sensitive to general knowledge about heart rate at rest, instead of or in addition to truly interoceptive processes (e.g., Brener & Ring, 2016; Desmedt, Luminet, & Corneille, 2018; Murphy, Brewer, Hobson, Catmur, & Bird, 2018).

Given the theoretical and practical implications of the assumed regulatory role of interoception, it is important (1) to examine the robustness of previously reported findings, (2) their generalization to other experimental inductions, (3) their generalization to the subjective dimension of interoception (i.e., IS), and (4) their generalization to broader measures of negative affect. Finally, it is important (5) to examine the latter questions in the context of a large sample size, allowing for high sensitivity.

The four studies reported here addressed these questions. The robustness test was achieved by examining the replication of Pollatos and colleagues' (2015) interactive effect between social exclusion and IAcc on participants' responses to a Needs Threat Scale (i.e., a questionnaire measuring participants' sense of belonging, self-esteem, meaningful existence, and mood). Generalization was achieved by assigning participants to an inclusion or an exclusion condition in the Cyberball paradigm in Studies 1, 2, and 4 and, in Study 3, by giving them false negative feedback. It was also achieved by including a measure of subjective interoceptive abilities (i.e., IS), and by using a more general measure of mood (i.e., Positive and Negative Affect Schedule, or PANAS). Whereas IAcc assesses the objective performance component of interoception, IS assesses its subjective side (Garfinkel et al., 2015). And, whereas the Needs Threat Scale is concerned with experiences directly related to ostracism-elicited emotions, the PANAS allows for a broader assessment of participants' mood states.

The following hypotheses were made. First, consistent with research on ego-threat (Baumeister, Heatherton, & Tice, 1993) and social exclusion (Eisenberger, 2012), we predicted more negative emotions in the exclusion and negative feedback conditions than in the control condition (i.e., manipulation check). Second, and more theoretically important for the present research endeavor, we hypothesized, based on previous findings and theorization, that interoception would moderate the effect of social exclusion on mood, such that the negative emotional impact of social exclusion should be lower for individuals with higher IAcc and IS.

Method

Participants

Ninety-nine healthy participants (50 females, 50.5 %, M_{age} = 22.25, *SD* = 4.84) took part in Experiment 1, one hundred fifty-eight participants (118 females, 74.7 %, M_{age} = 21.85, *SD* = 3.52) took part in Experiment 2, one hundred fifty-seven participants (118 females, 75.2 %, M_{age} = 22.24, *SD* = 2.94) took part in Experiment 3, and one hundred and twenty participants (100 females, 83.3 %, M_{age} = 22.60, *SD* = 6.00) were included in Experiment 4. Power analyses were conducted before each experiment using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007) in order to secure enough power for detecting effects. The participants taking part in the four studies were all different individuals. Descriptive statistics of the whole sample and measures used in each experiment are displayed in Table 1. All participants were university students recruited using a Facebook page dedicated to paid studies at a Psychological Science Research Institute. The study received the approval from the Ethics Committee of the Research Institute. Participants signed an informed consent form and were fully debriefed at the end of the experiment. The session lasted for about 30 minutes. Participants received five euros for their participation.[1]

Cyberball (Experiment 1, 2 & 4). This ball-tossing game was administered in order to induce a short episode of ostracism (Williams, Cheung, & Choi, 2000). Participants were told they were going to play a game on the Internet with two other students. The Cyberball game was presented as a visual imagination task, in which participants had to form a mental picture of the people and the situation they were in. The Cyberball started with one of the "players" throwing the ball to the participant who had to click with the mouse on the icon of a chosen player to pass the ball. In the exclusion condition, after receiving the ball twice, the participant was not involved anymore in the game by the other two players who kept throwing the ball to each other. In the inclusion condition, the participant received the ball about 33% of the time. The game lasted for about five minutes, with a total of 30 throws for each condition.

Negative feedback manipulation (Experiment 3). Participants were asked to write an essay on the topic of the last exam they studied for. They were told that a software would assess their writing skills, which were predictive of their success at university. Participants had five minutes to write down their essay and, after 30 seconds, they received the feedback. In the negative condition, they were told that their performance was below average and, therefore, their chances of success at the university were very low. In the neutral condition,

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[1] Three of these studies were published but measured IAcc in relation to alexithymia (Zamariola, Vlemincx, Corneille, & Luminet, 2018), and the fourth study also served another research purpose (Zamariola, Luminet, & Corneille, under revision).

participants were told that they were going to receive the feedback only at the end of the experiment.

Heartbeat counting task. Participants' heart rate was assessed using the Polar Watch RS800CX heart monitor. Polar products have been used in previous studies, showing excellent validity and reliability in measuring heart rate and R-R interval data (e.g., Quintana, Heathers, & Kemp, 2012; Weippert et al., 2010). Following the Mental Tracking Method by Schandry (1981), data were recorded during three randomly presented time intervals (25s, 35s, 45s), each separated by a pause of 20s. The Polar ProTrainer5 software was used to extract the actual number of heartbeats. One acoustic start cue was presented at the beginning of each time interval and another acoustic stop cue indicated the end of the interval. Throughout the experiment, participants were instructed to silently count their own heartbeats. At the end of each time interval, participants were asked to verbally report how many heartbeats they had counted. No feedback on the length of the counting phases or the quality of performance was given.

In order to quantify the IAcc from the heartbeat counting task the following formula was used:

$$\frac{1}{3}\sum\left(1-\frac{|recorded\ heartbeats - counted\ heartbeats|}{recorded\ heartbeats}\right)$$

Higher scores indicate higher IAcc.[2]

Body Awareness Questionnaire (Shields, Mallory, & Simon, 1989). The BAQ is an 18-item scale developed to measure self-reported attentiveness to normal non-emotional body processes, i.e., sensitivity to body cycles and rhythms, ability to detect small changes in normal functioning, and ability to anticipate bodily reactions. Examples of items are: “I notice differences in the way my body reacts to various foods”, “I notice distinct body reactions when I am fatigued”, “I notice specific reactions to being overhungry”. Responses to the 18

[2] Another formula has been proposed by Garfinkel et al. (2015), namely: 1–(|actual heartbeats – reported heartbeats|)/((actual heartbeats + reported heartbeats)/2). However, in order to replicate previous findings, we used the formula adopted by Werner et al. (2013) and Pollatos et al. (2015). Of note, the two formulas were highly correlated in the present set of data (i.e., 98%).

items are given on a Likert scale going from 1 (not at all true about me) to 7 (very true about me). The total score is calculated summing the score given at each item after reversing item 10, resulting in one body awareness score. In order to use comparable measures of interoception at the objective and subjective levels, the BAQ was used. Since the heartbeat counting task does not involve emotion perception, but cardiac perception, the aim was to administer a questionnaire that focused as well only on bodily sensations and not emotions. The French version of the questionnaire was used (Shankland, Guillaume, & Carré, 2016).

Positive And Negative Affect Schedule (PANAS) – State version. This 20-item questionnaire (Watson, Clark, & Tellegen, 1988) was used to evaluate general affective states through two affect scales: one, composed of 10 items, measures positive affect (interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, active), while the remaining 10 items measure negative affect (distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery, afraid). Participants were asked to rate each sentence concerning their affect state on that specific moment on a 5-point Likert scale ranging from "not at all" to "extremely". The validated French version of the questionnaire was used (Gaudreau, Sanchez, & Blondin, 2006).

Needs Threat Scale (manipulation check for Experiment 1, 2 & 4). In order to measure the perceived ostracism, the manipulation check developed by the authors of the Cyberball paradigm was used (Williams et al., 2000). The version of the Needs Threat Scale used consisted of 31 items. It included five different subscales: 1) Belonging (12 items, e.g., "I felt poorly accepted by the other participants", reverse-scored); 2) Self-esteem (5 items, e.g., "During the Cyberball game I felt good about myself"); 3) Meaningful existence (5 items, e.g., "I felt non-existent during the Cyberball game", reverse-scored), 4) Control (5 items, e.g. "I felt that I was able to throw the ball as often as I wanted during the game); 5) Mood (8 items of which 4 positive, e.g., "I felt good", and 4 negative, e.g., "I felt bad". The negative items were reverse-scored, such that higher scores indicated more positive mood).

Two additional items measured the feeling of exclusion (“I felt excluded”, “I felt rejected”) and the last item asked to give a percentage of how many throws the participant received, knowing that 33% is the percentage of equal throws. Participants were asked to answer on a Likert scale going from 1 (not at all) to 5 (very much so). Cronbach’s alphas of all measures are displayed in Table 2.

Procedure

After signing the consent form, the PANAS - state was administered to check the affect state prior to affect induction. In a second step, the IAcc was assessed using the heartbeat counting task, while heartbeats were recorded with the Polar watch. Next, in Studies 1, 2, and 4 the Cyberball was administered, whereas in Study 3 the negative feedback manipulation was used. Participants were then asked to complete the Needs Threat Scale (only studies 1, 2, and 4) and, again, the PANAS (post-induction measure). In studies 2, 3, and 4 the BAQ was also administered after the manipulation in order to assess interoceptive sensibility. The BAQ was administered after the mood induction since we suspected that completing the BAQ before the mood induction may have interfered with its effectiveness. The completion of the BAQ is likely to draw participants’ attention to their bodily states, and the latter may have elicited an effective emotion regulation process that (some) participants may not engage in otherwise. Finally, participants were fully debriefed on the real purpose of the study and they received five euros as compensation for their participation.[3]

Results

Preliminary analyses

The mean IAcc score was .65 (*SD* = .18) in Exp. 1, *M* = .64 (*SD* = .18) in Exp. 2, *M* = .61 (*SD* = .19) in Exp. 3, and *M* = .61 (*SD* = .17) in Exp. 4. The mean IS score was 78.25 (*SD* = 14.94) in Exp. 2, *M* = 77.60 (*SD* = 15.48) in Exp. 3, *M* = 78.09 (*SD* = 14.81) in Exp. 4. Correlation analyses between IS and IAcc revealed a weak positive correlation, $r = .148$, $p <$

[3] These studies included also a visual memory task or eye-tracking task with food pictures (these tasks were included between the experimental manipulation and the questionnaires), but these variables are not discussed in the present research article.

.001. Correlation analyses between Mood (Needs Threat Scale) and the pre/post difference in negative affect from the PANAS (NA post – NA pre) showed no significant correlation (r = -.095, p = .065) confirming that, while the Needs Threat Scale specifically refers to mood experienced during social exclusion, PANAS is a more general measure of negative mood.

Main analyses

Four fixed-effects integrated data analyses (IDA; Curran & Hussong, 2009) across all four studies (N = 534) were performed according to Curran and Hussong's (2009) guidelines. As suggested by Curran and Hussong (2009), we chose to conduct fixed-effects rather than random-effects IDAs because of the relatively low number of studies (k = 4). A fixed-effect IDA considers each study as a fixed and known characteristic of each individual observation nested within that study. As a consequence, (i) we restrict our inferences to the specific samples available here rather than back to an infinite population of samples (as would imply to conduct random-effects IDAs), and (ii) every possible between-sample difference is controlled for in the estimation of the effect of interoception on mood.

In each IDA, we regressed the DV (Needs threat Mood subscale or PANAS score) on the experimental condition (contrast coded: -1 = social exclusion; 1 = social inclusion), the grand-mean centered interoception score (for IAcc or IS by subtracting the average interoception score across all studies to each individual interoception score), the study (dummy coded), as well as their interactions. Data as well as the R analysis script are publicly available on Zenodo (https://doi.org/10.5281/zenodo.1292500). We focus first on the results on the Needs Threat Scale (Studies1, 2, and 4; n = 377), as a function of Condition, IAcc and their interaction (IDA1, n = 377) and then as a function of Condition, IS and their interaction (IDA2, n = 278). Second, we report the results on the PANAS (Studies 1, 2, 3, and 4; n = 534), first as a function of Condition, IAcc and their interaction (IDA3, N = 534) and then as a function of Condition, IS and their interaction (IDA4, n = 435). Given the design and the sample sizes, with a statistical power of $(1 - \beta) = .95$, and a bilateral α of .05, we were able to detect effect sizes respectively as small as Cohen's f^2 = .021 (IDA1), .028 (IDA2), .015 (IDA3), and .018 (IDA4), which correspond to small effect sizes according Cohen's norms (1988). Note that this is a conservative estimate as we did have, based on the previous literature, directional hypotheses.

In order to test our two hypotheses (one of which - the main effect hypothesis - is a manipulation check), frequentist and Bayesian analyses were performed. The data were analyzed using the 'aov' and 'anovaBF' functions in R (R Development Core Team, 2017; from the R package 'BayesFactor', Morey, Rouder, & Jamil, 2015) for the frequentist and Bayesian analyses, respectively. We report the Bayes factors associated with models comparison made in the frequentist analyses. We report Bayes Factors in addition to the frequentist analyses for two reasons (for a more detailed description of the use of Bayes Factors in psychological sciences, see Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011). First, since the Bayes Factor allows the comparison of the probability of an empirical observed statistic when the null-hypothesis is true to the probability of this statistic when the alternative hypothesis is true, it allows *supporting* (rather than merely not rejecting) the null-hypothesis. Second, the Bayes Factor (for a given statistic) depends on the sample size and will therefore be conclusive only with sufficient statistical power. The Bayes factors in favor of the alternative hypothesis (or BF10) are presented when the conventional p-value of .05 is encountered. The Bayes factors in favor of the null hypothesis (or BF01) are reported when the p-value is above this threshold.

Assuming a prior equiprobability of the null and the alternative hypotheses, the BF01 reflects the relative likelihood that the null hypothesis is true as compared to the alternative hypothesis. For example, a BF01 of 8 can be interpreted as the fact that the null hypothesis is eight times more likely than the alternative hypothesis. Although there is not strict BF threshold, a BF that is between 1/3 and 3 is typically seen as "inconclusive" or of "anecdotal evidence" (e.g., Jeffreys, 1961; Wagenmakers et al., 2011). As depicted in Figure 1, the statistical conclusions for the individual studies were neither conclusive according to this rule of thumb nor consistent across studies. For this reason, but also for allowing enhanced sensitivity, we conducted and reported the IDAs aggregating data from the four studies.

Needs Threat Scale

***IDA1:* IAcc and Needs Threat Scale.** The mood scores obtained with the Needs Threat Scale were submitted to a General Linear Model (GLM) using the experimental condition (inclusion vs. exclusion), the grand-mean centered IAcc score, the study, as well as their interaction as predictors. The main effect of the experimental condition was observed, $F(1, 364) = 121.588$, $p < .001$, $\eta^2_p = .244$, BF10 > 1000. In support to our first hypothesis, mood was more positive for participants in the social inclusion ($M = 3.85$, $SD = .59$) than in the social exclusion ($M = 3.12$, $SD = .71$) condition. No main effect of IAcc was observed, $F(1, 364) = .01$, $p = .95$, $\eta^2_p = .00$, BF01 = 8.24. The linear relation between IAcc and mood was not different from 0, $b = -.002$, 95% Confidence Interval (CI)[-.374, .369]. Contrary to our second hypothesis, the critical Condition × IAcc interaction did not reach conventional significance threshold, $F(1, 364) = 3.77$, $p = .053$, $\eta^2_p = .017$, BF01 = 1.60. Within a Bayesian framework, neither the alternative nor the null hypothesis did however receive consequential support. The test of the moderating role of IAcc on the impact of social exclusion on mood was therefore inconclusive. Neither the remaining 'study' main effect nor its interactions were observed.

***IDA2:* IS and Needs Threat Scale.** The mood scores obtained with the Needs Threat Scale were submitted to a GLM using the experimental condition (inclusion vs. exclusion), the grand-mean centered IS score, the study, as well as their interaction as predictors. The main effect of condition was observed, $F(1, 270) = 93.65$, $p < .001$, $\eta^2_p = .252$, BF10 > 1000. As expected, mood was more positive for participants in the social inclusion ($M = 3.87$, $SD = .57$) than in the social exclusion ($M = 3.14$, $SD = .70$) condition. A small though significant main effect of IS was observed, $F(1, 270) = 6.25$, $p = .013$, $\eta^2_p = .030$, BF10 = 0.98. The linear relation between IS and Mood was slightly greater than 0 *b* = .007, 95% CI [.002, .011], although the test is inconclusive within a Bayesian Framework. More importantly, the Condition × IS interaction was not observed, $F(1, 270) = .28$, $p = .60$, $\eta^2_p = .008$, BF01 = 6.33. None of the remaining main effect or interactions were observed.

PANAS: Negative Affect

IDA3: **IAcc and PANAS.** Changes in negative affects measured with the PANAS (i.e., NA post – NA pre) were submitted to a GLM using the experimental condition (inclusion vs. exclusion), the grand-mean centered IAcc score, the study, as well as their interaction as predictors. The main effect of Condition was observed, $F(1, 518) = 14.86$, $p < .001$, $\eta^2_p = .031$, BF10 = 64.55. As expected, negative affects were induced to a lower extent for participants in the social inclusion (*M* = -.56, *SD* = 3.15) than in the social exclusion (*M* = .67, *SD* = 4.47) condition. No main effect of IAcc was observed, $F(1, 518) = .034$, $p = .874$, $\eta^2_p = .002$, BF01 = 10.16. The linear relation between IAcc and mood was not different from 0 *b* = .131, 95% CI [-1.635, 1.897]. Importantly, the critical Condition × IAcc interaction was not observed, $F(1, 518) = .144$, $p = .705$, $\eta^2_p = .003$, BF01 = 5.69.

IDA4: **IS and PANAS:** The negative affects scores obtained with the PANAS (i.e., NA post – NA pre) were submitted to a GLM using the experimental condition (inclusion vs. exclusion), the grand-mean centered IS score, the study, as well as their interaction as predictors. The main effect of Condition was observed, $F(1, 423) = 13.87$, $p < .001$, $\eta^2_p = .036$, BF10 = 40.34. The induction of negative affects was weaker for participants in the social inclusion condition (*M* = -.49, *SD* = 3.30) as compared to participants in the social exclusion condition (*M* = .89, *SD* = 4.77). The main effect of IS was not observed, $F(1, 423) = .021$, $p = .886$, $\eta^2_p = .002$, BF01 = 9.15. The linear relation between IS and mood was not different from 0, *b* = -.001, 95% CI [-.026, .024]. The critical Condition x IS interaction reached the significance threshold, $F(1, 423) = 4.011$, $p = .046$, $\eta^2_p = .015$, BF10 = 1.40, though the test was inconclusive within the Bayesian Framework. To further decompose the interaction, we examined the simple slopes of the relation between the negative affect and IS separately for the exclusion and the inclusion conditions. Results were inconclusive as IS did not predict change in negative affects, neither in the exclusion (b = .024, $t(210)$ = 1.30, p = .20) nor in the inclusion (b = -.030, $t(210)$ = -1.84, p = .07) condition.

Complementary analyses

Our sample being predominantly female, we conducted exploratory analyses to check the presence of a potential gender effect. The triple condition x interoception x gender interaction was observed once in the third IDA, which was furthermore qualified by a fourth way condition × interoception ×gender × study interaction. To further probe this interaction, we conducted the analyses separately for each study and observed a significant condition × interoception × gender interaction only in the third study. Since the impact of gender was found only one time out of the 16 analyses looking for the same psychological phenomenon, it would not be cautious to draw conclusions on gender effects.

As Experiment 3 (N = 157) included also a measure of emotion regulation, namely the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003), the correlation between this measure and IAcc and IS was checked, resulting in a nonsignificant correlation for both interoceptive measures (r = .11, p = .17 for IAcc/Reappraisal; r = .09, p = .27 for IAcc/Suppression; r = .12, p = .13 for IS/Reappraisal; r = -.05, p = .53 for IS/Suppression.

Discussion

The aim of this research was to examine whether IAcc and IS moderate the impact of experiencing negative events on negative affect. To this purpose, four studies were conducted. Contrary to expectations, although the mood induction manipulations proved highly successful, and despite large and sensitive samples, the moderation by interoceptive abilities was at best inconclusive, and this was true both for specific (i.e., Needs Threat Scale) and broader (i.e., PANAS) mood measures, both for the objective (i.e., IAcc) and subjective (i.e., IS) dimension of interoception, and for both experimental inductions of negative affect.

Moreover, the only evidence for a moderation was, if anything, found in a direction opposite to the one predicted, i.e., individuals scoring higher in IS reported more negative affect post social exclusion or negative feedback manipulation.

The literature assumes that higher interoceptive abilities help people cope with the negative emotional consequences of adverse circumstances. In this very large sample, we found no support for this widely held assumption. One could argue that the null findings might not be evidential *per se* but rather constitute a false negative. It should be noted however that this moderating effect was *systematically* rejected in the frequentist framework which means that a false negative would be very unlikely. In the Bayesian framework, it was at best inconclusive and rather the null-effect was *supported* in two of the four types of analysis which were the two analyses conducted on the largest set of participants of the four analyses. Furthermore, by totalizing between 435 and 534 participants in the IDAs, we have 95% chance to reliably observe an effect whose size is as small as $\eta^2 = 0.029$ to 0.0238, which is at the edge between "small effect" and "no effect" according Cohen (1988)'s norms. If the present studies do indeed constitute false negatives, the buffering effect of interoception on the relation between social exclusion and negative mood would be so small that it is negligible.

It is worth highlighting that the present research slightly differs from the original studies presented in the introduction (Pollatos et al., 2015; Werner et al., 2013). First, the sample of the first paper in which participants were excluded from a conversation (Werner et al., 2013) was constituted of an equal number of males and females and a median split analysis was performed in order to compare high versus low interoceptive groups. This previous study also used the ECG technique and, instead of the Cyberball or providing a negative feedback, an exclusion from a real conversation with confederates was implemented. Second, the sample of the paper in which the Cyberball manipulation was used (Pollatos et al., 2015) was constituted of 69 females, whereas males were included as well in the present study. Additionally, the mean IAcc score of this paper was .70, while the average in our sample was .63. The previous paper also used the ECG technique and four time intervals for the heartbeat counting task, while here the Polar watch and three time intervals were used. Lastly, the social exclusion manipulation adopted also pictures of the participants and the players, whereas in the present studies the original version of Cyberball (without pictures) was used. It remains a question for future research and theorization whether these small differences play a significant role in observing or not the predicted regulation advantage effect. More generally, it is possible that individuals with better interoceptive abilities are generally better at regulating negative emotions, but that, in laboratory contexts, they do not have sufficient time to find out the most effective emotion regulation strategy. If so, the regulation advantage hypothesis may be correct, but laboratory settings may not be best suited for validating it.

Alternatively, the lack of support for the predicted interaction may speak to the lack of validity of current theoretical views about interoception, which postulate a positive relationship between interoceptive abilities and the ability to recognize and regulate emotions. Two papers reported the existence of a negative relationship between interoception and alexithymia (Brewer, Cook, & Bird, 2016; Murphy, Brewer, Catmur, & Bird, 2017). Recent research, however, failed to replicate this association (Bornemann & Singer, 2017; Zamariola, Vlemincx, Corneille, & Luminet, 2018) or partially replicated it only when considering a relatively long list of covariates, such as blood pressure, BMI, depression, and anxiety (Murphy et al., 2018).

Relatedly, people with difficulties in identifying feelings may actually be “over-focused” on their bodily sensations (Betka et al., 2018; Longarzo et al., 2015). A confirmation of this different view of the link between bodily and emotional awareness can be found in the literature on interoception and anxiety, in which a positive correlation was found between interoceptive accuracy and anxiety scores, indicating that more anxious individuals are more aware of their heartbeats and show good cardiac awareness (Dunn et al., 2010; Pollatos, Traut-Mattausch, Schroeder, & Schandry, 2007). Therefore, it might be that the direction of the relationship between interoception and emotion regulation is reversed at some level, up to the point that paying too much attention to bodily signals may predict disordered emotion recognition and regulation. This view was recently supported in a study in which the relationship between interoceptive sensibility and anxiety was mediated by alexithymia: individuals with anxiety trait reported both greater interoceptive sensibility and higher alexithymia (Palser et al., 2018). Research on interoception and pain regulation provides a similar point of view: focusing on pain does not help to regulate this uncomfortable feeling, while distraction from body signals might be more beneficial (Cramer et al., 2018; Mehling et al., 2009; Pollatos, Füstös, & Critchley, 2012). This line of research highlights that a mindful attitude towards bodily sensations and pain might be helpful for decreasing pain perception, whereas simply focusing on somatic symptoms is related to rumination, catastrophizing, and somatization. We may speculate that, since social pain has been linked to physical pain (Eisenberger, 2012), focusing on the perceived pain during social exclusion has detrimental effects instead of representing an effective aid for emotion regulation. Complementary analyses conducted on the present data, however, revealed no evidence for quadratic interactive effects that would support such reversal hypothesis. Admittedly, however, reversals may be observed at higher levels of interoceptive accuracy or sensibility.

Finally, the absence of robust support for the regulation advantage hypothesis may be due to a lack of validity of the interoceptive measures used here and in previous research. As discussed in the introduction, the validity of the heartbeat counting task, the measure that represents the gold standard for interoceptive accuracy assessment, has been recently questioned by various authors who argued that people performing this task may rely on prior semantic knowledge about heart rate instead of attempting to perceive them (e.g., Desmedt et al., 2018; Ring, Brener, Knapp, & Mailloux, 2015). Recently, Zamariola, Maurage, et al.

(2018) additionally questioned the construct validity of the IAcc scores. In particular, these authors found in a large sample that (1) IAcc scores are essentially driven by under-reporting of heartbeats (due to either a lack of sensitivity or to higher decision thresholds) and that (2) correlation between recorded and reported heartbeats are actually higher for participants showing moderate than high IAcc scores. If the task and scores derived from it have low validity, the regulation advantage hypothesis may be correct, but the lack of validity of the heartbeat counting task would make it unlikely to support it. A more valid measure of interoceptive accuracy may be the six intervals heartbeat discrimination task (see Ring & Brener, 2018), which has participants judging if external stimuli (e.g., acoustic tones) are synchronous with their heartbeat sensations. This method allows controlling individual variability in the timing of perception of heartbeats, as stimuli are presented at six delays after the R-wave, better covering the whole cardiac cycle.

Regarding the IS questionnaire, it faces the usual limitations of self-reports or, as stated above, it might be that high interoceptive sensibility is not related to adaptive emotion regulation, but to difficulties in identifying feelings and anxiety. Since IS was measured after the manipulation, which may influence responses, future studies should also administer the questionnaire on another testing day.

Future studies should examine if the lack of support found here generalizes to other experimental manipulations of social exclusion. It would also be relevant to consider other methods, such as mixed or qualitative methods (e.g., Zamariola, Frost, Van Oost, Corneille, & Luminet, 2019), in order to gain a better insight into the personal experience of people scoring high and low on interoceptive measures. In particular, one limitation of the current (and past) studies is that IAcc was only measured using the heartbeat counting task, which investigates specifically the cardio-vascular functions. New techniques assessing other bodily functions like the water load task (Herbert, Muth, Pollatos, & Herbert, 2012) for gastric interoception are currently under development. Therefore, it may also be possible in future research to assess gastric interoception using this non-invasive technique. Again, the current findings should not be interpreted as demonstrating the absence of a regulatory advantage in people with high interoceptive abilities. However, it invites much caution on the conclusion that this advantage has been reliably demonstrated yet.

Conclusion

In conclusion, we conducted four studies to investigate the potential moderating role of interoceptive accuracy and sensibility on negative affect after experiencing social exclusion or receiving negative feedback on a performance. Findings revealed that, even though manipulations were effective, interoception did not modulate negative affect, such that no support was found to the view that better interoceptive abilities help to regulate negative emotions. Future studies may use different methods to assess interoception. It will also be important to conduct more qualitative studies in order to further explore how people with high and low interoception deal with adverse circumstances in their daily life.

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Table 1: Descriptive statistics of the whole sample.

Study	Sample size	Mean Age *(SD)*	Females (%)	Males (%)	Manipulation	Moderators	DVs
1	99	22.25 (4.84)	50 (50.5)	49 (49.5)	Cyberball	IAcc	Needs Threat Scale and PANAS
2	158	21.85 (3.52)	118 (74.7)	40 (25.3)	Cyberball	IAcc and IS	Needs Threat Scale and PANAS
3	157	22.24 (2.94)	118 (75.2)	39 (24.8)	Negative feedback	IAcc and IS	PANAS
4	120	22.60 (6.00)	100 (83.3)	20 (16.7)	Cyberball	IAcc and IS	Needs Threat Scale and PANAS
Total	534	22.21 (4.31)	386 (72.3)	148 (27.7)			

Note
IAcc = Interoceptive Accuracy
IS = Interoceptive Sensibility
PANAS = Positive and Negative Affect Schedule

Table 2: Cronbach's alphas of the interoceptive accuracy scores and the questionnaires used in the studies.

Studies **Scales**	**1**	**2**	**3**	**4**
IAcc	.93	.89	.93	.84
IS (BAQ)	-	.79	.82	.81
PANAS_PA_PRE	.86	.87	.86	.83
PANAS_NA_PRE	.84	.81	.85	.83
PANAS_PA_POST	.89	.90	.87	.90
PANAS_NA_POST	.87	.83	.88	.88
NTS_Belonging	.82	.87	-	.90
NTS_Self-Esteem	.81	.85	-	.82
NTS_Meaningful Existence	.84	.85	-	.88
NTS_Control	.74	.72	-	.75
NTS_Mood	.83	.85	-	.82
NTS_Feeling Excluded	.89	.94	-	.95

Note
IAcc = Interoceptive Accuracy
IS (BAQ) = Interoceptive Sensibility (Body Awareness Questionnaire)
PANAS = Positive and Negative Affect Schedule
PA = Positive Affect
NA = Negative Affect
PRE = Pre-manipulation
POST = Post-manipulation
NTS = Needs Threat Scale

Figure 1: Frequentist and Bayesian analyses separately for the four individual studies, and the four different predictive models. Rows represent the results for each individual study (as well as an additional aggregating the data across studies); columns represent the results for each individual predictive model. Black whiskers represent the standardized regression coefficients as well as their associated 95% confidence interval. The red-and-white pizza plots represent the Bayes Factors. The red part depicts the BF10 (alternative hypothesis) and the white part depicts the BF01 (null hypothesis). IAcc = Interoceptive Accuracy. IS = Interoceptive sensibility. NA = Negative Affect. BF01 = Bayes Factor in favor of the null hypothesis.