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The effect of 10-week long yoga training on interoceptive abilities: cross-sectional and longitudinal investigation of cardiac and gastric accuracy

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Abstract
Based on their characteristics, it is likely that mind–body techniques develop interoception, the perception of bodily state. Nevertheless, findings on mindfulness, meditation, yoga, and body scan techniques are inconclusive. Additionally, the methodological scope is not exhaustive, neither in terms of the intervention nor the applied measure of interoception. This study investigated for the first time the effect of regular yoga training on cardiac and gastric perceptual ability (measured with the mental heartbeat tracking task and the water load task, respectively). With the involvement of 90 female university students (yoga group n = 57, control group n = 33) we did not find any connection between baseline heartbeat perception score and gastric fullness. Moreover, the applied 10-week-long regular yoga training did not develop any of the measured interoceptive abilities. We conclude that yoga might develop other abilities than these specific sensations. Very probably, the measured cardiac and gastric perceptual abilities do not represent bodily sensations in general. It would be worth to investigate, however, the effect of longer yoga training on interoception.

Keywords Interoception · Interoceptive ability · Mental tracking task · Water load test · Yoga intervention · Hatha yoga

Introduction

Interoception, the perception of the bodily state (Ceunen et al. 2016) is described both as multimodal (Ferentzi et al. 2018) and multidimensional (Garfinkel et al. 2015; Khalsa et al. 2018). Multimodality grasps that interoception covers a wide range of internal channels, i.e. bodily sensations such as pain, tickle, and muscular and visceral sensations (Craig 2002). Multidimensionality is described in various ways (Garfinkel et al. 2015; Murphy et al. 2019; Suksasilp and Garfinkel 2022) but regardless of the authors, questionnaire and behavioral measures of interoception are identified as benchmarks of different interoception dimensions (Garfinkel et al. 2015).

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These measures of interoception investigate different phenomena. While questionnaires cover a wide range of bodily sensations and measure the related beliefs of the participants, behavioral tasks focus on a perceptual ability related to a single modality (e.g. heartbeat perception) or a few aspects of a single modality (e.g. feelings of fullness and discomfort in the stomach). The individual differences approach describes these as measures of past or typical behavior and ability measures, respectively (Cronbach 1949; Ferentzi et al. 2022).

In the literature on interoception, the construct measured with questionnaires is usually called interoceptive sensibility, while the one measured with a behavioral task is called interoceptive accuracy (Garfinkel et al. 2015). It is important to highlight that these labels might be misleading, as they suggest an underlying construct, while empirical studies so far show that neither questionnaires (Desmedt et al. 2022; Vig et al. 2022; Todd et al. 2022), nor behavioral measures are interchangeable (Ferentzi et al. 2018). It is also worth noting that there is no agreement regarding the number of interoception dimensions (Garfinkel et al. 2015; Herbert and Pollatos 2018; Khalsa et al. 2018; Murphy et al. 2019; Suksasilp and Garfinkel 2022).

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Interoception is considered to be related to many important psychological phenomena in the normal, sub-clinical, and clinical domains, such as emotion regulation, alexithymia, and symptoms of depression and anxiety (Khalsa et al. 2018; Köteles 2021a). The topic of developability became popular in parallel with the findings that a higher level of interoception might be beneficial. For example, it might help in emotion regulation (Füstös et al. 2013), and in overcoming social exclusion (Pollatos et al. 2015). Developability, however, is not a new topic in interoception research, as the first methods to measure accuracy were developed from biofeedback procedures (Carroll 1977). With the growing popularity of various mind–body practices (e.g. breathing exercises, yoga, or chi kung) in Western culture, this scientific question has begun to be examined from a new angle, with the possible developmental effect of mind–body techniques representing the "bright side" of interoception (Köteles 2021b). Most of these mind–body approaches include breathing exercises that affect cognitive, emotional, and sensory processing (Homma and Masaoka 2008; Varga and Heck 2017). As the vagus nerve regulates respiration, its transcutaneous stimulation can also effect interoceptive pathways; thus, it might have a therapeutic effect on various conditions (Weng et al. 2021).

Both typical behavior (assessed with questionnaires, called interoceptive sensibility) and interoceptive ability (interoceptive accuracy) are regarded as stable and trait-like; questionnaire scores are, however, more likely to change due to modification attempts (Köteles 2021b). Studies investigating mind–body techniques and interoception also support this notion.

Cross-sectional questionnaire studies (i.e. measures of interoceptive sensibility) found that people practicing mind–body techniques had higher questionnaire scores than the control group. For example, mind–body therapy-experienced people had higher scores on the Multidimensional Assessment of Interoceptive Awareness (MAIA, Mehling et al. 2012) than naive individuals (Mehling et al. 2013). Daubenmier (2005) found women practicing yoga had higher interoception (measured with the Body Awareness Questionnaire, BAQ; Shields et al. 1989) than aerobic exercisers. Delaney and Anthis (2010) showed that those types of yoga interventions that contain more meditative components rather than focusing on postures led to increased body awareness measured by the BAQ.

Longitudinal studies using mind–body approaches to improve interoceptive sensibility show that these interventions are promising. A 2-month long yoga program led to higher interoception measured by BAQ (Impett et al. 2006). Another study found that a 3 month-long contemplative, meditation-based program (ReSource training) led to higher scores on some MAIA subscales (Bornemann et al. 2015). Mehling et al. (2018) also found an increase in MAIA subscale scores after a 12-week-long integrative training that contained mindfulness and yoga elements as well. Fischer et al. (2017), however, found no effect of an 8-week-long smartphone-assisted mindfulness practice on the Interoceptive Awareness Subscale of the Eating Disorder Inventory-2 (Paul and Thiel 2005). There is some evidence that shorter interventions might also develop questionnaire scores. Fissler et al. (2016) found an increase in some MAIA subscale scores after a 3-week long intervention that used practices of Mindfulness-Based Cognitive Therapy among major depression patients.

Cross-sectional studies that investigated interoceptive ability with measures of accuracy, however, did not show any connection between mind–body practice and interoception. During discrimination tasks assessing cardiac interoceptive accuracy, participants have to judge whether a series of external tones are synchronous with their heartbeats (Brener et al. 1993; Wiens et al. 2000). During tracking tasks, participants have to follow their heartbeats with counting (mental tracking) or finger movements (motor tracking) (Schandry 1981; Körmendi et al. 2022). Studies investigating heartbeat perception with discrimination tasks did not find any differences between meditators and non-meditators (Nielsen and Kaszniak 2006; Khalsa et al. 2008). Similar results were revealed by a study that compared long and short-term meditation practitioners and non-meditators using a motor heartbeat tracking task (Melloni et al. 2013).

Studies using longitudinal design show mixed results. The longest intervention study that applied a 9-month-long contemplative mental practice found increased heartbeat perception accuracy assessed with a mental heartbeat tracking task (Bornemann and Singer 2017). A paper about the effect of mindfulness and cardiac interoception introduced four intervention studies; none of them found a change in interoception measured with a mental heartbeat tracking task (Parkin et al. 2013). A paper introduced two studies investigating an 8-week body scan training (Fischer et al. 2017); only one of them found significant change in mental heartbeat tracking scores. Interoception (measured with mental heartbeat tracking task) significantly increased after a biofeedback procedure (i.e. contingent feedback), but did not after other interventions (i.e. non-contingent cardiac feedback, mindfulness practice, and a waiting period with an external focus on interoception) (Meyerholz et al. 2019); these findings, however, were not replicated (Rominger et al. 2021). A 20-min yoga session did not improve interoception assessed with mental heartbeat tracking (Schillings et al. 2021). To sum up, current empirical studies do not provide strong evidence for the developmental influence of mind–body practices in the case of interoceptive accuracy.

As we can see, in the context of mind–body practices, interoceptive accuracy has been usually investigated with heartbeat perception tasks. This is no wonder, as among the behavioral measures of interoception, the most studied internal modality is the cardiac one (Jones 1994), i.e. cardiac accuracy or ability measured with various versions of the heartbeat perception tasks (e.g. Ring & Brener 1992; Schandry 1981; Whitehead et al. 1977). It is an open question whether we can expect any changes in other interoception modalities due to mind–body practices. One related argument is about the generalizability of interoceptive abilities, while the other is related to the developmental effect of mind–body practices.

Related to the topic of generalizability, some authors claim that the cardiac modality is an appropriate model of other visceral modalities (Jones 1994), while others argue that greater accuracy or sensitivity in one area does not necessarily correspond with higher ability in other areas (Vaitl 1996; Ceunen et al. 2013). Recently published theoretical studies emphasize the importance of studies comparing multiple abilities (Suksasilp and Garfinkel 2022; Nord and Garfinkel 2022). Still, there is surprisingly little knowledge about the association of multiple internal modalities. Most of the related studies had mixed findings (Kollenbaum et al. 1996; Steptoe and Noll 1997; Ferentzi et al. 2021) or showed no connection (Ferentzi et al. 2017, 2018; Crucianelli et al. 2022). Two studies found a medium-level correlation between heartbeat perception and gastric sensitivity (Whitehead and Drescher 1980; Herbert et al. 2012), while another study that investigated a relatively large sample ($n = 117$) did not find any significant connection (Ferentzi et al. 2018). There were, however, some methodological differences among the aforementioned studies. Whitehead and Drescher (1980) used the discrimination version of the heartbeat perception task (Whitehead et al. 1977) and compared it to the sensitivity to stomach contractions (Stunkard and Fox 1971). Herbert et al. (2012) used a mental heartbeat tracking task (Schandry 1981) and a water load test (Koch et al. 2000; Jones et al. 2003; Chen et al. 2005). Similarly, the study of Ferentzi et al. (2018) that did not find any connection used a mental heartbeat tracking task (Schandry 1981) and a water load test (Boeckxstaens et al. 2001). There is a report on an association between cardiac and gastric perception (Garfinkel et al. 2017); but as this preliminary report does not reveal any methodological details it is difficult to interpret the results in their complexity.

Thus, studies investigating the relationship between gastric and cardiac interoceptive abilities show mixed results and need further investigation. It is important to highlight, that gastric interoception is an important modality in its own right. In everyday life, gastric sensations are relatively often in focus, and a better understanding of normal and abnormal gastric sensory mechanisms has great significance (Andresen 2009). Gastrointestinal complaints are prevalent in various conditions; thus it is important to measure and understand gastric interoceptive abilities better (Schulz et al. 2017). This research interest is also expressed by newly developed measures of gastric interoceptive ability (Desmedt et al. 2023).

Although yoga requires attention to focus on the entire body, so far, no studies investigated the effect of regular yoga training on interoceptive abilities. Additionally, to our knowledge, studies with a focus on the development of interoceptive perceptual abilities involved a single modality only. Besides the cardiac modality, we decided to involve the gastric one, to shed more light on the mixed results and to see whether gastric sensation can be developed by regular yoga practice. We investigated the effect of a 10-week long yoga training, believing that a longer than 8-week intervention has a bigger chance of changing interoceptive abilities than a shorter one (Bornemann and Singer 2017; Fischer et al. 2017; Schillings et al. 2021). We found yoga practice a good candidate as it focuses on body sensations in a complex way (Daubenmier 2005; Impett et al. 2006).

Based on the aforementioned studies, we hypothesized that there would be no connection between the cardiac and gastric domains. Furthermore, we expected that the yoga training would lead to an improvement in both interoceptive abilities.

Materials and methods

Participants

The study enrolled 115 female participants. They were all Hungarian university students, studying primarily human or natural sciences. 90 participants remained in the final sample (see the details of the dropout in Fig. 1). Participants' mean age was 21.98 years ($SD = 3.76$) ranging between 18–44. The age of the yoga group ($M = 21.53$, $SD = 2.38$, n = 57) and the control group ($M = 22.76$, $SD = 5.32$, $n = 33$) did not differ significantly in terms of age ($t(39.56) = -1.26$, $p = 0.21$).

Self-declared inclusion criteria of the study were (I) no previous experience with yoga, (II) the intention to maintain current physical activity level during the experiment, (III) not starting new body-focused activities beyond the study, (IV) avoiding yoga practice at home between yoga classes, and (V) no known psychiatric diagnosis.

Before starting the study, participants gave their consent by signing an informed consent form. The study was approved by the Research Ethics Committee of the Faculty of Education and Psychology at ELTE Eötvös Loránd University, Budapest, Hungary.

Design

Beginner-level Hatha yoga courses were announced on the university's online registration platform at the beginning

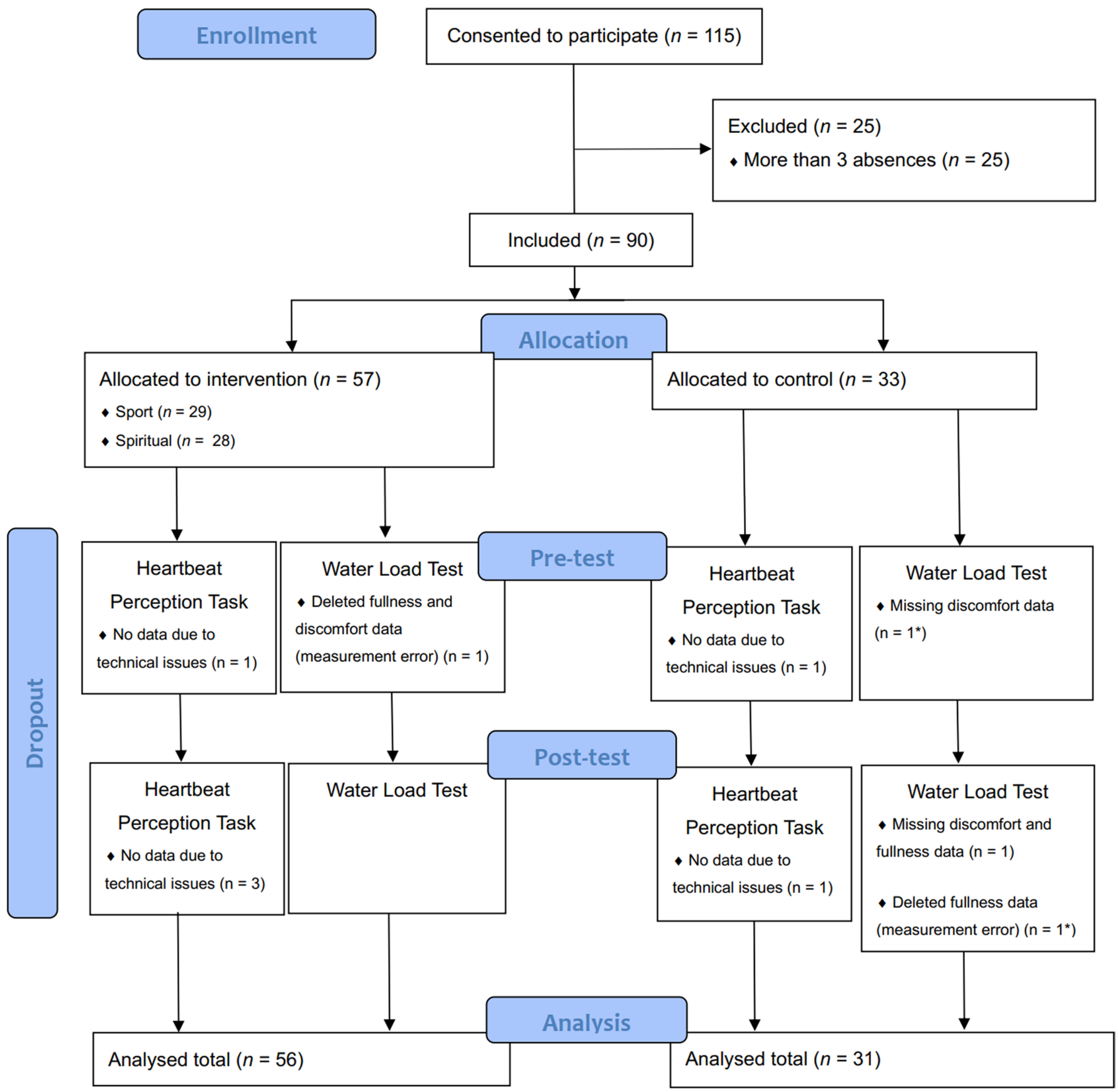

Fig. 1 Number of participants at each time point. *Note*: The participant marked with an asterisk is the same person

of three semesters. As the study was conducted as a practical course at the university, a maximum of 3 absences were allowed. Only female participants were included to avoid any effects of sex differences. A control course was also advertised in the same way. Participants were aware that they would not receive any intervention but take part in the pre and post-measurements only (see below). Both groups got university course credits for their participation. Measurements of cardiac and gastric interoception were conducted one week before and after the yoga program. As this study was part of a larger project, during pre- and post-measurement other measures were also registered (see: Csala et al. 2020, 2021).

Yoga intervention

The 10-week yoga program was held in groups of up to 14 people. Each session lasted for 1.5 h. The classes were led by a certified female yoga instructor (RYT500). They focused on Asana practice, beginning with a brief body and breath focus, and ending with a relaxation period of approximately

8–10 min (Savasana). The class content was based on two yoga books (Iyengar 1991; Satyananda Saraswati 2013).

Participants who signed up for the yoga course were randomly assigned to one of two groups (Sport or Spiritual) and were not aware that there were two different classes with different verbal instructions. The physical aspects of the classes, such as specific movements and posture sequence, were the same for both groups, just like the amount of verbal instruction given during each session. However, while the Sport group received instructions that focused on the physical aspects of yoga practice, the Spiritual group received more holistic instructions that emphasized the overall experience of yoga practice. (For more details see Csala et al. 2020). The average number of absences was 1.35 ($SD=0.88$).

Measurements

Mental heartbeat tracking task

A modified version of Schandry's tracking task (1981) was used to measure heartbeat perception ability (Ferentzi et al. 2017, 2018). Participants were asked to silently count their heartbeats while seated, during three time periods (30, 45, and 100 s, in random order), with a 15-s practice trial before. Participants were not permitted to use techniques that could help in perceiving their heartbeats such as taking their pulse and were instructed to breathe normally. They were encouraged to only count heartbeats they were certain of but were also instructed to take into account weak sensations (for instruction see: Supplementary 1). Heartbeats were recorded with a Polar watch (model RS-400), using a chest strap. Heartbeat perception score was calculated for each trial using the following formula: 1 −|(recorded heartbeats − counted heartbeats)/recorded heartbeats|; which was followed by the calculation of the mean score of the three trials; so the values of the final heartbeat perception scores were ranging between 0 and 1.

Water load test

A modified version of the water load test of Boeckxstaens et al. (2001) was used to evaluate participants' sensitivity to stomach fullness (Ferentzi et al. 2018). Participants consumed the same amount of water every minute (adjusted to their body height in such a way that they should drink as many ml of water as they are tall in cm) for 5 min. Thus, everybody had to drink a total of 5 portions. After each dose of water, participants rated their feelings of both fullness and discomfort on a piece of paper presenting two 10 cm long visual analog scales, thus values ranged between 0 and 100. The difference between their first and fifth ratings was calculated to determine the level of fullness and discomfort (Ferentzi et al. 2018). For participants who did not drink all five doses, the calculation was based on the evaluation made after the last dose drunk. This calculation method was used in the case of pre-test results of 4 participants, 3 of them did not drink the fifth dose and one did not drink the fourth dose. During post-test measurements, 3 participants did not drink the fifth, 2 the fourth, and 1 the third dose. Higher fullness and discomfort scores indicate a greater gastric sensitivity. This study investigates gastric fullness only, as this is what represents the accuracy of perception, comparable to what is assessed by a heartbeat perception task. Results regarding gastric discomfort (which is more about symptom perception) are summarized in Supplementary 2.

Statistical analyses

The statistical analyses were performed using IBM SPSS v.26.0 software. Normal distribution of the baseline variables and change scores from pre- to post-tests of each variable were analyzed by the Shapiro–Wilk test. If the data was not normally distributed, nonparametric tests (Kruskal–Wallis test, Mann–Whitney U test, Kendall's correlation) were run, while in the case of normal distribution parametric tests (Student t-test, Pearson correlation) were run.

As a first step, a possible link between cardiac and gastric interoception was investigated by correlational analyses in the whole sample, and then the possible differences between the two instructions were evaluated. Since the instruction (Sport vs. Spiritual) did not affect the variables involved either when it was investigated with Kruskal–Wallis test (Δ heartbeat perception score: $H(2)=1.54$, $p=0.46$, Δ gastric fullness: $H(2)=0.89$, $p=0.64$), or when the Sport and Spiritual group was compared (Δ heartbeat perception score: $U=310.00$, $p=0.47$, Δ gastric fullness: $U=348.00$, $p=0.48$), the two yoga groups were treated together. For descriptive data and analyses testing the effect of the intervention see Table 1.

Results

The heartbeat perception score did not significantly correlate with gastric fullness ($r=0.13$, $p=0.22$, $n=87$).

There were no significant pre-test differences between the control group and the yoga group in terms of heartbeat perception score, ($t(86)=-0.42$, $p=0.68$) and gastric fullness ($t(87)=1.96$, $p=0.05$).

Effects of the intervention

There was no significant difference in change scores from pre- to post-test measurements ($U=708.00$, $p=0.29$)

Table 1 Descriptive statistics of the assessed variables before and after the intervention

Measurement	Pre-test				Post-test			
	Intervention		Control		Intervention		Control	
	Mean (SD)	*n*	Mean (*SD*)	*n*	Mean (*SD*)	*n*	Mean (*SD*)	*n*
Heartbeat perception task								
Heartbeat perception score	0.417 (0.247)	53	0.443 (0.207)	31	0.420 (0.243)	53	0.409 (0.230)	31
Water load test								
Fullness	39.040 (21.750)	56	30.484 (19.770)	31	42.074 (22.071)	56	36.194 (22.105)	31

between the intervention (*Mdn* = 0.0054) and the control group (*Mdn* = −0.0237).

Change scores of gastric fullness from pre- to post-test did not differ significantly ($U = 935.00$, $p = 0.55$) between the control (*Mdn* = 6.00) and the yoga group (*Mdn* = 3.00).

Unlike in the study of Ferentzi et al. (2018), the participants of this study did not drink all the water that was given to them. Thus, we investigated whether there was a difference between subjects who drank all the water they were given and those who did not. In the case of those who did drink all the water, no significant difference was found in change scores of fullness ($t(33) = 1.42$, $p = 0.16$, $n = 35$) between the intervention ($M = 10.35$, $SD = 20.94$, $n = 17$) and control group ($M = -0.78$, $SD = 24.91$, $n = 18$). For those who did not drink all of the water, a significant difference was found ($U = 352{,}00$, $p = 0.04$, $n = 52$) between the intervention (*Mdn* = 3.00, $n = 39$) and control participants (*Mdn* = 22.00, $n = 13$).

Discussion

Our study investigated the effect of a 10-week-long beginner-level Hatha yoga course on interoceptive abilities. In accordance with our hypothesis, we did not find any connection between cardiac (measured with mental heartbeat tracking task, Schandry 1981) and gastric interoception (i.e. fullness and discomfort, induced with a water load test, Boeckxstaens et al. 2001). Furthermore, no improvement in either cardiac or gastric interoception was observed as a result of yoga practice.

There are surprisingly few studies comparing multiple interoceptive channels (Suksasilp and Garfinkel 2022; Nord and Garfinkel 2022). The present study aims to increase the number of these by focusing on the relationship between interoceptive sensations related to heartbeat and stomach distension. We found the same results as in our previous study (Ferentzi et al. 2018), which used the same method to measure cardiac and gastric interoceptive abilities investigating a similar sample size; but also including male participants. Thus, our present results confirm the previous ones that the ability to perceive bodily events cannot be generalized from one internal channel to the other. These findings also raise some questions about what interoceptive accuracy refers to. If the interoceptive accuracy of various organ systems does not relate, this supports the notion that 'interoceptive accuracy' is a methodological umbrella term of interoceptive ability measures, without an underlying, shared construct. General interoceptive ability might still exist, as the ability to sense various bodily events might be on different levels, resulting (together with unconscious sensation) in a coherent unique feeling of the bodily state (Ferentzi et al. 2018). We hypothesize that none of the interoceptive abilities represents this bodily feeling.

Just like some previous studies using mind–body techniques to develop interoceptive abilities, our study did not find any improvement in the cardiac and gastric domains. There are many possible explanations for this. One of the most plausible is the length of the intervention. Bornemann and Singer, who investigated the effects of contemplative training, used a much longer intervention of 9 months than the present study (Bornemann and Singer 2017). Another paper reported two studies using body scan intervention, and only one of them showed significant change after an 8-week-long intervention (Fischer et al. 2017). All the other studies used a shorter intervention (Parkin et al. 2013; Meyerholz et al. 2019; Schillings et al. 2021; Rominger et al. 2021) or were cross-over studies (Nielsen and Kaszniak 2006; Khalsa et al. 2008; Melloni et al. 2013). However, it should also be pointed out that these investigated methods are very different, despite the obvious overlaps, which are roughly described by the "mind–body" category. As far as we know, this is the first interoception study to investigate the effect of regular yoga training. Another explanation could be the different amount of breathing exercises because as far as we know it could affect the vagus nerve that receives somatosensory afference and is involved in the regulation of the respiratory function (Weng et al. 2021).

It is also possible that we did not choose the right interoceptive domains to investigate in connection with yoga. For example, the investigation of breathing and proprioceptive accuracy might have been more suitable, as the focus on inhalation, exhalation, and posture is particularly emphasized during yoga practices. Nonetheless, neither cardiac nor gastric interoception is therefore associated with the kind of general (or specific) interoceptive accuracy that yoga develops. In line with our results, a recent study shows that cardiac and gastric attention have different neural backgrounds (Haruki and Ogawa 2023).

Studies using interoception-related questionaries, however, show that interoception can be developed by yoga (Rani and Rao 1994) and by other mind–body practices (Fissler et al. 2016; Mehling et al. 2018). It is important to emphasize, however, that past or typical behavior differs substantially from abilities (Cronbach 1949), a difference that is typically described in the interoception literature as sensitivity and accuracy (Garfinkel et al. 2015). This is also supported by a recent study that investigated the effect of an 8-week intervention on either cardiac or gastrointestinal activity (Davey et al. 2023) and found that the latter led to improved interoceptive sensibility (measured by MAIA) and better self-reported emotion regulation. The authors suggest that gastroception might have a distinct contribution to the benefits of body focus. In line with these and with our recent results, we assume this effect works on the self-reported level only. This still could be beneficial, as self-reports are important contributors to well-being (Ferentzi et al. 2019). This is also supported by our previously published results that the applied yoga intervention decreased negative affect (Csala et al. 2020), and increased balance, flexibility, and core muscle strength (Csala et al. 2021). Thus, the applied yoga course was beneficial without developing the investigated interoceptive abilities.

Methodologically, it is interesting that there was no difference in change scores of fullness between the intervention and control group if we investigated those who did drink all the water, but there was if we investigated those who did not although the small number of participants make this result uncertain. This result may be a statistical artifact; alternately, it suggests that the method is not reliable among these subjects. Our (speculative) explanation of this is that those people in the control group who did not drink all the water could be less motivated, and also did not focus on their internal sensations that much during the drinking task, providing unreliable results. The previous study (Ferentzi et al. 2018) investigated a different sample, including undergraduates who had taken sports-related subjects. They may have been more motivated to follow the expectations of the experimenter, i.e. drink all the water given. This phenomenon partly raises questions regarding the currently used method that needs further investigation. If motivation is a significant influencing factor that affects the amount of water consumed, this puts those methods in a new light that use the amount of water drunk as an indicator of interoceptive ability (Koch et al. 2000; Jones et al. 2003; Chen et al. 2005; Herbert et al. 2012).

Finally, it should be noted that the development of interoception was not considered beneficial by all authors. Based partly on theoretical considerations and partly on animal experiments (Moiseeva 1952, 1966), it is assumed that during childhood, the perception of internal bodily mechanisms dominates. This dominance gradually diminishes due to various learned and automatic processes. In adulthood, a significant amount of interoceptive information is filtered out, and according to György Ádám, the alteration of this is not recommended (Ádám 1998); as far as we know, this view of him has never been confirmed directly.

Conclusions for future biology

As far as we know, our study is the first that investigated more than one interoceptive ability in the context of mind–body practice, and the first that investigated the effect of regular yoga practice on interoceptive abilities. Our results support the notion that gastric and cardiac interoceptive accuracy are not related, and indirectly that interoception is not generalizable. Based on this, further studies should investigate how these interoceptive modalities can be improved. Probably a modality-specific way to improve interoception would be more effective. It is also possible that people with specific bodily complaints react to regular yoga practice differently. Finally, it would be worth investigating, the effect of longer yoga training on interoception.

The water load test applied in our study might have its limitations. Stomach size can depend on several factors, only one of which is body height. Future studies should use a more sophisticated method to control this factor. Additionally, the sample of this recent study differed from the previous one (Ferentzi et al. 2018). In this study, some of the subjects did not drink all the water, and several participants stopped drinking water before the 5th dose ($n = 8$). This might be due to the differences in the study context or the motivation level. Future studies should interview the participants about the reasons for not drinking all the given water.

Another limitation of the study is the usage of the mental heartbeat tracking task, whose validity is frequently questioned nowadays (Ferentzi et al. 2022). Our study, however, used strict instruction (Desmedt et al. 2020) which reduces the influence of top-down processes, such as knowledge and expectations.

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Declarations

Conflict of interest All authors declare that there is no conflict of interest.

References

Ádám G (1998) Visceral perception: understanding Internal cognition. Plenum Press, New York

Andresen V (2009) Visceral sensitivity testing. Best Pract Res Clin Gastroenterol 23:313–324. https://doi.org/10.1016/j.bpg.2009.04.007

Boeckxstaens GE, Hirsch DP, Van Den Elzen BDJ et al (2001) Impaired drinking capacity in patients with functional dyspepsia: relationship with proximal stomach function. Gastroenterology 121:1054–1063. https://doi.org/10.1053/gast.2001.28656

Bornemann B, Singer T (2017) Taking time to feel our body: steady increases in heartbeat perception accuracy and decreases in alexithymia over 9 months of contemplative mental training. Psychophysiology 54:469–482. https://doi.org/10.1111/psyp.12790

Bornemann B, Herbert BM, Mehling WE, Singer T (2015) Differential changes in self-reported aspects of interoceptive awareness through 3 months of contemplative training. Front Psychol 5:1504. https://doi.org/10.3389/fpsyg.2014.01504

Brener J, Liu X, Ring C (1993) A method of constant stimuli for examining heartbeat detection: comparison with the Brener-Kluvitse and Whitehead methods. Psychophysiology 30:657–665

Carroll D (1977) Cardiac perception and cardiac control. A Review. Biofeedback Self-Regul 2:349–369

Ceunen E, Van Diest I, Vlaeyen JWS (2013) Accuracy and awareness of perception: related, yet distinct (commentary on Herbert et al., 2012). Biol Psychol 92:426–427. https://doi.org/10.1016/j.biopsycho.2012.09.012

Ceunen E, Vlaeyen JWS, Van Diest I (2016) On the origin of interoception. Front Psychol 7:743. https://doi.org/10.3389/fpsyg.2016.00743

Chen CL, Lin HH, Chen MC, Huang LC (2005) Dyspeptic symptoms and water load test in patients with functional dyspepsia and reflux disease. Scand J Gastroenterol 40:28–32

Craig AD (2002) How do you feel? Interoception: the sense of the physiological condition of the body. Nat Rev Neurosci 3:655–666. https://doi.org/10.1038/nrn894

Cronbach LJ (1949) Essentials of psychological testing. Harper, Oxford

Crucianelli L, Enmalm A, Ehrsson HH (2022) Interoception as independent cardiac, thermosensory, nociceptive, and affective touch perceptual submodalities. Biol Psychol 172:108355. https://doi.org/10.1016/j.biopsycho.2022.108355

Csala B, Ferentzi E, Tihanyi BT et al (2020) Verbal cuing is not the path to enlightenment. Psychological effects of a 10-session hatha yoga practice. Front Psychol. https://doi.org/10.3389/fpsyg.2020.01375

Csala B, Szemerszky R, Körmendi J et al (2021) Is weekly frequency of yoga practice sufficient? physiological effects of hatha yoga among healthy novice women. Front Public Health 9:1549. https://doi.org/10.3389/fpubh.2021.702793

Daubenmier JJ (2005) The relationship of yoga, body awareness, and body responsiveness to self-objectification and disordered eating. Psychol Women Q 29:207–219. https://doi.org/10.1111/j.1471-6402.2005.00183.x

Davey S, Bell E, Halberstadt J (2023) Using targeted visceroception to improve interoceptive sensibility and emotion regulation. New Ideas Psychol 68:100989. https://doi.org/10.1016/j.newideapsych.2022.100989

Delaney K, Anthis K (2010) Is women's participation in different types of yoga classes associated with different levels of body awareness satisfaction? Int J Yoga Ther 20:62–71. https://doi.org/10.17761/ijyt.20.1.t44l6656h22735g6

Desmedt O, Corneille O, Luminet O et al (2020) Contribution of time estimation and knowledge to heartbeat counting task performance under original and adapted instructions. Biol Psychol 154:107904. https://doi.org/10.1016/j.biopsycho.2020.107904

Desmedt O, Heeren A, Corneille O, Luminet O (2022) What do measures of self-report interoception measure? Insights from a systematic review, latent factor analysis, and network approach. Biol Psychol 169:108289. https://doi.org/10.1016/j.biopsycho.2022.108289

Desmedt O, Luminet O, Walentynowicz M, Corneille O (2023) The new measures of interoceptive accuracy: a systematic review and assessment. Neurosci Biobehav Rev 153:105388. https://doi.org/10.1016/j.neubiorev.2023.105388

Ferentzi E, Köteles F, Csala B et al (2017) What makes sense in our body? Personality and sensory correlates of body awareness and somatosensory amplification. Personal Individ Differ 104:75–81. https://doi.org/10.1016/j.paid.2016.07.034

Ferentzi E, Bogdány T, Szabolcs Z et al (2018) Multichannel investigation of interoception: sensitivity is not a generalizable feature. Front Hum Neurosci 12:223. https://doi.org/10.3389/fnhum.2018.00223

Ferentzi E, Horváth Á, Köteles F (2019) Do body-related sensations make feel us better? Subjective well-being is associated only with the subjective aspect of interoception. Psychophysiology 56:e13319. https://doi.org/10.1111/psyp.13319

Ferentzi E, Geiger M, Mai-Lippold SA et al (2021) Interaction between sex and cardiac interoceptive accuracy in measures of induced pain. Front Psychol. https://doi.org/10.3389/fpsyg.2020.577961

Ferentzi E, Wilhelm O, Köteles F (2022) What counts when heartbeats are counted. Trends Cogn Sci 26:832–835. https://doi.org/10.1016/j.tics.2022.07.009

Fischer D, Messner M, Pollatos O (2017) Improvement of interoceptive processes after an 8-week body scan intervention. Front Hum Neurosci. https://doi.org/10.3389/fnhum.2017.00452

Fissler M, Winnebeck E, Schroeter T et al (2016) An investigation of the effects of brief mindfulness training on self-reported interoceptive awareness, the ability to decenter, and their role in the reduction of depressive symptoms. Mindfulness 7:1170–1181. https://doi.org/10.1007/s12671-016-0559-z

Füstös J, Gramann K, Herbert BM, Pollatos O (2013) On the embodiment of emotion regulation: interoceptive awareness facilitates reappraisal. Soc Cogn Affect Neurosci 8:911–917. https://doi.org/10.1093/scan/nss089

Garfinkel SN, Seth AK, Barrett AB et al (2015) Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. Biol Psychol 104:65–74. https://doi.org/10.1016/j.biopsycho.2014.11.004

Garfinkel SN, Manassei MF, Engels M et al (2017) An investigation of interoceptive processes across the senses. Biol Psychol 129:371–372. https://doi.org/10.1016/j.biopsycho.2017.08.010

Haruki Y, Ogawa K (2023) Cardiac and gastric interoceptive awareness have distinct neural substrates. Eneuro 10:0157–22. https://doi.org/10.1523/ENEURO.0157-22.2023

Herbert BM, Pollatos O (2018) The relevance of interoception for eating behavior and eating disorders. In: Tsakiris M, De Preester H (eds) The interoceptive mind. From homeostasis to awareness. Oxford University Press, Oxford, pp 165–186

Herbert BM, Muth ER, Pollatos O, Herbert C (2012) Interoception across modalities: on the relationship between cardiac awareness and the sensitivity for gastric functions. PLoS One 7:e36646. https://doi.org/10.1371/journal.pone.0036646

Homma I, Masaoka Y (2008) Breathing rhythms and emotions. Exp Physiol 93:1011–1021. https://doi.org/10.1113/expphysiol.2008.042424

Impett EA, Daubenmier JJ, Hirschman AL (2006) Minding the body: yoga, embodiment, and well-being. Sex Res Soc Policy 3:39–48. https://doi.org/10.1525/srsp.2006.3.4.39

Iyengar BKS (1991) Light on yoga. The Aquarian Press, London

Jones GE (1994) Perception of visceral sensations: a review of recent findings, methodologies, and future directions. In: Jennings JR, Ackles PK, Coles MGH (eds) Advances in psychophysiology: a research annual, vol 5. Jessica Kingsley Publishers, London, pp 55–191

Jones MP, Hoffman S, Shah D et al (2003) The water load test: observations from healthy controls and patients with functional dyspepsia. Am J Physiol Gastrointest Liver Physiol 284:G896-904. https://doi.org/10.1152/ajpgi.00361.2002

Khalsa SS, Rudrauf D, Damasio AR et al (2008) Interoceptive awareness in experienced meditators. Psychophysiology 45:671–677. https://doi.org/10.1111/j.1469-8986.2008.00666.x

Khalsa SS, Adolphs R, Cameron OG et al (2018) Interoception and mental health: a roadmap. Biol Psychiatry Cogn Neurosci Neuroimaging 3:501–513. https://doi.org/10.1016/j.bpsc.2017.12.004

Koch KL, Hong SP, Xu L (2000) Reproducibility of gastric myoelectrical activity and the water load test in patients with dysmotility-like dyspepsia symptoms and in control subjects. J Clin Gastroenterol 31:125–129. https://doi.org/10.1097/00004836-200009000-00007

Kollenbaum V-E, Dahme B, Kirchner G (1996) 'Interoception' of heart rate, blood pressure, and myocardial metabolism during ergometric work load in healthy young subjects. Biol Psychol 42:183–197. https://doi.org/10.1016/0301-0511(95)05154-6

Körmendi J, Ferentzi E, Köteles F (2022) A heartbeat away from a valid tracking task. An empirical comparison of the mental and the motor tracking task. Biol Psychol 171:108328. https://doi.org/10.1016/j.biopsycho.2022.108328

Köteles F (2021a) Body sensations and emotions. In: Köteles F (ed) Body sensations: the conscious aspects of interoception. Springer International Publishing, Cham, pp 279–314

Köteles F (2021b) The bright side of body sensations. In: Köteles F (ed) Body sensations: the conscious aspects of interoception. Springer International Publishing, Cham, pp 343–364

Mehling WE, Price C, Daubenmier JJ et al (2012) The multidimensional assessment of interoceptive awareness (MAIA). PLoS One 7:e48230. https://doi.org/10.1371/journal.pone.0048230

Mehling WE, Daubenmier J, Price CJ et al (2013) Self-reported interoceptive awareness in primary care patients with past or current low back pain. J Pain Res 6:403–418. https://doi.org/10.2147/JPR.S42418

Mehling WE, Chesney MA, Metzler TJ et al (2018) A 12-week integrative exercise program improves self-reported mindfulness and interoceptive awareness in war veterans with posttraumatic stress symptoms. J Clin Psychol 74:554–565. https://doi.org/10.1002/jclp.22549

Melloni M, Sedeño L, Couto B et al (2013) Preliminary evidence about the effects of meditation on interoceptive sensitivity and social cognition. Behav Brain Funct 9:47. https://doi.org/10.1186/1744-9081-9-47

Meyerholz L, Irzinger J, Witthöft M et al (2019) Contingent biofeedback outperforms other methods to enhance the accuracy of cardiac interoception: a comparison of short interventions. J Behav Ther Exp Psychiatry 63:12–20. https://doi.org/10.1016/j.jbtep.2018.12.002

Moiseeva NA (1952) Interoceptive reflex in embryogenesis. Dokl Akad Nauk SSSR 37:321

Moiseeva NA (1966) Visceral analysis in the early stages of ontogenesis. Vopr Sravn Fiziol Anal 2:128–145

Murphy J, Catmur C, Bird G (2019) Classifying individual differences in interoception: implications for the measurement of interoceptive awareness. Psychon Bull Rev 26:1467–1471. https://doi.org/10.3758/s13423-019-01632-7

Nielsen L, Kaszniak AW (2006) Awareness of subtle emotional feelings: a comparison of long-term meditators and nonmeditators. Emotion 6:392–405. https://doi.org/10.1037/1528-3542.6.3.392

Nord CL, Garfinkel SN (2022) Interoceptive pathways to understand and treat mental health conditions. Trends Cogn Sci. https://doi.org/10.1016/j.tics.2022.03.004

Parkin L, Morgan R, Rosselli A et al (2013) Exploring the relationship between mindfulness and cardiac perception. Mindfulness 5:298–313. https://doi.org/10.1007/s12671-012-0181-7

Paul T, Thiel A (2005) Eating disorder inventory-2, Deutsche version. Hogrefe, Göttingen

Pollatos O, Matthias E, Keller J (2015) When interoception helps to overcome negative feelings caused by social exclusion. Front Psychol 6:786. https://doi.org/10.3389/fpsyg.2015.00786

Rani NJ, Rao PVK (1994) Body awareness and yoga training. Percept Mot Skills 79:1103–1106. https://doi.org/10.2466/pms.1994.79.3.1103

Ring C, Brener J (1992) The temporal locations of heartbeat sensations. Psychophysiology 29:535–545. https://doi.org/10.1111/j.1469-8986.1992.tb02027.x

Rominger C, Graßmann TM, Weber B, Schwerdtfeger AR (2021) Does contingent biofeedback improve cardiac interoception? A preregistered replication of Meyerholz, Irzinger, Withöft, Gerlach, and Pohl (2019) using the heartbeat discrimination task in a randomised control trial. PLoS ONE 16:e0248246. https://doi.org/10.1371/journal.pone.0248246

Satyananda Saraswati S (2013) Four chapters on freedom: commentary on the yoga sutras of sage Patanjali. Yoga Publications Trust, Munger

Schandry R (1981) Heart beat perception and emotional experience. Psychophysiology 18:483–488. https://doi.org/10.1111/j.1469-8986.1981.tb02486.x

Schillings C, Schultchen D, Pollatos O (2021) Effects of a single yoga session on cardiac interoceptive accuracy and emotional experience. Brain Sci 11:1572. https://doi.org/10.3390/brainsci11121572

Schulz A, van Dyck Z, Lutz APC et al (2017) Gastric modulation of startle eye blink. Biol Psychol 127:25–33. https://doi.org/10.1016/j.biopsycho.2017.05.004

Shields SA, Mallory ME, Simon A (1989) The body awareness questionnaire: reliability and validity. J Pers Assess 53:802. https://doi.org/10.1207/s15327752jpa5304_16

Steptoe A, Noll A (1997) The perception of bodily sensations, with special reference to hypochondriasis. Behav Res Ther 35:901–910
Stunkard A, Fox S (1971) The relationship of gastric motility and hunger. A summary of the evidence. Psychosom Med 33:123–134. https://doi.org/10.1097/00006842-197103000-00004
Suksasilp C, Garfinkel SN (2022) Towards a comprehensive assessment of interoception in a multi-dimensional framework. Biol Psychol 168:108262. https://doi.org/10.1016/j.biopsycho.2022.108262
Todd J, Swami V, Aspell JE et al (2022) Are some interoceptive sensibility components more central than others? Using item pool visualisation to understand the psychometric representation of interoception. PLoS ONE 17:e0277894. https://doi.org/10.1371/journal.pone.0277894
Vaitl D (1996) Interoception. Biol Psychol 42:1–27
Varga S, Heck DH (2017) Rhythms of the body, rhythms of the brain: respiration, neural oscillations, and embodied cognition. Conscious Cogn 56:77–90. https://doi.org/10.1016/j.concog.2017.09.008
Vig L, Köteles F, Ferentzi E (2022) Questionnaires of interoception do not assess the same construct. PLoS ONE 17:e0273299. https://doi.org/10.1371/journal.pone.0273299
Weng HY, Feldman J, Leggio L et al (2021) Interventions and manipulations of interoception. Trends Neurosci 44:52–62. https://doi.org/10.1016/j.tins.2020.09.010
Whitehead WE, Drescher VM (1980) Perception of gastric contractions and self-control of gastric motility. Psychophysiology 17:552–558. https://doi.org/10.1111/j.1469-8986.1980.tb02296.x
Whitehead WE, Drescher VM, Heiman P, Blackwell B (1977) Relation of heart rate control to heartbeat perception. Biofeedback Self-Regul 2:371–392. https://doi.org/10.1007/BF00998623
Wiens S, Mezzacappa ES, Katkin ES (2000) Heartbeat detection and the experience of emotions. Cogn Emot 14:417–427. https://doi.org/10.1080/026999300378905