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The duration discrimination respiratory task: A new test to measure respiratory interoceptive accuracy

Alice Bodart | **Sandra Invernizzi** | **Mélanie De Leener** | **Laurent Lefebvre** | **Mandy Rossignol**

Cognitive Psychology and Neuropsychology Laboratory, Department of Psychology and Educational Sciences, University of Mons, Mons, Belgium

Correspondence
Alice Bodart, Cognitive Psychology and Neuropsychology Laboratory, Department of Psychology and Educational Sciences, University of Mons, 20 place du Parc, 7000, Mons, Belgium.
Email: alice.bodart@umons.ac.be

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Abstract

Interoception, which refers to the perception of body's internal state, is implicated in emotional processes and psychopathological disorders. Over the last decades, different tools have been developed to measure interoceptive accuracy, or the ability to accurately perceive physiological signals. Most of these tools have focused on cardiac interoception, but respiratory interoception has been less investigated due to the more complex and less portable equipment required. In this study, we suggest a new duration discrimination respiratory (DDR) task that does not require complex equipment. Using an adaptive staircase procedure, this task aims to determine an individual's ability to detect exhalation longer than their resting reference duration. One hundred and twenty-three healthy subjects completed the DDR task, an interoceptive task of heart rate discrimination, and filled out questionnaires on interoceptive awareness (Multidimensional Assessment of Interoceptive Awareness), alexithymia (Toronto Alexithymia Scale [TAS]), affects (Positive and Negative Affect Scale [PANAS]), and anamnestic. Results demonstrated a good internal consistency (Cronbach's alpha = .93) of the DDR task. On average, subjects needed 99.22% (*SD* = 36.38) of their reference exhalation time in addition to reference exhalation to detect a prolonged exhalation. Higher self-reported fitness levels, not counting during the DDR task and lower difficulty in describing feelings (TAS subscale), predicted higher respiratory discrimination duration. In conclusion, this study demonstrates the utility of the DDR task as a valid measure of interoception.

KEYWORDS

alexithymia, emotion, heart rate discrimination, interoception, respiration

1 | INTRODUCTION

From the James-Lange theory of emotion (James, 1884; Lange, 1885), which suggests that visceral afferent feedback plays a causative role in emotional experiences, the exploration of the connection between emotions and bodily state drives research. These theories postulate that the relative capacity to perceive visceral responses (i.e., interoception) impacts emotional experiences (Critchley et al., 2004). Interoception refers to the processes, both top-down and bottom-up, by which an organism senses, interprets, and combines signals from within itself and from below the skin. These processes involve both conscious and non-conscious levels (Desmedt et al., 2023). Interoception relies on distinct neurobiological pathways that underlie the emotional and bodily components of

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self-awareness (Craig, 2002; Critchley & Garfinkel, 2017; Seth & Tsakiris, 2018).

On the conscious level, Critchley and Garfinkel (2017) suggest three dimensions of interoception: accuracy, sensibility, and awareness. Interoceptive accuracy is the ability to perceive physiological signals accurately, generally measured by a heartbeat counting (HBC) task (Schandry, 1981) or a heartbeat discrimination (HBD) task (Whitehead et al., 1977). Interoceptive sensibility is the subjective perception of the ability to detect or discriminate body signals, measured through self-report questionnaires such as the Multidimensional Assessment of Interoceptive Awareness Questionnaire (MAIA, Mehling et al., 2018). Finally, interoceptive awareness refers to the metacognitive measure of interoception. It can be measured by relating interoceptive scores on HCT or HBT to the participant's degree of confidence in their performance on the task.

Empirical research showed a positive correlation between interoceptive accuracy and emotional experiences (Critchley et al., 2004; Ferguson & Katkin, 1996; Wiens et al., 2000). In other words, individuals categorized as highly interoceptive or "viscerally aware" tend to display more emotional expression and may even experience emotions with greater intensity than individuals with lower interoception. Contrastingly, diminished interoception is observed in alexithymia (Brewer et al., 2016), a condition characterized by difficulties in identifying and describing one's own emotions and distinguishing between feelings and the bodily sensations of emotional arousal (Nemiah, 1976). Moreover, disrupted interoception is involved in several psychiatric disorders (Khalsa et al., 2018), including depression, anxiety disorders (Paulus & Stein, 2010), eating disorders (Herbert, 2020), and autism (DuBois et al., 2016). Khalsa and Lapidus (2016) suggest that disrupted interoception could be a biomarker in psychiatry, by a common mechanism of an error in interoception prediction, giving rise to key symptoms and behaviors. In addition, evidence has shown the usefulness of interoception-based interventions in psychiatric disorders (Khoury et al., 2018). Given the involvement of interoception in mental health, the use of reliable interoceptive measurement tools is crucial. One critical objective of this work was therefore to develop a new measure of interoception and investigate its implications in emotion processing.

The HBC and HBD tasks are the most used methods to evaluate interoceptive accuracy. In the HBC task, participants are asked to silently count their heartbeat at rest during different time intervals. Their answers are then compared to the real heartbeat recorded during these intervals (Whitehead et al., 1977). In the HBD task, a series of tones synchronized or asynchronized with the participant's heartbeats are presented. Participants were then asked to indicate whether the tones were faster or slower than their heartbeat. Unfortunately, these two methods have limitations as they are influenced by non-interoceptive processes (Desmedt et al., 2018). On the one hand, regarding the HBC task, the major issue is the influence of subjective beliefs about heart frequency. These believed heart rates predicted counted heart rates better than the actual heart rate (Ring & Brener, 1996), and improving knowledge about heart rate can enhance performance on the task (Ring et al., 2015). Additionally, manipulating heart rate with a cardiac pacemaker does not change the heartbeat counts (Windmann et al., 1999). Finally, good performance on the HBC task has been associated with time estimation abilities (Brener & Ring, 2016). On the other hand, the HBD task requires simultaneous attention to both exteroceptive signals (tones) and interoceptive signals which generate interference and constitute a confounding factor (Couto et al., 2015). As the cardiac interoceptive tasks present limitations, new and more precise tools are being developed, such as Legrand et al.'s (2021) novel psychophysical method of heart rate discrimination (HRD) task. Like the classic HBD task, this protocol involves comparing the heartbeat in the interoceptive condition or a reference tone in the exteroceptive condition to a series of tones. However, in this task, the speed of the tones to be compared is adapted from trial to trial according to a Bayesian model, to correctly measure the accuracy, precision, and metacognitive sensitivity of the decision in both the interoceptive and exteroceptive conditions.

Focusing on other physiological signals, such as respiratory signals, allows us to address the limitations of cardiac tasks. Dyspnea, or the sensation of difficulty breathing, is an interoceptive sensation that does not rely on feedback from chest muscles (Critchley & Garfinkel, 2017). Compared to cardiac signals, respiratory signals are more consciously detectable and can be more easily modified in a non-invasively way by altering the respiratory rate or holding the breath. Respiratory interoceptive accuracy is typically assessed using respiratory load detection or discrimination tasks. In the detection tasks, participants are required to detect whether resistance has been induced into the tube through which they are breathing (Zhao et al., 2002). In the discrimination tasks, participants are asked to discriminate between multiple loaded breaths to determine which contains the strongest respiratory load (Webster & Colrain, 2000). This type of task allows for the use of psychophysical methods, such as the adaptive staircase method, to accurately determine a participant's level of perception (Leek, 2001). In the adaptive paradigm, the restrictive loads are modified at each trial based on the participant's responses to the previous trial to determine

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their perceptive threshold. The use of adaptive paradigms in discrimination tasks minimizes the number of trials required, which can be an issue in conventional versions of the task (Harrison et al., 2021). However, the respiratory tasks present some limitations. First, resistive loads have an instinctive aversive connotation that can interfere with the detection of respiratory sensations (Tan et al., 2019). Second, they require specialized equipment such as respiratory filters. Recently, Van Den Houte et al. (2021) suggested a new respiratory occlusion discrimination task that decreases this aversive bias of resistive loads by using very short interruptions of inhalation. In this task, participants must judge the length of two inspiratory occlusions in an adaptive staircase paradigm. However, this task also requires advanced and not transportable equipment to deliver occlusions.

We developed a new duration discrimination respiratory (DDR) task that does not require complex respiratory equipment. The DDR task aims to determine an individual's ability to detect exhalations that are longer than their resting reference duration. As the length of inhalation and exhalation varies across individuals according to factors such as gender (Ragnarsdóttir & Kristinsdóttir, 2006), age (Kaneko & Horie, 2012), body mass index (BMI) (Robinson, 2014), or general health status (Kharitonov & Barnes, 2001), a reference exhalation and inhalation durations are defined for each participant at rest. The reference exhalation is then compared to an extended exhalation across two breaths in a row. An adaptive staircase procedure allows for an accurate determination of an individual's discrimination score, expressed as a relative percentage of self-respiratory time required to discriminate between a reference exhalation duration and an extended duration. To validate this task, a large sample of 125 healthy subjects completed the DDR task, as well as the recent HRD task of Legrand et al. (2021), which is referred to as one of the most accurate tasks for measuring the accuracy and the precision of cardiac interoception (Garfinkel et al., 2022).

The first goal of this study was to explore the internal consistency and discriminant validity of the DDR task. Internal consistency was investigated by calculating the alpha Cronbach of the six scores used to calculate the final score. Discriminant validity was verified by investigating the correlation between the DDR task score and the exteroceptive control condition of the HRD task. Additionally, to verify whether the DDR task scores are a valid reflection of the use of interoception, we collected measures on self-reported strategies used to complete the task. The secondary goal was to investigate the relationship between DDR task scores and the cardioception interoceptive accuracy task (Legrand et al., 2021). We also explored the link between the DDR task and self-reported strategies, positive and negative affects, alexithymia, and interoceptive awareness measured through self-reported questionnaires and demographic data. Finally, we tried to determine which of these variables best predicted the DDR task's scores.

2 | METHOD

2.1 | Participants

Participants were recruited from university students. Exclusion criteria included any self-reported psychiatric disorders, taking antidepressants and/or anxiety medication, or having taken part in the pilot study. The inclusion criteria were the ability to read and speak French and being between 18 and 65 years old. One hundred and twenty-eight healthy participants (50 men) were involved in the study, all of whom were French speakers. The mean age was 25.46 (*SD* = 9.84, range = 18–65). All participants gave written informed consent prior to the experiment. Data were collected between September and December 2022. We excluded three participants due to extreme outlier data on the respiratory task or HRD task, as well as two additional participants because of technical problems during the task administration.

2.2 | Procedure

After participants completed the informed consent form, they filled out the anamnestic, and questionnaires. Subsequently, electrocardiogram (ECG) electrodes and a chest belt were applied. Finally, participants completed the DDR task followed by the HRD task. The entire session lasted approximately an hour.

2.3 | Physiological measures and material

2.3.1 | The DDR task

During the DDR task, ECG data were recorded with a data acquisition system (MP160 BIOPAC System, Inc, Goleta, CA, USA) with three disposable 8-mm Ag/AgCl ECG electrodes (Kendall H66LG, Medtronic, Ireland) placed over the participants' clavicles and at the left lower ribs. The heart rate, measured in beats per minute, was derived from the ECG signal using the BIOPAC data analysis packages within the AcqKnowledge 5.0 software. The ECG was visually inspected during the task and processed offline with AcqKnowledge 5.0 software. Respiration was recorded with a belt positioned around the chest (respiratory

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transducer TSD201, BIOPAC Systems, Inc). The ECG and respiration signals digitalized at 2000 kHz. ECG and respiratory data were recorded during the 2-min baseline and throughout the entire task. The reference exhalation and inhalation times were determined during the baseline period, in which participants were seated and instructed to relax, limit their motion, and avoid speaking. To calculate the inhalation and exhalation times, the AcqKnowledge 5.0 software was used to place event markers at the maximum and minimum points of each respiration cycle curve. The difference between the curve's minimum and maximum points represented the inhalation time, whereas the difference between the maximum and minimum points represented the exhalation time. The reference exhalation and inhalation times were computed as the mean of the inhalation and exhalation times. On average, these reference times were calculated over 25.66 inhalation cycles (*SD* = 5.89, range 16–43) and 25.42 exhalation cycles (*SD*: 6.45, range 16–43). The respiration was visually inspected during the task to ensure that the participants respected the inhalation and exhalation instructions. The DDR task was implemented using Psychopy v2021.2.3 (Peirce et al., 2019). The code for the DDR task is made publicly available on OSF (https://osf.io/d9u24/).

2.3.2 | Heart rate discrimination task

The HRD task developed by Legrand et al. (2021) is available in the Cardioception Python Package (https://github.com/embodied-computation-group/Cardioception). The task was coupled with the Nonin 3012LP Xpod USB pulse oximeter and a Nonin 8000SM "soft clip" fingertip sensor (https://www.nonin.com/) by interfacing with the "Systole" python package (v0.1.3) for pulse oximetry (Legrand & Allen, 2022).

2.4 | The DDR task

2.4.1 | The DDR task: Procedure

During the task, participants took two breaths in a row, one with an extended exhalation duration and the other with a reference exhalation duration. The inhalation durations were not extended and were of reference duration. To ensure that the task was not entirely comprised of trials with different breath durations, a third of the trials included two breaths of identical duration, both featuring a reference exhalation duration. Responses from these trials were not considered in the staircase procedure. As a result, the task encompassed one-third of the trials with an extended exhalation during the first breath, a third with a reference exhalation during the first breath, and the final third with identical breathing durations. The sequence of trials was randomized. Before the main task, a tutorial phase consisting of trials similar to the main task was completed, along with a concurrent calculation task without accuracy feedback. In this tutorial, the exhalation durations were not extended using an adaptative staircase; instead, they were simply double the reference expiration duration. Similar to the main task, the tutorial included one trial with an extended exhalation during the first breath, another with a reference exhalation during the first breath, and a final trial with two identical breathing durations. The trial sequence was also randomized. This tutorial aimed to clarify the instructions, present participants with a simplified version of the task and enable them to practice and become familiar with it before the main task. Figure 1 illustrates the DDR task procedure. Participants were seated in front of a screen and the following instructions were provided: "The objective of this task is to evaluate your capacity to perceive the

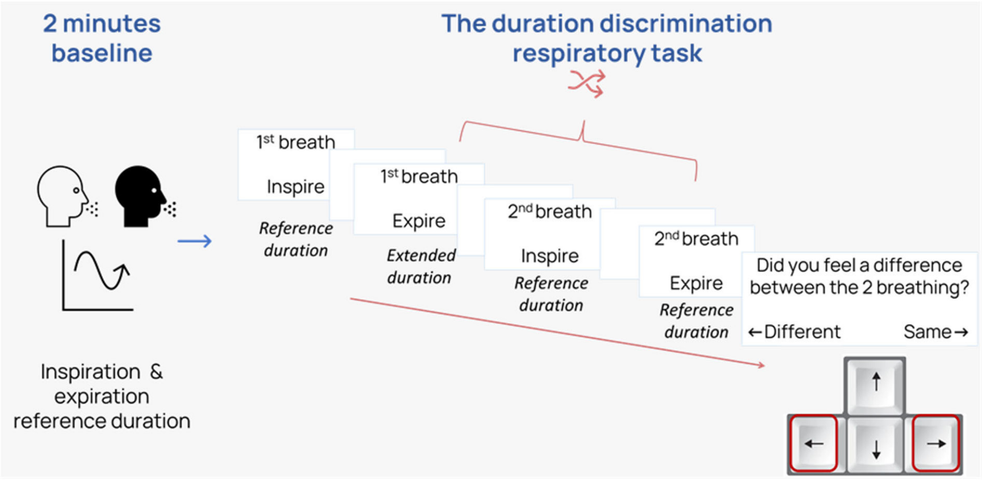

FIGURE 1 DDR task procedure.

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difference between two consecutive breaths by concentrating on your internal sensations and abstaining from mental counting. To accomplish this, you will need to perform two consecutive breaths according to the instructions displayed on the screen. In other words, when the instruction 'Breathe in' appears, breathe in and continue until the instruction 'Breathe out' appears. Then, exhale until the instruction 'Breathe in' reappears, and repeat this pattern." Following each trial consisting of two breaths, participants were required to determine whether they perceived a difference between the two breaths. Participants provided their responses by using the left and right arrow keys on the keyboard. To avoid participants relying on screen time to differentiate the two breaths rather than on their internal sensations, the instructions disappeared after 1 second. A pilot study involving 64 individuals indicated that counting strategies were diminished with this 1-second presentation. These pilot participants did not take part in the current study. The subsequent instruction was as follows: "The 'Breathe in' and 'Breathe out' instructions will not remain displayed on the screen. However, their disappearance does not indicate that you should halt your breathing in or out. Please continue to breathe in or breathe out until the next instruction is shown on the screen." Furthermore, to discourage participants from mentally counting during the breaths, a concurrent verbal calculation task aimed at loading the phonological loop (Seitz & Schumann-Hengsteler, 2002) was administered concurrently with the breaths. These calculations involved simple additions or subtractions not exceeding 100. The experimenter orally provided the first number during the initial exhalation and completed the calculation during the second exhalation. Following this, participants were required to orally provide their answers after indicating whether they felt a difference between the two breaths. Each trial ended with a 5-second intertrial pause and participants could either proceed to the next trial by pressing the space bar or choose to extend the pause.

2.4.2 | The DDR task: Adaptative staircase

Adaptive staircase methods are commonly used in human perception research to determine the limits of discrimination among similar stimuli. In our case, the staircase procedure adapted the duration of the exhalation on each trial to determine the duration for which the participant could no longer discriminate between two breaths. To avoid hyperventilation which could be caused by shortened exhalations (Gilbert, 1998), we decided to use a staircase in one direction only with extended duration. Figure 2 illustrates an example of the task procedure for a participant with a reference exhalation duration of 2419 ms. We used a two-down, one-up rule to target the duration for which participants reported a difference in 70% of the cases. Specifically, the extended exhalation was shortened after two correct answers and extended after one incorrect answer. The amount by which the exhalation was decreased or increased corresponded to the step size that was adjusted during the task. The staircase contained six steps ranging from 10% of the baseline exhalation duration to 5%, with the transition step occurring at each reversal (represented with an arrow in Figure 2). Reversal refers to a change in the direction of the staircase, such as a downward reversal following a sequence of one incorrect answer and two correct answers (first, third, and fifth arrows), or an upward reversal after one incorrect

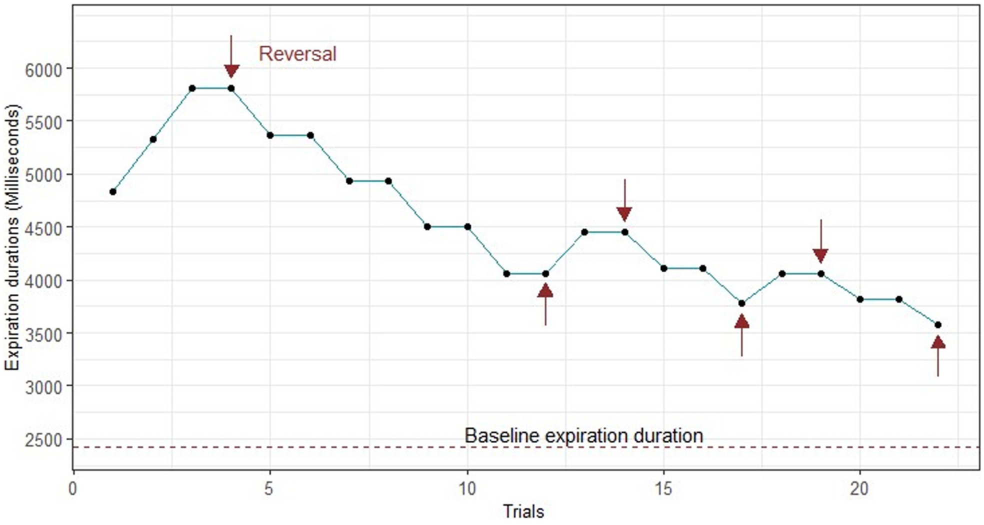

FIGURE 2 Example of staircase procedure.

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answer in a sequence of correct answers (second, fourth, and sixth arrows). The start value of extended exhalation was twice the baseline exhalation time. In the example shown in Figure 2, the participant's mean baseline exhalation time was 2419 ms, so the start value was 4838 ms. At the start of the task, the extended exhalation was reduced/increased by 10% of the baseline exhalation duration (first step). After a reversal, the extended exhalation was reduced/increased by 9% (second step) of the reference exhalation duration, and so on. The task stopped after 6 reversals and at least 10 trials. The final score formula was as follows: ((mean duration at 6 reversals − baseline exhalation duration)/baseline exhalation duration)*100. This score represented the percentage of reference exhalation time required to differentiate between the extended exhalation duration and the reference duration. In Figure 2, the score was 77.33%, meaning that the participant needed 77.33% of their reference exhalation time to differentiate between the extended exhalation duration and the reference duration.

2.5 | HRD task

The cardiac interoceptive accuracy was measured with a recent psychophysical method of HRD (Legrand et al., 2021) using the staircase adaptive procedure-based Bayesian psychophysical method “Psi” (Kingdom & Prins, 2016; Kontsevich & Tyler, 1999; Prins & Kingdom, 2018). The task consisted of two conditions, one involving interoception and the other involving exteroception. The exteroceptive condition was used to control for possible non-interoceptive processes like working memory or general temporal estimation biases. During the interoceptive condition, participants first had to silently attend to their heart rate for 5 seconds. During this “listening phase”, the heart rate was recorded by an oximeter placed on the participant's index finger of the non-dominant hand. After this phase, the participant heard feedback tones composed of a sequence of five tones (frequency 440 Hz; duration: 200 ms) and had to decide whether it was faster or slower than their average heart rate.

During the exteroceptive control condition, participants first heard a reference sequence of five tones (randomly selected between 40 and 100 BPM) followed by a feedback tone. They then had to decide whether the feedback tone was faster or slower than the reference sequence. The difference between the reference sequence (exteroceptive condition) or the true heart rate (interoceptive condition) and the feedback tone is referred to as the delta beats per minute (Δ-BPM).

In both conditions, in the next trial, the frequency of the feedback tone was adapted according to a Psi staircase procedure. Like the staircase method described above, the Psi method aimed to determine the psychophysical threshold (α) for discriminating between the true heartbeat (for interoception condition) or tones (for exteroception condition) and the estimated cardiac/tone frequency. The Psi method used a probabilistic approach to adjust the Δ-BPM during the task. This method used a likelihood function to determine the probability of a participant responding “Faster” or “Slower” given the Δ-BPM. The function updated the Δ-BPM at each trial according to the previous answers and the a priori distribution of the participants' detection abilities. At the end of the task, the function estimated the α, which referred to the degree of over- or underestimation. A negative α indicates that the participant is underestimating their cardiac frequency, whereas a positive α indicates that they are overestimating it. For example, an α of −6 BPM for interoception indicates that the participant underestimated their heart rate by 6 BPM. Along with the α value, this function also estimated the slope (β) in Δ-BPM units, which refers to the precision or uncertainty around this perceptual bias estimation of under- or overestimation. In practice, a larger β indicated lower precision and greater uncertainty in the cardiac interoceptive decision process. The procedure and detailed analysis of this HRD task can be found in the Legrand et al. (2021)'s article.

2.6 | Questionnaires

2.6.1 | Anamnestic questionnaire

A general information questionnaire was administered, which contained questions about demographics (education, height, weight, and occupation), medical history, medication use, and addictive behaviors, such as alcohol, tobacco, and drug use. Being important for interoception, the level of fitness condition was investigated with a Likert scale from 1 (very fit) to 4 (not fit) (McMorris et al., 2020).

2.6.2 | DDR task self-report

A feedback questionnaire was created to evaluate the difficulty, motivation, comfort, and strategies used to complete the DDR task. The questionnaire consisted of nine Likert scales ranging from 1 (not at all) to 10 (very much). The first three scales evaluated the difficulty, motivation, and comfort experienced during the task. The remaining six scales focused on the strategies used to complete the task, which were grouped into four categories: internal body sensations (such as paying attention to internal sensations and breath intensity), external body sensations

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(including movements of the bust and chest compression), gut feeling, and counting.

2.6.3 | Multidimensional assessment of interoceptive awareness

The interoceptive sensibility was evaluated using the French version of the Multidimensional Assessment of Interoceptive Awareness Questionnaire ([version 2, MAIA-2] Mehling et al., 2018; French validation by Da Costa Silva et al., 2022). The MAIA-2 is a 37-item questionnaire that assesses eight facets of interoceptive body awareness: (1) *Noticing*: awareness of uncomfortable, comfortable, and neutral body sensations; (2) *Not distracting*: tendency not to be distracted by oneself from sensations of pain or discomfort; (3) *Not worrying*: tendency not to worry with sensations of pain or discomfort; (4) *Attention regulation*: ability to sustain and control attention to body sensation; (5) *Emotional Awareness*: awareness of the connection between body sensations and emotional states; (6) *Self-regulation*: ability to regulate psychological distress by attention to body sensations; (7) *Body listening*: actively listens to the body for insight; and (8) *Trusting*: experiences one own's body as safe and trustworthy. Each item is scored on a Likert scale from 0 (never) to 5 (always). The score of each of the eight subscales was calculated by averaging the scores of the items belonging to the subscale.

2.6.4 | Toronto alexithymia scale

Alexithymia was assessed using the Toronto Alexithymia Scale (TAS-20) developed by Bagby et al. (1994) (French validation by Loas et al., 1997). The TAS-20 is a self-report questionnaire consisting of 20 items that are scored on a Likert scale from 1 (completely disagree) to 5 (completely agree). The scale is divided into three subscales that assess the main dimensions of alexithymia: difficulty identifying feelings (DIF), difficulty describing feelings (DDF), and externally oriented thinking (EOT).

2.6.5 | Positive and negative affect scale state version

The Positive and Negative Affect Scale (PANAS) (Watson et al., 1988, French validation by Gaudreau et al., 2006) measures general affective states in 20 items, consisting of two 10-item subscales of positive and negative affects. On a Likert scale from 1 (not at all) to 5 (very much), participants reported how they experienced negative and positive emotions in that specific moment.

2.7 | Statistics

Data analysis was performed using R software (4.2.2) and RStudio interface. The internal consistency was verified by calculating Cronbach's alpha for the score at the six reversals. Discriminant validity was checked using Pearson's correlation between DDR task scores and the exteroception condition of the HRD task. To investigate the relationship between DDR task performance and traits questionnaires, demographics data, and the interoception condition of HRD task, Pearson's correlation analyses were performed. Afterward, a principal component analysis (PCA) using the "factorextra" (Kassambara & Mundt, 2021) R' package was conducted to extract the principal variables correlated with DDR task scores. Before applying PCA, all the variables were standardized (*Z*-transformed). Then, multiple regression models including the main variables identified through the PCA were performed to investigate which components predict the DDR task performance best. Age, body mass index, and physical condition influencing interoception were also entered as predictors. For these models, collinearity between covariates was controlled with variance inflation factor (VIF) produced with "check_collinear" function of the *performance* (Lüdecke et al., 2021) package in R. We used a VIF cut-off of 5 or greater as a collinearity criterion and excluded all variables meeting this criterion. After excluding collinear variables, we ensured the assumptions of linearity, normality, homoscedasticity, and no outliers with the "check_model" and "check_outlier" functions of the *performance* (Lüdecke et al., 2021) package.

Finally, we grouped our participants into categories based on their levels of predictor variables identified via multiple regression models. We performed analyses of variance (ANOVA) to examine group differences in the DDR task.

3 | RESULTS

Table 1 presents descriptive statistics (means, standard deviations, minimum, and maximum) for demographics data and all included tasks and questionnaires.

3.1 | DDR task

The mean score was 99.22% (*SD* = 36.38). This means that, on average, participants could distinguish two breaths if one of the two exhalations is extended by 99% of the reference exhalation time. The distribution of the DDR score was moderately positively skewed (skewness = 0.97). There was no significant difference in scores between men

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TABLE 1 Descriptive statistics.

	Mean	*SD*	Min	Max
Demographics				
Age	25.57	9.93	18	65
Physiology				
Body mass index, kg/m^2	24.48	5.44	16	44.87
Fitness level	2.07	0.72	1	4
Resting inhalation time, milliseconds	1714.06	391.24	1068	3744
Resting exhalation time, milliseconds	2234.07	516.49	1200	4433
Interoceptive accuracy				
DDR task				
Total score, percentage	99.22	36.38	27.33	225.33
DDR task self-report				
Comfort	6.61	1.91	2	10
Difficulty	6.79	2.41	1	10
Motivation	8.70	1.41	2	10
Feeling	7.65	2.20	1	10
Respiratory intensity	7.34	2.65	1	10
Chest compression	4.90	3.19	1	10
Bust movements	6.56	2.99	1	10
Counting	2.29	2.72	1	10
Gut feeling	7.22	2.66	1	10
HRD task				
Intero α	−7.38	16.16	−38.87	36.75
Intero β	13.47	6.64	4.28	31.18
Extero α	−0.03	3.83	−12.55	14.79
Extero β	8.66	3.88	3.4	27.75
Interoceptive sensibility (MAIA scale)				
Noticing	3.52	0.79	0.25	5
Not distracting	1.91	0.87	0	4
Not worrying	2.61	0.99	0.4	4.8
Attention regulation	2.48	0.79	0.42	4.42
Emotional awareness	3.55	0.96	0	5
Self-regulation	2.73	1.01	0	5
Body listening	2.15	1.12	0	5
Trusting	3.51	1.04	0.66	5
Total MAIA	22.47	3.88	9.52	31.53
PANAS				
Positive affect	29.03	5.62	15	43
Negative affect	15.20	5.01	10	33
TAS scale				
DIF	15.77	4.45	5	25
DDF	18.32	5.11	7	31
EOT	18.86	4.64	9	35
Total TAS	52.94	10.01	30	78

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($M = 92.4$) and women ($M = 103$) ($W = 2183.50$, $p = .089$). The DDR task score was weakly correlated with difficulty ($M = 6.79$, $SD = 2.41$; $r(123) = -.17$, $p = .051$) but not correlated with self-reported motivation ($M = 8.70$, $SD = 1.41$; $r(123) = -.06$, $p = .47$) nor comfort ($M = 6.61$, $SD = 1.91$; $r(123) = -.01$, $p = .86$). The average number of trials was 20.9 ($SD = 5.67$), and the mean duration of the task was 15 min ($SD = 4$ min).

Concerning strategies, higher scores were reported for strategies based on internal body sensation (feelings/sensations [$M = 7.65$, $SD = 2.20$], respiratory intensity [$M = 7.34$, $SD = 2.65$]), and gut feeling ($M = 7.22$, $SD = 2.66$) followed by strategies based on external body sensation (bust movements [$M = 6.632$, $SD = 2.97$], chest compression [$M = 4.89$, $SD = 3.21$]), and counting-based strategies ([$M = 2.29$, $SD = 3.72$], $F_{(5,744)} = 70.36$, $p < .001$, $\eta^2_p = .320$).

3.2 | Internal constancy and discriminant validity

The Cronbach's alpha was .93 which is considered acceptable (Tavakol & Dennick, 2011). No significant correlation was found between the exteroceptive condition of HRD scores and the score of the DDR task. This suggests a strong discriminant validity of the DDR task as a measurement of *interoceptive* discrimination.

3.3 | The HRD task

The mean α for the interoceptive condition was -7.38 BPM ($SD = 16.16$), meaning that participants underestimated their heartbeat by 7.37 BPM. For the exteroceptive control condition, it was -0.03 BPM ($SD = 3.83$), meaning that participants slightly underestimated the sequence of tones by 0.03 BPM. The mean β of the interoceptive and exteroceptive conditions were 13.47 ($SD = 6.64$) and 8.66 BPM ($SD = 3.88$), respectively, reflecting lower precision for interoceptive conditions. Together, these results revealed that participants were significantly lower and less precise in the interoceptive condition than in the exteroceptive condition ($t\ (124) = -5.37$, $p < .001$; $t(124) = 8.34$, $p < .001$).

To verify whether HRD performance primarily indexed general temporal estimation ability, we conducted a correlation between interoceptive and exteroceptive α. A high correlation would suggest that participants used temporal estimation to perform the interoceptive condition. On the contrary, if participants utilized other information (like afferent cardiac sensory information) to complete the interoceptive condition, minimal to no correlation between both conditions would be expected (Legrand et al., 2021).

A significant correlation was found between the α of interoception and exteroception conditions ($r(123) = .34$, $p = < .001$), suggesting a temporal estimation influence on interoceptive condition.

No significant correlation was found between both conditions of HRD scores and the score on the DDR task. The lack of correlation between the DDR task and the alpha of the HRD exteroception condition suggests the absence of influence of time estimation processes during the DDR task.

3.4 | Correlation analyses

Table 2 presents the detailed correlation results among the DDR task performance, demographic factors, self-reported questionnaires, and the HRD task. First, DDR task scores were significantly correlated with fitness level ($r\ (123) = .03$, $p = .025$), indicating that low scores on the DDR task are associated with poor fitness condition and inversely. Second, DDR task scores were correlated with the counting strategy ($r\ (123) = .28$, $p = .025$), indicating that counting during the DDR task is associated with low scores and inversely. Third, DDF subscale of TAS was positively correlated with DDR task performance ($r\ (123) = .26$, $p = .035$). Indeed, poor scores on the DDR task were associated with high level of difficulty in describing feelings and inversely. No other significant correlations with the DDR task scores were found.

3.5 | Principal component analysis

The PCA showed that two dimensions with eigenvalues greater than 1 accounted for a total of 26.40% of the variance (Factor 1: eigenvalue 5.11, explaining 17.62% of the variance; Factor 2: eigenvalue 2.54, explaining 8.77% of the variance). We focused on components with a factor loading of 0.3 or above considered a medium effect size (Cohen, 1988). In the first dimension (see Figure 3a), which accounted for the most variability in the dataset, the total score of MAIA scale (factor loading = 0.89) and its subscales body listening (factor loading = 0.63), self-regulation (factor loading = 0.57), attention regulation (factor loading = 0.56), trusting (factor loading = 0.55), noticing (factor loading = 0.54), and emotional awareness (factor loading = 0.52), as well as age (factor loading = 0.32), loaded positively. Conversely, the total score of TAS scale (factor loading = −0.78) and its subscales DIF (factor loading = −0.71), DDF (factor loading = −0.58), and EOT (factor loading = −0.38), the negative affect subscale of PANAS (factor loading = −0.39), and the α of exteroceptive control condition of the HRD task (factor

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TABLE 2 Pearson correlation coefficients between measures and DDR task score.

	Coefficient *r*	*p*-value Corrected FDR[a]
Demographics		
Age	.08	.67
BMI	.09	.67
Fitness condition	.29	.025*
DDR task		
Self-reported		
Comfort	−.02	.86
Difficulty	−.18	.27
Motivation	−.06	.70
Strategy		
Feeling	.10	.67
Respiratory intensity	−.15	.44
Gut feeling	−.09	.67
Chest compression	−.05	.71
Bust movements	.11	.67
Counting	.28	.025*
PANAS		
Trait positive affect	−.02	.86
Trait negative affect	.04	.74
MAIA		
Noticing	.07	.70
Not distracting	.07	.70
Not worrying	−.17	.27
Attention regulation	−.02	.86
Emotional awareness	.08	.67
Self-regulation	−.08	.67
Body listening	.04	.74
Trusting	−.06	.71
Total	−.02	.86
TAS		
DIF	.08	.67
DDF	.26	.035*
EOT	.05	.71
Total	.19	.27
HRDT		
Intero alpha	.11	.67
Intero beta	−.08	.67
Extero alpha	.05	.71
Extero beta	−.09	.67

[a] *p*-values are corrected for multiple testing using the false discovery rate (FDR) method.

$^{*}p < .05$.

loading = −0.34) loaded negatively. This first dimension revealed a negative association between the sensibility to perceived physiological changes and the inability to perceive feelings and is therefore defined as the interoceptive/emotional awareness axes.

In the second dimension (see Figure 3b), counting strategies during the DDR task (factor loading = 0.52), the DDF subscale of TAS (factor loading = 0.49), scores on the DDR task (factor loading = 0.48), BMI (factor loading = 0.45), time of inhalation during the baseline (factor loading = 0.42), emotional awareness subscale of the MAIA scale (factor loading = 0.41), and perceived physical condition (factor loading = 0.35) all loaded positively. The not worrying subscale of the MAIA (factor loading = −0.68) and gender (factor loading = −0.33) loaded negatively. Mainly, this second dimension showed a negative association between the tendency not to worry or experience emotional distress about sensations of pain or discomfort (not worrying subscale of MAIA) and the difficulty in describing feelings (DDF subscale of TAS 20) and estimating differences during the DDR task, resulting in high scores on the task and counting to achieve it. This dimension is therefore defined as the perception of feelings and breath regarding experience of stress axes.

3.6 | Multiple linear regression: DDR task scores predictors

As expected, a first regression model, that included variables from the first PCA dimension was not significant ($R^2 = .1$, $R^2_{adj} = .012$, $p = .336$), as the DDR scores were not in the first dimension. The second model, which included variables from the second dimension, was significant ($R^2 = .21$, $R^2_{adj} = .16$; $p < .001$, See Table 3). Physical condition ($\beta = 0.285 \pm 0.092$, $p = .003$), counting strategy ($\beta = 0.278 \pm 0.092$, $p = .003$), and the DDF subscale of the TAS ($\beta = 0.171 \pm 0.089$, $p = .056$) predicted DDR task scores. Since high scores on the DDR task reflect low interoceptive accuracy, these results suggested that higher physical condition (where low scores reflected good physical condition) predicts higher respiratory interoception. Conversely, using a counting strategy during the task predicted low performance in the DDR task. Finally, higher difficulty in describing feelings (as measured by the subscale DDF of the TAS) predicted lower interoceptive accuracy.

To better understand these findings, we proceeded with a supplementary analysis by composing subgroups. First, we divided our sample into three subgroups according to their perceived physical condition

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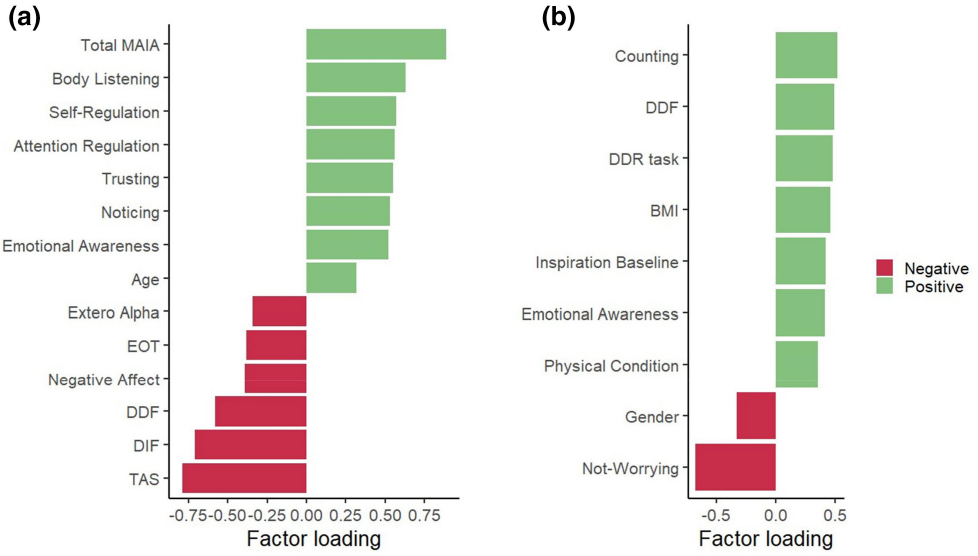

FIGURE 3 Contribution of each variable on two dimensions for PCA. (a) Dimension 1 (17.62% of variance): interoceptive/emotional awareness axes; (b) Dimension 2 (8.77% of variance): perception of feeling and breath regarding experience of stress axes.

TABLE 3 DDR task predictors multiple regression analyses for second-dimension PCA.

Predictors	*β*-Estimate (*SE*)	*p*-value
(Intercept)	0.03 (0.11)	.79
Counting	0.28 (0.09)	.003**
DDF	0.17 (0.09)	.056*
BMI	−0.04 (0.09)	.61
Baseline inhalation	0.04 (0.09)	.64
Emotional awareness	0.06 (0.09)	.55
Physical condition	0.28 (0.09)	.002**
Gender male	−0.07 (0.19)	.69
Not worrying	0.04 (0.10)	.71

Abbreviation: SE, standard error.

$^*p<.06$; $^{**}p<.05$.

(*not moderately fit*: $n=35$, *Fit*: $n=63$, *Very fit*: $n=27$). An ANOVA revealed a significant effect of physical condition ($F_{2,122}=5.10$, $p=.007$, $\eta^2_p=.077$) on breath scores. Post hoc Tukey-adjusted analyses showed higher respiratory interoception in the *very fit* group ($M=83.7$) compared to the *not moderately fit* group ($M=112$) ($p_{\text{adj}}=.005$, see Figure 4a). Interestingly, the same effect was observed for the MAIA total scale ($F_{2,122}=4.03$, $p=.020$, $\eta^2_p=.062$) with higher MAIA scores in the *very fit* group ($M=24$) compared to the *not moderately fit* group (21.2) ($p_{\text{adj}}=.015$). No effect of physical condition was observed for the interoception condition of HRD task ($F_{2,122}=0.13$, $p=.88$).

Second, we divided our group according to the usage of counting during the DDR task. Participants self-reporting 2 or greater on the 10-point Liker scale were considered "counters" ($n=30$) and the others were considered "non-counters" ($n=95$). Analyses revealed lower DDR task scores in the non-counters group ($M=93.6$) compared to the counters group ($M=116$) ($T=1010.5$, $p=.017$, see Figure 4b).

Third, the sample was divided into three subgroups according to the DDF subscale (high DDF [$n=42$]: DDF score≥20; moderate DDF [$n=36$]: 15 < DDF score < 20; and low DDF [$n=47$]: DDF score≤15). An ANOVA revealed a significant effect of DDF group on DDR task score ($F_{2,122}=6.22$, $p<.003$, $\eta^2_p=.093$). Post hoc Tukey-adjusted analyses showed lower respiratory interoception in the high DDF group ($M=115$) compared to the low DDF group ($M=90.3$) ($p_{\text{adj}}=.007$) and the moderate DDF group ($M=92.2$) ($p_{\text{adj}}=.008$) (see Figure 4c). Interestingly, an effect of DDF group was observed for the MAIA total scale ($F_{2,122}=6.87$, $p=.001$, $\eta^2_p=.101$) with higher MAIA scores in the low DDF group ($M=24.1$) compared to the high DDF ($M=20.9$) ($p_{\text{adj}}<.001$).

4 | DISCUSSION

The aim of this study was to validate a new respiratory interoceptive task considering inter-individual breathing differences without specialized equipment. This task measured interoceptive accuracy by assessing the ability to discriminate a longer exhalation from a reference resting exhalation. Using an adaptive staircase method, we accurately determined the discrimination threshold, represented by the percentage relative to the reference time required to discriminate between a reference and

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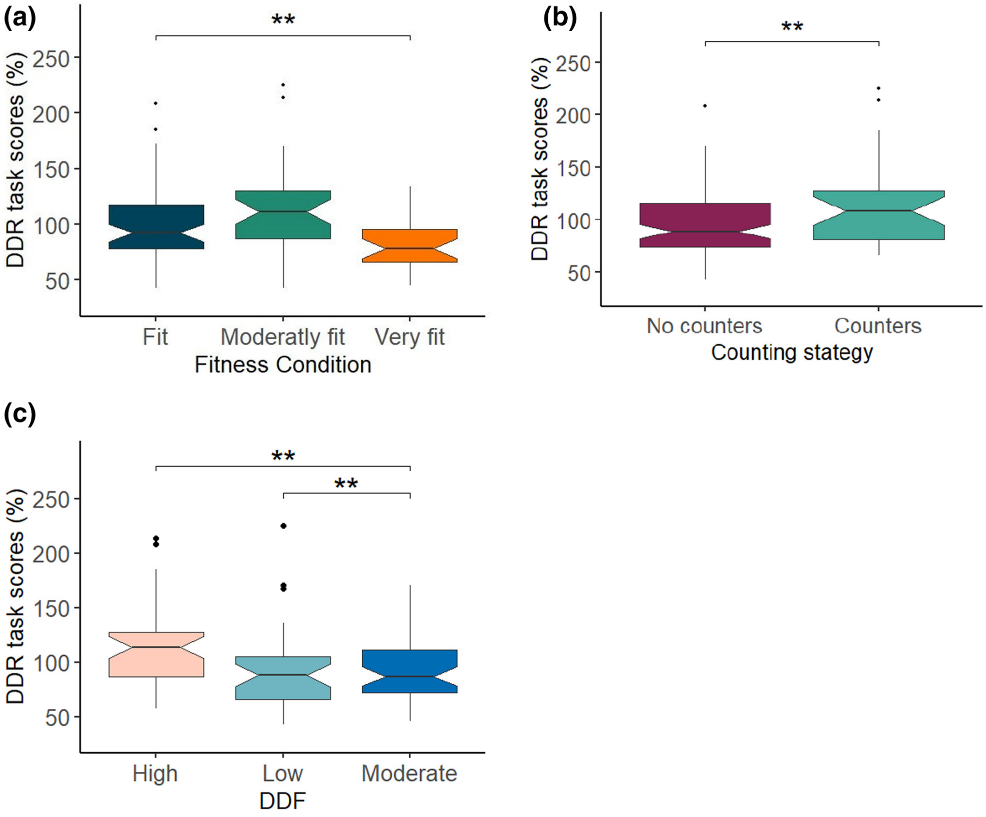

FIGURE 4 (a) DDR task scores across physical condition groups; (b) counters and non-counters groups; and (c) high, low, and moderate DDF groups. $^{**}p < .01$. DDF, difficult to describe feelings subscale (TAS 20).

an extended exhalation. This percentage score allowed for comparisons while accounting for inter-individual differences.

First, our results demonstrated good internal consistency, supporting the accuracy of using the six reversal values to calculate the total score.

Second, to ensure that the DDR task scores were not influenced by exteroceptive processes such as time estimation ability, we compared them to the exteroception condition of HRD. This condition measured the ability to discriminate between two tones with different frequencies. The absence of correlation between these measures and the DDR task scores demonstrated that the DDR task was not influenced by exteroceptive ability. Additionally, according to the DDR task feedback questionnaire, most participants reported relying on their internal sensations rather than external body sensations or counting to discriminate between the two breaths. However, despite instructions not to count but to rely on internal sensations and the use of a concurrent verbal calculation task, a minority of participants still reported using counting strategies. Our regression analyses revealed that counting strategies predicted lower scores on the DDR task. We might hypothesize that participants using counting strategies despite instructions not to do so may have tried to overcome difficulties to perform the task based on their internal sensations. Counting may therefore reflect a consequence of poor respiratory interoceptive accuracy.

Furthermore, to investigate whether the DDR task was a valid measure of interoception, we compared its scores to those of the interoceptive condition from the HRD task developed by Legrand et al. (2021). We found a non-significant correlation between HRD and the DDR task. Although contrary to our assumptions, this lack of relationship could be explained by the fact that these tasks assess interoception in two different modalities. The literature has shown a weak correspondence between cardiac and respiratory interoception accuracy (Garfinkel, Manassei, et al., 2016). Moreover, we found a correlation between the scores of the interoception and exteroception HRD conditions, which suggests an influence of exteroceptive temporal estimation ability on the HRD interoceptive condition. Given all this, the non-correlation between HRD and DDR task does not prove that our task does not assess respiratory interoceptive accuracy. A future study could explore the relationship between our task and another interoceptive task within the same modality, such as the respiratory occlusion task by Van Den Houte et al. (2021) which employs a similar staircase paradigm, or the respiratory resistance sensitivity task (Nikolova et al., 2022).

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Interoceptive accuracy can be measured across several modalities, including cardiac, respiratory, or gastric functions, using tasks such as the Water Load Test (Van Dyck et al., 2016), which involves detecting the amount of water in the stomach. The literature shows a significant association between tasks belonging to the same modality, but not across different modalities (Ferentzi et al., 2018). The lack of generalization between modalities could suggest that interoception accuracy is modality specific. According to this view, in their discussion, Ferentzi et al. (2018) developed the idea that each interoceptive modality carries specific information to the organism (e.g., dyspnea and gastric perception) not equally relevant for survival, representing distinct subjective sensations. The information of each modality is then evaluated in low-level and automatic processes before being integrated into a "whole-body pattern" giving rise to behavioral or verbal reports of these sensations. The general interoceptive ability would therefore be an integration or combination of all the possible interoceptive modalities. As each modality brings specific information, inferring from one modality to another seems irrelevant. In our case, expanded expiration could give rise to a different type of low-level evaluation than that of a resting heartbeat. As interoceptive modalities result in different automatic processes leading to distinct subjective sensations, their relationship to affective and cognitive constructs could diverge (Garfinkel et al., 2016). For example, anxiety was associated with increased cardiac interoception (Domschke et al., 2010) but poor respiratory interoception (Garfinkel et al., 2016). Similarly, gastric interoceptive tasks are more helpful to investigate eating disorders (Khalsa et al., 2018, 2022). In our case, we found a possible association between difficulties in describing emotions and Respiratory Score but not with HRD. Respiratory interoception as evaluated in the DDR task could therefore be more strongly linked to emotional processes than resting heart rate. The link between respiration awareness and emotional regulation could be intuitively illustrated by the fact that during times of stress, slowing one's breath allows for the activation of parasympathetic response, leading to physiological relaxation (Boyadzhieva & Kayhan, 2021). Individuals with higher respiratory interoception may be more conscious of changes in their breathing rhythm and therefore better able to regulate it. Indeed, enhancing respiratory awareness through practice, such as with meditation or slow-paced respiration (cardiac coherence methods), has shown positive clinical benefits in various disorders, including depression or anxiety (Fournié et al., 2021; Payne & Crane-Godreau, 2013), as well as panic disorder (Meuret et al., 2009). Our study seems to be contributing to the fundamental research investigating interoceptive modalities, their relationship to each other, cognitive and affective aspects, and their implications in rehabilitation.

Concerning the association between difficulties in describing emotions and the DDR task, we observed a potential effect of the alexithymia facet of DDF on respiratory interoception. Specifically, DDF levels predicted DDR task scores and participants with high DDF levels demonstrated lower respiratory interoception. Additionally, interoceptive awareness measured with the MAIA scale was lower in the high DDF group compared to the low DDF group. Generally, the PCA demonstrated negative associations between the TAS and MAIA total scales and their subscales. Alexithymia is associated with reduced cardiac interoception accuracy on the HBC task (Herbert et al., 2011; Shah et al., 2016) and hypersensitivity to painful stimulation (Kano et al., 2007; Katz et al., 2009). However, the link between alexithymia and interoception has been questioned, notably by the meta-analysis conducted by Trevisan et al. (2019) on 44 studies, which failed to find an association between TAS-20 and interoception when measured with the HBC task, but not with self-reports. Although this meta-analysis questions the association between interoception and alexithymia, their finding is based on studies using the HBCT task. As this task has well-established limitations (see Introduction), the lack of association could be due to the use of non-valid interoceptive measures rather than the absence of a true association. Respiratory tasks could potentially be more valid and not mask this association, as found in the current study. Indeed, a few respiratory studies have shown an association between alexithymia and respiratory interoception. For example, Abdulhamid et al. (2022) found an association between TAS-20 and lower abilities to synchronize respiration with an external pacer. Similarly, Murphy et al. (2018) demonstrated a negative correlation between TAS-20 scores and the ability to accurately estimate and produce a target exhalation. They also found this association with a muscular effort task and a taste sensitivity task. The authors proposed that alexithymia could be a marker of multimodality interoceptive impairment associated with both reduction in interoceptive accuracy and a decrease in multimodal integration. Moreover, authors consider alexithymia as a general deficit of interoception as it is associated with poor self-reported non-affective interoception (Brewer et al., 2016). Alexithymia could also be useful to discriminate tasks that measure actual interoception. In our case, the association between TAS and lower respiratory interoception, and the fact that DDF predicted scores on our task, suggested that our task is a good tool to measure interoception.

Finally, ur results showed an association between the DDR task performances and self-reported fitness

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condition, suggesting that a high fitness condition predicts higher respiratory interoception. Interestingly, a similar relationship can be observed between fitness condition and interoceptive awareness measured with the MAIA scale. These results are in line with Herbert and Pollatos (2014)'s study, which showed a negative correlation between BMI and HBC task among overweight and obese participants. Generally, cardiac interoception is associated with fitness conditions, with the assumption that more fit subjects are more aware of their heart action (Cameron, 2001; Cameron, 2002). The literature has also shown that the insula, the brain region involved in interoception, is involved in the regulation of physical exercise (for review, see Paulus et al., 2013). Indeed, the interoceptive model of central fatigue (McMorris et al., 2020) is based on the idea that the default mechanism in humans is the maintenance of homeostasis by stopping a physical activity earlier rather than too late. To achieve this, a prediction of the expected sensory feedback is fed forward by prefrontal brain regions to the insula. This prediction of interoceptive feedback depends on past experiences of physical activity and the individual's perception of their current fitness level. In our case, we could assume that participants with a higher fitness level may use their past experiences of heavy breathing induced by sports activities to achieve the task. Furthermore, we found a negative correlation between the *not worrying* subscale of the MAIA scale, which assesses the tendency not to worry about sensations of pain or discomfort and the respiratory interoception. Fitness condition was also positively correlated with this *not worrying* subscale. This could mean that the participants with a higher fitness level had experienced more unpleasant physical experiences while doing sports, such as breathlessness. These experiences enabled them to increase their respiratory awareness and to not associate breathlessness with worrying, but rather link it to physical activity that can bring health benefits and a feeling of well-being. These participants may have therefore felt less aversion to extended exhalations during the DDR task and had a greater respiratory awareness. However, this implies that extended exhalations may have created an aversive feeling in less fit participants. Nevertheless, the assessment of the comfort of the DDR task was not associated with fitness level, and the DDR task was not perceived as uncomfortable. This suggests that it was the greater respiratory awareness and not a lower aversive bias to the breathlessness that allowed fitter participants to score higher on our task.

The DDR task has many advantages, including easy manageability and the ability to adapt to inter-individual differences in respiratory rhythm and interoceptive reactivity through an adaptive staircase paradigm. Additionally, it exhibits a high ecological validity, as prolonged breathing is a common experience in everyday life, particularly during physical exertion or meditation practices. However, the DDR task does have some limitations. First, we used a belt to measure respiration. However, the variation in belt compression could provide a clue to discriminate the duration of the exhalations. The use of non-contact respiratory measurement tools could make the task even more ecological. For example, there are phone applications that detect respiratory phases using either a smartphone's microphone to detect variations in sound of inhalation and exhalation (Shih et al., 2019) or it's camera to detect chest movements (Reyes et al., 2016). Another way to address this initial limitation would be the use of respiratory inductive plethysmography. This technique incorporates an abdominal (ABD) belt in addition to the rib cage (RC) belt. As it is based on measuring variations in the magnetic field around the thorax or abdomen induced by breathing, it avoids compression of the belt. Furthermore, by measuring both thoracic and abdominal movements during breathing, it becomes possible to determine the level of abdominal breathing using the rib cage to abdominal motion ratio (RC/ABD ratio) (Yamaguti et al., 2012). A lower ratio indicates a higher degree of abdominal breathing. Abdominal or diaphragmatic breathing (DB) is a breathing awareness technique that aims to enhance abdominal movement while minimizing respiratory muscle activity in the chest wall (Dechman & Wilson, 2004). DB is a fundamental technique used in meditation to address anxiety disorders or chronic obstructive pulmonary disease (Hamasaki, 2020). This additional measurement allows for a deeper understanding of individual differences in their breathing awareness. Second, although we measured interoception accuracy, we did not measure interoceptive metacognition, which is the correspondence between subjective confidence in performance and objective performance. Yet, metacognition is considered a psychological dimension of interoception (Critchley & Garfinkel, 2017). In addition, individuals with greater confidence in their interoceptive accuracy may be more likely to use interoceptive signals in daily life. Moreover, discrepancies between subjective interoceptive sensibility and objective interoceptive accuracy can predict emotional states such as anxiety and affective psychopathology (Garfinkel, Tiley, et al., 2016). In future versions of the DDR task, a confidence scale should be added after each of the participants' responses. Finally, the gender imbalance of our sample could be considered a limitation, but no gender effect was observed for our task, demonstrating the absence of gender bias.

Nevertheless, these limitations could easily be overcome in future work and did not impact the quality of our innovative task. In the future, the DDR task should be administered in psychopathological populations to investigate the assumption that atypical interoception may be a common factor across psychopathology. Finally, the dysfunction of interoception is now gaining

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more acknowledgment as a significant factor in various mental health disorders (Khalsa et al., 2018). Therefore, it becomes crucial to introduce the measurement of interoceptive accuracy within clinical settings. For instance, utilizing tools such as ours can open avenues for interventions designed to enhance respiratory interoception. Techniques like paced breathing or DB methods could be employed for this purpose.

In conclusion, this study demonstrates the practical and innovative value of the DDR task. Moreover, we found interesting associations with fitness level and alexithymia that confirm the usefulness of the DDR task as a valid measure of interoception. This study also emphasizes the need for validated tasks in different bodily modalities to understand the links between them and their contributions to general interoceptive ability.

AUTHOR CONTRIBUTIONS

Alice Bodart: Conceptualization; data curation; formal analysis; investigation; methodology; software; writing – original draft. **Sandra Invernizzi:** Formal analysis; writing – review and editing. **Mélanie De Leener:** Data curation; investigation. **Laurent Lefebvre:** Funding acquisition; supervision; writing – review and editing. **Mandy Rossignol:** Supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors report no financial interests or other potential conflicts of interest.

DATA AVAILABILITY STATEMENT

The data for this study and the respiratory duration discrimination task are publicly available at: https://osf.io/d9u24/.

ORCID

Alice Bodart https://orcid.org/0000-0002-0088-9685

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