ROOM TO BREATHE: USING ADAPTIVE ARCHITECTURE TO EXAMINE THE RELATIONSHIP BETWEEN ALEXITHYMIA AND INTEROCEPTION

Haneen Abdulhamid (1)
Nils Jäger (2)
Holger Schnädelbach (3)
Alastair D. Smith (4, 5)

1. School of Psychology, University of Nottingham, United Kingdom
2. Department of Architecture and Built Environment, University of Nottingham, United Kingdom
3. Holger Schnädelbach Adaptive Architecture (HSAA), Berlin, Germany
4. School of Psychology, University of Plymouth, United Kingdom
5. Brain Research & Imaging Centre, University of Plymouth, United Kingdom

Contact:
Correspondence can be directed to Dr Alastair D. Smith, School of Psychology, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK (email: alastair.smith@plymouth.ac.uk) or Haneen Abdulhamid, MSc (email: Haneen_abdulhamid@hotmail.com).

ABSTRACT

Objective: Individuals with alexithymia experience difficulties interpreting emotional states in self and others, which has been associated with interoceptive impairment. Current theories are primarily based on subjective and conscious measures of interoceptive sensitivity, such as heartrate detection, but it is unclear whether similar observations would be found for objective or implicit psychophysiological measures. The present exploratory study assesses the potential of a novel assay through the use of adaptive immersive architecture [*ExoBuilding*].

Methods: N=88 participants were screened for alexithymic traits and N=27 individuals, representing the range of scores, were sampled to participate in the behavioural task. In a repeated-measures design, participants were placed within ExoBuilding and asked to match their respiration to its movement. Performance was compared to a two-dimensional pacer condition. Behavioural (accuracy) and psychophysiological (Respiratory Sinus Arrhythmia [RSA] and heartrate) measures were compared across conditions, and also related to individual alexithymic traits.

Results: Participants with higher levels of alexithymia performed less accurately than participants with lower levels, in both conditions. High-alexithymia participants showed a smaller reduction in heartrate over the course of the ExoBuilding condition than low-alexithymia participants, although there were no differences in RSA between conditions or participants.

Conclusion: Alexithymia extends beyond conscious interoceptive activities and is also observed in immersive contexts that usually exert psychophysiological effects on typical occupants. These initial findings highlight the importance of considering both conscious and implicit measures of interoception, and we suggest ways in which theories of alexithymia might benefit from capturing this distinction.

Keywords: interoception; alexithymia; adaptive architecture; Respiratory Sinus Arrhythmia

INTRODUCTION

Since the inception of the discipline, psychological theories of emotion have proposed a fundamental relationship between mental and bodily states that continues to inform present-day medicine (Critchley, Wiens, Rotshtein, Ohman, and Dolan, 2004). This approach can be traced back to the James-Lange theory of emotion (James, 1884; Lange, 1922), which postulates that viscero-afferent feedback has a causatory role in phenomenological emotional experiences. In other words, emotions (e.g. fear) originate from the individual's perception of physiological responses (e.g. quickening heartbeat, blood pressure, and temperature) that are generated by the autonomic nervous system in response to external events (Critchley et al., 2005; Nummenmaa, Glerean, Hari & Hietanen, 2013; Pollatos, Kirsch, & Schandry, 2005). As such, emotions can be considered the conscious experience of a bodily response, and whilst subsequent theories of emotion have sought to specify a more complicated array of cognitive and motivational factors, the core notion of emotions as somatic appraisal remains a common feature (see: Moors, 2009).

A clear antecedent of this standpoint is that individual differences in emotional experiences should be associated with the ability to accurately detect one's own physiological states, a process known as interoception (Cameron, 2001; Seth, 2013; Sherrington, 1948). Empirical studies have revealed a positive relationship between interoceptive sensitivity (e.g. in heartbeat perception tasks) and emotional experiences (Critchley et al., 2004; Ferguson & Katkin, 1996; Schandry, 1981; Wiens, Mezzacappa, & Katkin, 2000). That is, individuals classified as highly interoceptive, or "viscerally aware", are more emotionally expressive and may even experience higher-intensity emotions (Craig, 2004; Wiens et al., 2000). In contrast, other individuals demonstrate a particular impairment in the ability to interpret physiological information. This condition, known as alexithymia, is characterised by difficulties in representing, understanding, and describing one's own emotional and internal physiological states (Taylor, 1984). In line with an embodied account of affective experience, people who struggle to identify emotional states, such as fear, also have difficulty identifying and differentiating interoceptive states, such as hunger and fatigue (Craig, 2004; Lane et al., 1998, 2000).

This relationship has since proved to be a useful predictor of physical and psychological symptoms associated with a variety of recognised conditions (Demers & Koven, 2015; Schaefer, Egloff, Gerlach, & Witthoft, 2014; Shah, Catmur, & Bird, 2017). For example, higher levels of alexithymia are characterised in individuals with depression (Honkalampi et al., 2000, 2001), anxiety (Leweke, Leichsenring, Kruse, & Hermes, 2012), and somatoform disorders (Cox et al., 1994; Karvonen et al., 2005).

Current understanding of the relationship between alexithymia and interoception tends to be based on conscious somatic detection and estimation tasks, such as asking participants to silently count their heartbeat within specified timeframes, or to judge whether feedback from a signal is synchronous with their heartbeat (Schandry, 1981). The utility of such an approach is that it mirrors the affective appraisal of somatic variations in everyday life (Nicholson et al., 2018), whilst also possessing good test-retest reliability (Mussgay, Klinkenberg, & Rüddel, 1999; Nicholson et al., 2018). It is unclear, however, whether the same insights would be observed from assays that do not necessarily rely on conscious (or effortful) monitoring. For example, Respiratory Sinus Arrhythmia (RSA) has been proposed as a particularly sensitive biomarker for heightened interoceptive awareness and as an index of emotional regulation (Beauchaine, 2001; Beauchaine, 2015). RSA is a non-invasive measure of parasympathetic influences on cardiovascular output and is assessed by extracting the high frequency component of the heartrate (i.e., beat-to-beat variability). During a resting state, higher RSA might be indicative of physiological flexibility and a higher ability to adapt to environmental stressors (Price & Crowell, 2016). A higher resting RSA (indicative by greater RSA amplitude) may be associated with superior emotional regulation abilities (Beauchaine, 2001), reflected by better cognitive control of emotions and, therefore, processing of negative affect (Park & Thayer, 2014; Tonhajzerova, Mestanik, Mestanikova & Jurko, 2016). Lower respiration rates (achieved through abdominal breathing) tend to reduce heartrate, which is shown to reduce stress (Prinsloo et al., 2010). The more that heartrate variability (HRV) and respiration are aligned, the more likely participants are to achieve a state of relaxation. This measure of relaxation might, therefore, also indicate higher interoceptive abilities. Hence, an individual's RSA magnitude at rest may be informative to the physiological flexibility during emotional regulation (Porges, 1995, 2007; Tonhajzerova, et al., 2016).

The exploratory study reported here was conducted with two broad aims. The first was to investigate the use of RSA as an implicit dependent measure of interoceptive ability in alexithymia. The second was to examine the role of context in obtaining this measure. Whilst most studies of alexithymia require participants to respond to a simple external stimulus (or to attend to internal autonomic signals) much of our everyday experience of interoception and, indeed, emotion occur in a more immersive context (i.e. we are somehow a part of the situation, rather than a passive observer). We, therefore, sought to investigate whether making use of a more immersive context in the laboratory might generate new insights. Accordingly, our volunteers interacted with *ExoBuilding*, a three-dimensional single-occupant adaptive architecture structure (Jäger, Schnädelbach, Hale, Kirk, & Glover, 2017; Schnädelbach, Glover, & Irune, 2010). Previous multidisciplinary research with ExoBuilding has modulated the form of the structure in response to concurrent psychophysiological measures taken from its occupants. For example, Schnädelbach et al. (2012) used ExoBuilding to mirror participants' respiration rates by expanding and contracting the walls in sync with their breathing. They found that it triggered reciprocal physiological changes in its occupants, resulting in lower heart rates, higher respiration amplitudes, and lower frequency of heartrate variability, which are indicative of relaxation states (see also: Jäger, Moran, Schnädelbach, 2014; Jäger et al., 2017). This suggests that simple modulation of immersive environments can have concomitant effects on psychophysiological factors and we, therefore, sought to ascertain whether participants with higher levels of alexithymic traits might demonstrate greater awareness of their physiological states when in the context of a powerful adaptive architecture, compared to a simple 2D stimulus.

Our participants were asked to match their respiration patterns to an external pacer. In one condition, this was the movement of ExoBuilding, and in another the pacer was a 2D on-screen representation of an expanding and contracting balloon. For each of these tasks, we measured respiration matching accuracy (i.e. the correlation between respiration rates and the rate of the pacer), as well as participants' heartrate and RSA values. Whilst heartrate was primarily recorded to provide a measure of RSA, we analysed this data independently, since it might be indicative of the extent to which a participant was feeling relaxed throughout the experiment- i.e., greater synchrony in respiration matching should be related with a lower heartrate, indicating a higher state of relaxation (Russo, Santarelli, & Rourke, 2017). We hypothesized that individuals with high levels of alexithymia traits (as classified by the TAS-20; Bagby, Parker, & Taylor, 1994) would perform less accurately at the respiration matching tasks, reflected in a relative lack of improvement in performance across time, and in lower RSA levels. However, based on previous findings of the positive effects of adaptive architecture, we also predicted that this effect would interact with the particular task, with superior performance in ExoBuilding for all participants. This is because performance under ExoBuilding may become more implicit overtime (see: Froese & Fuchs, 2012), and may hence require less cognitive control than other forms of pacing tasks (Schnädelbach, Slovák, Fitzpatrick, & Jäger, 2016).

METHOD

Participants

To identify a pool of participants from which a representative range could be recruited, on the basis of alexithymic traits, an opportunity sample of undergraduate students from the University of Nottingham were asked to complete the *Toronto Alexithymia Scale* (TAS-20; Bagby et al., 1994). The TAS-20 (Bagby et al., 1994) is a 20-item self-report measure that is scored using a 5-point Likert scale, whereby 1= strongly disagree and 5= strongly agree. Responders answer questions associated with three separate subscales: difficulty describing feeling, difficulty identifying feeling, and externally oriented thinking. A score of 61 or greater is indicative of alexithymia, whereas scores between 52-60 indicate possible alexithymia. The TAS-20 demonstrates good internal consistency ($\alpha = .81$) and test-retest reliability (.77, $p<.01$) (Bagby et al., 1994; Taylor et al., 1997, 1988).

A total of 88 participants completed the scale and, based on their TAS-20 scores, respondents were grouped into low ($x < 52$), medium ($52 < x < 60$), and high ($x > 61$) categories. Opportunistic sampling was then employed to recruit participants from across the groups to participate in the second part of the experiment. A total of 27 participants (22 females and 5 males), aged between 18-24 years (M= 20.778, SD= 1.22), completed the full experiment. Nine participants were low scorers (M= 43.778, SD= 6.815), 10 were medium scorers (M= 55.700, SD= 3.129), and 8 were high scorers (M=

63.250, SD= 2.493). Alexithymia was, however, considered as a continuous measure in our analyses. A summary is provided in Table 1.

Table 1. Demographics of the dependent variables according to alexithymia grouping

		Low scorers	Medium scorers	High scorers
TAS-20	Minimum	29.00	52.00	61.00
	Maximum	50.00	59.00	68.00
	Mean (SD)	43.78 (6.82)	55.70 (3.13)	63.25 (2.49)

Note. TAS-20 refers to the Toronto Alexithymia Scale (Bagby et al., 1994)

Ethical approval for this study was granted by the School of Psychology Research Ethics Committee, at the University of Nottingham (approval number: 337). All participants provided fully informed consent and were granted research participation points upon completion.

Apparatus

ExoBuilding is a single-inhabitant, tent-like structure, originally based on the biofeedback principle. It is made of fabric, stretched over an aluminium spine, and suspended from two ceiling servomotors (Jäger et al., 2017). The footprint of the structure was approximately 350cm x 200 cm, with a height that varied between 130-160cm (Figure 1). ExoBuilding uses the MindMedia Nexus-10 biofeedback device, with electrocardiogram (ECG) electrodes and a respiration belt that measures expansion and contraction of the abdomen via a stretch sensor. All signals from the Nexus-10 device are synchronised within the same time domain. This raw data is processed by MindMedia's BioTrace+ software, which passes the data to a custom middleware platform (the Equator Component Toolkit [ECT]; Egglestone et al., 2006). ECT sends the data to the servomotors in real-time, resulting in the user's breathing directly controlling the upward (inhalation) and downward (exhalation) motion of ExoBuilding. The physical effects are an increase in volume, modulation of the shape (taller and narrower during inhalation), and visible billowing of the fabric, which causes a slight air movement. Modulation of the volume of the space (i.e. mirroring expansion and contraction of the lungs during respiration) has previously been shown to make its occupants more aware of their physiological states, and it has been argued that it can, over time, improve an individual's ability to control them (Schwartz & Andrasik, 2003). The feedback loop of the ExoBuilding has also been shown to reduce participants' respiration rates (i.e. breathing more deeply, and more regularly), even when they were not instructed to do so (Schnädelbach et al., 2012).

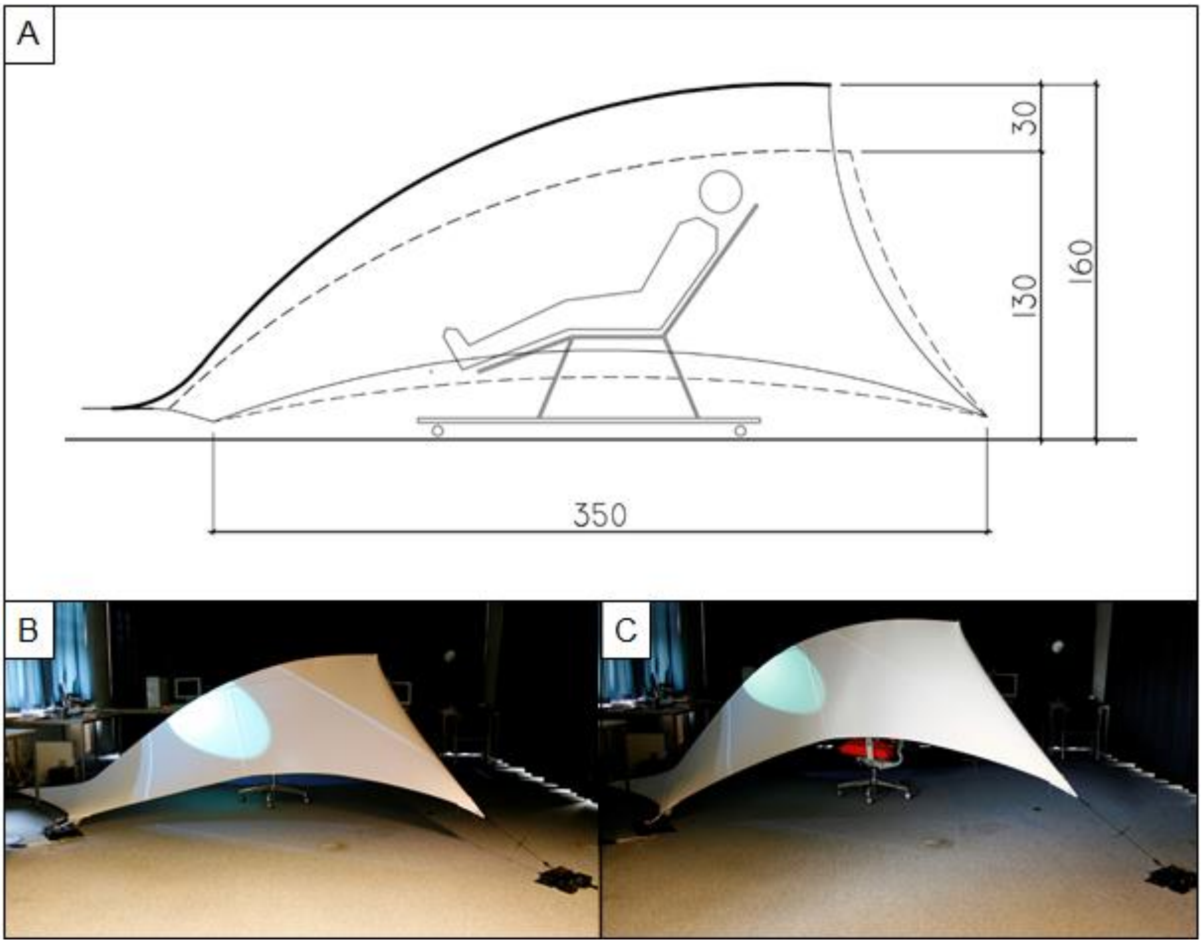


Figure 1. Schematic diagram of the ExoBuilding structure (A), and photographs illustrating its contracted (B) and expanded (C) states. Both extents are respectively represented in the schematic by dashed and solid lines.

The 2D Condition utilised a feature of the MindMedia Bio Trace software (http://www.mindmedia.nl/CMS/index.php): an animation of a red and white-striped balloon shown in the middle of a computer screen, with a neutral sky-like background. The balloon was set to inflate and contract to the same pacer as that set to ExoBuilding.

Design and Procedure

A timeline for the experimental session is illustrated in Figure 2. After providing their consent, participants were fitted with recording apparatus for the measurement of physiological variables. Participants were first given three electrode patches to apply directly onto their own skin, in order to measure heart muscle activity. The experimenter guided participants in attaching two electrodes below the right and left collarbones and one below the ribcage. Participants were also asked to wear a stretch-sensitive belt around their waist, to measure the expansion and contraction of the abdomen as a result of respiration. Physical data were tracked using NeXus-10 Bio-sensing feedback device, designed by MindMedia (2015). NeXus-10 was connected via Bluetooth to BioTrace+, running on Windows XP. BioTrace+ acquired signals from the sensors and translated them into graphs, comparing the pacemaker (5000ms in and 5000ms out) to the participants' heartrate and respiration patterns. Both ExoBuilding and the 2D pacer were automated to reach six breaths per minute, and so each condition was approximately 8 minutes in length (equating to 40 breaths per condition). Regulating breath to six breaths per minute is associated with increased fluctuations of heartrate and blood pressure (Bernardi, Gabutti, Porta & Spicuzza, 2001; Chang, Liu & Shen, 2013). Furthermore, maximisation of RSA/ heartrate variability is confirmed by several studies to reach at around 6 breaths per minute (Ben-Tal, Shamailov & Paton, 2014; Brown, Beightol, Koh & Eckberg, 1993).

The experiment was conducted in a quiet, sound-isolated room, with controlled lighting. Both conditions were completed in the same session, and the order in which conditions were completed was fully counterbalanced across participants. In the ExoBuilding condition, participants were guided to sit comfortably on a reclining chair, which rested on a wooden platform that was positioned in the middle of the structure. Before the commencement of the experiment, participants were told to expect an up and down movement, mirroring a breathing pattern, and were instructed to match their breathing patterns to the expansion (inhalation) and contraction (exhalation) movements of the structure. After all questions were answered, and participants had confirmed that they were ready to begin, the experimental procedure started. This was indicated by a signal from the experimenter, and then the onset of the ExoBuilding. The subsequent offset (approximately eight minutes later) signalled the end of the task.

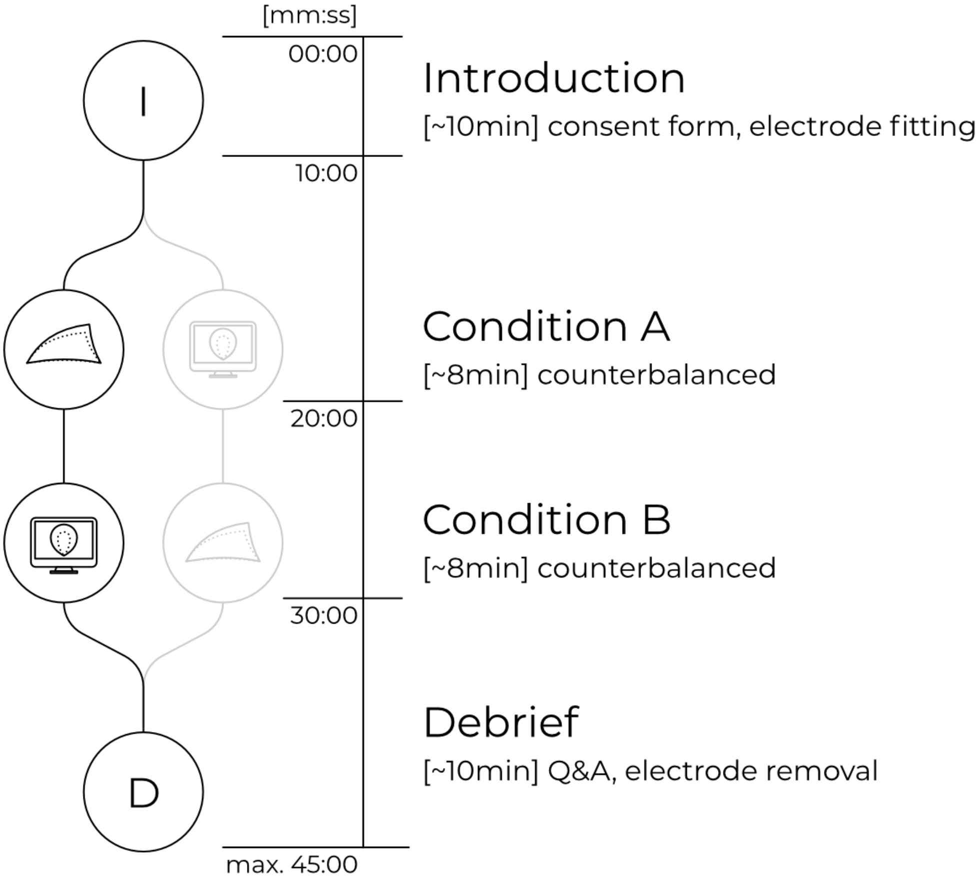


Figure 2. Illustration of the timeline for an experimental session. The order in which conditions were presented (i.e. ExoBuilding first, then 2D pacer second, or vice versa) was counterbalanced across participants.

In the 2D condition, participants were comfortably seated in front of a computer monitor. As in the ExoBuilding condition, participants were instructed to match their breathing patterns to the movement of an animated balloon that inflated and contracted- i.e. they were to inhale when the balloon expanded, and to exhale when it contracted. Again, once participants had confirmed that they were ready to begin, the experimenter gave a signal and the balloon animation started.

After both experimental conditions were completed, participants were fully debriefed and provided with the opportunity to ask further questions.

Data analysis

Respiration matching. Analysis of participants' abilities to match their breathing patterns to the movement of the structures provided a core assay of interoception. Pearson correlations were conducted between the pacers' movements and respiration for every 15s of data (after Jäger et al., 2019). All negative correlations (which were the result of participants inhaling during contraction, or exhaling during expansion) were unsigned to disregard the effects of possible misinterpretations of the instructions (i.e. reversal of in/out direction). To assess overall performance, an Analysis of Covariance (ANCOVA) was used to compare mean matching scores across the ExoBuilding and 2D conditions, with TAS-20 scores as a covariate. This approach allowed us to examine the overall effects of our manipulation in isolation of alexithymic traits by controlling for TAS-20, but also allowed direct assessment of whether that relationship was affected by individual differences in alexithymic traits through examination of the main effect and interaction effects of the covariate. Further analysis examined whether there was a reliable change in performance throughout the tasks. To expedite this, mean data from each minute of the tasks were entered into a 2 (Condition: 2D, Exobuilding) x 7 (Time: Minute 1, Minute 2, Minute 3, etc.) ANCOVA, with TAS-20 as a covariate.

Heartrate. To assess general heartrate levels across the tasks, an ANCOVA comparing mean heartrate under both conditions was performed, with TAS-20 score as a covariate. To examine the change in heartrate throughout the task, mean heartrates from each minute of the tasks were entered into a 2 (Condition: 2D and ExoBuilding) x 7 (Time: Minute 1, Minute 2, Minute 3, etc.) ANCOVA, with TAS-20 entered as a covariate.

RSA: Following the methods reported by Jäger et al. (2017), RSA was calculated by performing Pearson correlations between heartrate and respiration values. Overall RSA was analysed by inserting mean values for both conditions into an ANCOVA with TAS-20 scored entered as a covariate. Furthermore, to examine the change in heartrate throughout the task, mean heartrates from each minute of the tasks were entered into a 2 (Condition: 2D and ExoBuilding) x 7 (Time: Minute 1, Minute 2, Minute 3, etc.) ANCOVA, with TAS-20 entered as a covariate.

Individual differences. To examine the potential for individual differences in performance, Pearson's correlations were conducted between full-scale TAS-20 scores and subscales of the TAS-20, and our behavioural and psychophysiological measures (i.e. respiration matching, heartrate and RSA) for both conditions. Subscales of the TAS-20 measure: Difficulty Describing Feelings (items 2, 4, 11, 12, 17); Difficulty Identifying Feelings (items 1, 3, 6, 7, 9, 13, 14); and, Externally-Oriented Thinking, describing the tendency to focus attention on external stimuli (items 5, 8, 10, 15, 16, 18, 19, 20).

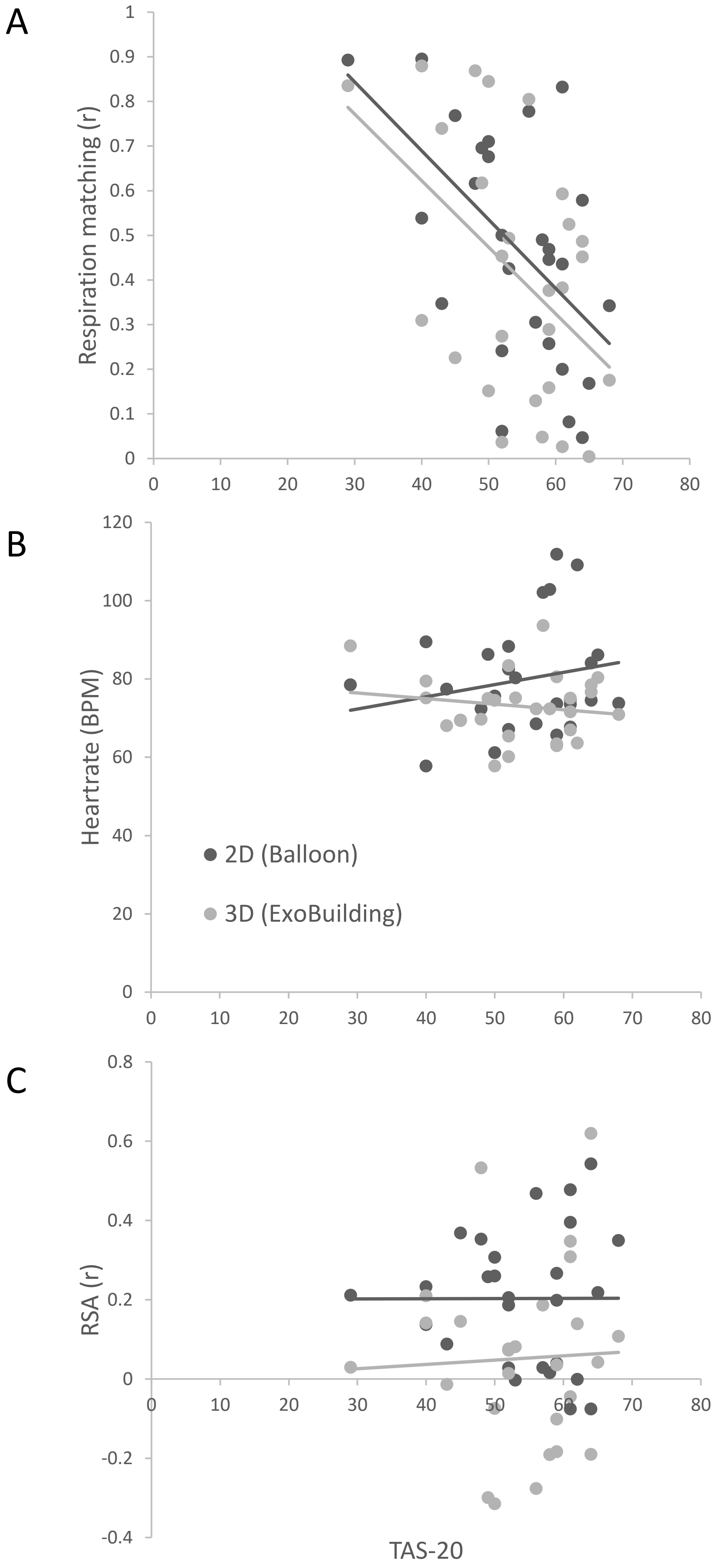
RESULTS

Data were sampled at 32Hz and normalised using the Minimum-Maximum method, whereby the minimum value was transformed into zero and the maximum to one. The first 15s and the final 60s data were discarded from the analysis, leaving approximately seven minutes of data per participant, under each condition. This ensured a similar duration across conditions and mitigated against the potential influence of inter-participant noise associated with individual differences in settling into and terminating the task. In the termination phase, the experimenter had to ensure that two different pieces of software (respectively controlling ExoBuilding [ECT] and recording data [BioTrace]) were no longer running, and that ExoBuilding was in an "up" position to facilitate easy exit by participants. This could not be precisely controlled across participants since they each needed to be at the top of an inhalation phase for ExoBuilding to be in the "up" position. This was, therefore, dependent upon individual respiration rates, and so data collected in the window within which these changes would be affected (i.e. the last minute) were excluded from analysis.

Prior to statistical processing, Shapiro-Wilk tests (along with inspection of histograms and Q-Q plots) were applied to evaluate the assumptions of normality. Normality was confirmed for all dependent measures: TAS-20 scores (p= .182), respiration matching rates under 2D and ExoBuilding conditions (p=.480 and .089, respectively), heart rate values under 2D and ExoBuilding conditions (p=.061 and .881, respectively), and RSA values under 2D ExoBuilding conditions (p=.471 and .321, respectively).

Respiration matching.

Mean data for each condition are plotted in Figure 3. Analysis of overall performance revealed no significant effect of condition ($F<1$), and no interaction between condition and TAS-20 ($F<1$). There was, however, a significant effect of TAS-20 scores upon behaviour (F (1,25) = 13.53, $p=.001$ $\eta_p^2= .351$), showing that participants with higher TAS-20 scores performed both matching tasks with lower accuracy. We next examined whether there was reliable change in performance throughout the tasks, and the associated ANCOVA revealed no significant effect of condition, or of time, and no interaction between any of the factors (all Fs <1). There was, however, an overall effect of TAS-20 (F (1,25) = 14.519, $p=.001$, $\eta_p^2 = .367$), confirming that participants with higher TAS-20 scores performed less accurately throughout the entirety of both conditions.


A
Respiration matching (r)
1
0.9
0.8
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Heartrate (BPM)
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60
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● 2D (Balloon)
● 3D (ExoBuilding)
C
RSA (r)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
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10
20
30
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60
70
80
TAS-20

Figure 3. Plots to illustrate the relationship between dependent measures and TAS-20 scores for 2D and 3D conditions: A) mean respiration matching performance (correlation between respiration rates and the pacer's movement); B) heartrate (beats per minute); and C) RSA (correlation between respiration rates and heartrate).

Heartrate.

Mean data for each condition are plotted in Figure 3. To assess general heartrate levels across the tasks, an ANCOVA revealed no effect of condition (F (1,25) = 1.44, p= .242, η_p^2 = .054), no effect of TAS-20 score (F<1), and no condition x TAS-20 interaction (F (1, 25) = 2.83, p=.105, η_p^2 = .102).

To examine the change in heartrate throughout the task, an ANCOVA revealed no significant effect of condition (F (1,25) = 1.430, p= .243, ηp2 = .054), no effect of TAS-20 score (F<1), and no condition x TAS-20 interaction (F (1,25) = 2.815, p= .106, ηp2 = .101). There was, however, a significant main effect of time (F (6,150) = 2.745, p= .015, ηp2 = .099), and inspection of Bonferroni-corrected pairwise comparisons revealed that heartrate in the final minute each condition was significantly lower than in the first minute (p=.005). A significant interaction between condition and time (F (6,150) = 5.435, p< .001, η_p^2 = .179) revealed that the reduction in heartrate was larger for the ExoBuilding condition (mean difference = 4.592 BPM) than it was for the 2D condition (mean difference = 3.746 BPM), although there was no significant time x TAS-20 interaction (F (6,150) = 1.994, p= .070, ηp2 = .074). Finally, there was a significant three-way interaction for condition x time x TAS-20, F (6,150) = 5.088, p< .001, ηp2 = .169. To examine this further, two independent ANCOVAs were conducted for each condition, with mean heartrate for Minutes 1-7 as a within-subjects factor (with seven levels), and TAS-20 as a covariate. Analysis of 2D data revealed no effect of time (F<1), no effect of TAS-20 (F (1,25) = 1.095, p= .305, ηp2 = .042), and no time x TAS-20 interaction (F<1). In contrast, analysis of ExoBuilding data revealed a significant effect of time (F (6,150) = 10.338, p< .001, ηp2 = .293), and inspection of Bonferroni-corrected pairwise comparisons revealed that heartrate in the final minute each condition was significantly lower than in the first minute (p=.002). There was no overall effect of TAS-20 on heartrate in this condition (F<1) but there was a significant interaction between time and TAS-20 (F (1,25) = 6.026, p= .021, ηp2 = .194) which revealed that participants with higher TAS-20 scores had smaller differences in heartrate across the time course of the ExoBuilding condition.

RSA.

Mean data for each condition are plotted in Figure 3. To assess overall RSA, An ANCOVA revealed no effects of condition, or TAS-20, and no interaction between the two factors (all Fs <1). To examine whether there was a reliable change in RSA over time, an ANCOVA revealed no significant effects of condition (F1, 25) = 1.760, p= .197, ηp2 = .066), time (F<1), or TAS-20 (F<1), and no interactions between conditions (all Fs <1).

Individual differences.

Few tests reached statistical significance, although there were reliable negative correlations between TAS-20 scores and respiration matching performance, both in 2D (p = .003) and Exobuilding (p = .012) conditions. This indicates that participants with higher TAS-20 scores performed more poorly in the behavioural task, irrespective of the condition tested. The Difficulty Identifying Feelings subscale was similarly related to respiration matching in both conditions (p =. 031 in the 2D condition; p = .027 in the Exo-Building condition), and the Externally Oriented Thinking subscale was negatively related to respiration matching in the 2D condition alone (p = .006).

Table 2. Correlation data Pearson's r for the association between the dependent variables and TAS-20 scores and subscales, across all conditions

			TAS-20 Subscales		
	Condition	TAS-20	Difficulty describing	Difficulty identifying	Externally oriented
Respiration matching	2D	-.552 **	-.289	-.416*	-.518**
	Exobuilding	-.479 *	-.362	-.426*	-.254
Heartrate	2D	.205	-.021	.299	.167
	Exobuilding	-.156	-.185	-.056	-.104
RSP	2D	.002	.337	-.172	-.164
	Exobuilding	.043	-.119	.057	.165

**Correlation is significant at the 0.01 level (two-tailed)

*Correlation is significant at the .05 level (two tailed)

DISCUSSION

Our findings support the prediction that higher alexithymia traits are associated with impaired respiration matching abilities, confirming links between high levels of alexithymic traits and atypical interoceptive abilities (Brewer et al., 2015; Herbert et al., 2011; Shah et al., 2017). The current study extends evidence that alexithymia might be associated with atypical interoception and associated with impaired perception of internal physiological signals (Murphy et al., 2019). Our tasks required participants to not only sustain their attention on an internal interoceptive domain (respiratory interoception), but to also regulate their breathing patterns. Thus, individuals with high alexithymic traits found it more difficult to be aware of, and to regulate, their breathing patterns in sync with the pacers.

Further investigation into the subscales of the TAS-20 revealed a relationship between difficulties in identifying emotions and respiration matching performance – i.e. individuals that reported difficulties in accurately understanding and appraising their emotional states had lower matching rates, across both conditions. There is a large body of empirical evidence that links emotional regulation abilities to interoceptive awareness (Craig, 2015), and accurate evaluation of physiological cues is related to regulation strategies that influence appropriate emotional response (Price & Hooven, 2018). The Externally Oriented Thinking subscale measures the extent to which individuals focus on the details of external events, rather than inner experiences. We found that a higher score on this subscale was associated with lower respiration matching abilities in the 2D condition – i.e. individuals with a higher score externally oriented thinking score performed less accurately in the 2D condition. However, this relationship was not present for the ExoBuilding condition. This might indicate that situation within an encompassing structure devoid of detailed stimuli (i.e. ExoBuilding) resulted in a reduced focus on the external environment for some participants and, therefore, greater interoceptive sensitivity.

Our data indicate the relative stability of alexithymia across contexts, since ExoBuilding did not seem to elicit greater accuracy in matching performance than the 2D condition in high-alexithymia participants. This tallies with other demonstrations of enduring domain-general properties of alexithymia. Several experimental studies have found features of alexithymia to remain stable over time, even after a clinical intervention, despite an improvement in related clinical conditions (Cohen, Auld, & Brooker, 1994; Salminen, Saarijärvi, Ääirelä & Tamminen, 1994). For example, a one-year longitudinal follow-up study of alexithymia in a group of patients with major depression reported no significant differences in alexithymia scores after the follow-up, while levels of depression and distress were significantly lower (Saarijärvi, Salminen, & Toikka, 2001).

Interoception does not only refer to the degree to which individuals consciously perceive and regulate interoceptive signals, but also to the unconscious/implicit physiological perception of those signals (Murphy, Brewer, Catmur, & Bird, 2017). Accordingly, we considered RSA as an implicit biomarker of participants' responses, indicating levels of self-regulation and interoceptive awareness (Ferri, Ardizzi, Ambrossecchia & Gallese, 2013). However, our data did not show that participants with high alexithymia traits had smaller differences in RSA values than low-alexithymia participants. In contrast, high-aleithymia participants showed a smaller reduction in heartrate over the course of the ExoBuilding condition than low-alexithymia participants. These data might, therefore, indicate that alexithymia is not only defined in terms of atypical explicit perception and control of interoceptive signals (i.e. respiration patterns), but that implicit responsivity to external cues might also be atypical.

Taken together, the current findings may offer an opportunity to refine our understanding of atypical interoception. The present study revealed reduction in both explicit behavioural response (i.e. respiration matching) and implicit psychophysiological responsiveness (i.e. heartrate) for individuals with higher alexithymia traits. However, the pattern of data was not consistent across all forms of measures, which suggests that it may be useful to consider a modification to the model of interoception proposed by Murphy, Catmur, & Bird (2019). Their 2 x 2 factorial framework highlights both *how* interoception is measured (e.g. objective vs. self-report), and *what* aspect of interoception is being measured (e.g. attention or accuracy).

Accordingly, we explored the utility of *objective* measures, designed to assess the degree to which participants were able to *attend* to their own interoception signals. It may, then, be useful to consider an additional dimension that accounts for *implicit/explicit* responsivity. Explicit responsivity may represent awareness and control of psychophysiological states, as in the case of respiration matching. Alternatively, implicit responsivity specifically signifies physiological states that are a consequence of an external stimulus, such as heartrate. This demonstrates the utility of considering the relationship between the implicit and explicit awareness in order to comprehensively characterise the full pattern of behaviour.

It is important to acknowledge that this study is exploratory in nature, and that future endeavours will benefit from larger sample sizes and a more representative cohort of participants. Moreover, the current study assessed the typical population, rather than a clinical group. It is also possible that the psychophysiological data may be influenced by cofounding variables that were not accounted for, such as poor aerobic conditioning, or use of arousing substances, such as caffeine or nicotine (Lumley, Neely, & Burger, 2007). However, the use of a more complex three-dimensional apparatus suggests that alexithymia can be tested in a more comprehensive array of settings. It would be useful for future studies to assess the validity of the measures used by comparing them to already existing measures of interoception. Although high-alexithymia participants did not benefit from performing an interoceptive task within ExoBuilding, more exploration of biofeedback paradigms like this one may help to identify potential benefits from increased awareness of psychophysiological states in this population (Lumley et al., 2007). Future studies should aim to investigate interventions that induce more attention to the individual’s internal states, and to explore whether that might enhance the individual’s sensitivity to interoceptive signals. For example, biofeedback paradigms that involve mindfulness exercises might enhance the individual’s interoceptive awareness, increasing the ability to identify, assess, and appraise bodily signals (Cameron, 2001; Price & Hooven, 2018). Within the paradigm we have presented here, it might be useful to assess how participants perform in a biofeedback variant, compared to a pacer. One could also individually match the rhythm of a pacer to the resonant frequency of a participant’s HRV, which may reveal a finer grain of interoceptive awareness.

We aim to further explore the more general utility of adaptive architecture within empirical psychological study. Previous research with ExoBuilding has shown that some users report feelings of calm and relaxation (Schnädelbach et al., 2012), and others have found it helpful in mindfulness exercises (Schnädelbach, 2016). This form of architectural biofeedback can be used in non-pharmaceutical, embodied treatment and has potential for the attenuation of anxiety and stress in users. Architectural biofeedback can also affect the interpersonal synchrony between a user dyad (Jäger et al., 2019) which opens new research avenues for studying the mediation of social dynamics and their relation to psychosomatic factors.

DECLARATIONS OF INTEREST: None

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