



City Research Online

City, University of London Institutional Repository

Citation: Christensen, J.F., Gaigg, S. B. and Calvo-Merino, B. (2017). I can feel my heartbeat: Dancers have increased interoceptive accuracy. *Psychophysiology*, doi: 10.1111/psyp.13008

This is the accepted version of the paper.

This version of the publication may differ from the final published version.

Permanent repository link: <http://openaccess.city.ac.uk/18063/>

Link to published version: <http://dx.doi.org/10.1111/psyp.13008>

Copyright and reuse: City Research Online aims to make research outputs of City, University of London available to a wider audience. Copyright and Moral Rights remain with the author(s) and/or copyright holders. URLs from City Research Online may be freely distributed and linked to.

City Research Online:

<http://openaccess.city.ac.uk/>

publications@city.ac.uk

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

I can feel my heartbeat: Dancers have increased interoceptive accuracy

Julia F. Christensen*^{1,2}, Sebastian B. Gaigg², Beatriz Calvo-Merino¹

¹ Cognitive Neuroscience Research Unit, Department of Psychology, City, University of London, UK

² Autism Research Group, Department of Psychology, City, University of London, UK

Author note

All authors, Department of Psychology, City, University of London, School of Arts and Social Science, St John Street, London EC1V 0HB, UK. Funded by a Newton International Fellowship of the British Academy (NF140935) (JFC) and PSI2012-34558 (BCM).

We are grateful to Dance works London, Pineapple Studios, Rambert School of Ballet and Contemporary Dance, and the London School of Russian Ballet for letting us recruit participants on their premises. Special thank you to the dancers who participated in the study.

Correspondence: Julia F. Christensen, City, University of London; Department of Psychology, School of Arts and Social Sciences; Rhind Building; Northampton Square; London, EC1V 0HB, UK.

26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

Abstract

Interoception is the process of perceiving afferent signals arising from within the body including heart rate (HR), gastric signals, etc. and has been described as a mechanism crucially involved in the creation of self-awareness and selfhood. The heart beat perception task is a tool to measure individuals' interoceptive accuracy (IAcc). IAcc correlates positively with measures of self-awareness and with attributes including emotional sensitivity, empathy, prosocial behavior, and efficient decision-making.

IAcc is only moderate in the general population. Attempts to identify groups of people who might have higher IAcc due to their specific training (e.g., yoga, meditation) have not been successful. However, a recent study with musicians suggests that those trained in the arts might exhibit high IAcc. Therefore, we here tested IAcc in professional dancers. Twenty professional dancers and 20 female control participants performed 4 intervals of a heartbeat perception task while their actual HR was recorded. Dancers had a higher IAcc, and this effect was independent of their lower heart rates (a proxy measure of physical fitness), counting ability and knowledge about HR. An additional between-group analysis after a median split in the dancer group (based on 'years of dance experience') showed that junior dancers' IAcc differed from controls, and senior dancers' IAcc was higher than both junior dancers and controls. General art experience correlated positively with IAcc. No correlations were found between IAcc and questionnaire measures of empathy, emotional experience, and alexithymia. These findings are discussed in the context of current theories of interoception and emotion –highlighting the features of arts training that might be related to IAcc.

Keywords: Interoceptive accuracy, dance, heart beat perception, self awareness, consciousness

51

52 **I can feel my heartbeat: Dancers have increased interoceptive accuracy**

53

54 **1. Introduction**

55 The empirical characterization of the neurocognitive mechanisms of consciousness and
56 self-awareness are increasingly the focus of empirical endeavor. Interoception is the
57 perceptual process that gives us the sense of the physical body from within (Craig, 2003;
58 Tsakiris, 2016). Bodily sensations arising from homeostatic processes in the body (e.g., heart
59 rate changes, arousal, temperature, hunger, touch, itch, gut motility, etc) are crucially related
60 to the conscious experience of affect (Cameron, 2001; Damasio, 1999b; Laird & Lacasse,
61 2014; Scherer, 2009), and to the creation of selfhood (Tsakiris, 2016). Therefore,
62 interoception has been suggested as a key perceptual system for consciousness and self-
63 awareness (Craig, 2002, 2003; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004;
64 Tajadura-Jimenez & Tsakiris, 2014).

65 Current empirical traditions measure interoception along 3 main dimensions (Garfinkel,
66 Seth, Barrett, Suzujum, & Critchley, 2015); (1) *interoceptive accuracy* (IAcc; objective
67 accuracy of perceiving bodily signals, e.g., heart rate (HR), gastric activity; Schandry, 1981;
68 Whitehead, Drescher, & Heiman, 1977; Whitehead & Drescher, 1980), (2) *interoceptive*
69 *sensibility* (self-rated tendency to focus on internal bodily signals as reported on
70 questionnaires; Bagby, Parker, & Taylor, 1994b; Mehling et al., 2012; Porges, 1993); and (3)
71 *interoceptive awareness* (meta-cognitive awareness of interoceptive accuracy; Receiver
72 Operating Characteristic; ROC curve; Garfinkel et al., 2015). These 3 dimensions are
73 commonly found to be uncorrelated (Garfinkel et al., 2015) and it is specifically *interoceptive*
74 *accuracy* (i.e., the objective accuracy of perceiving and reporting bodily signals as they
75 occur) that has been the most widely used in studies on self-awareness and emotional

76 experience. Specifically, interoceptive accuracy correlates positively with emotional
77 sensitivity (Dunn et al., 2010b), empathy (Fukushima, Terasawa, & Umeda, 2011; Herbert,
78 Pollatos, Flor, Enck, & Schandry, 2010), interpersonal sensitivity (Ferri, Ardizzi,
79 Ambrosecchia, & Gallese, 2013), altruistic behaviour (Weng et al., 2013), emotional
80 resilience (Haase et al., 2016), efficient decision-making under risk (Kandasamy et al., 2016;
81 Werner, Jung, Duschek, & Schandry, 2009; Werner et al., 2013; Wölk, Sütterlin, Koch,
82 Vögele, & Schulz, 2014), and inversely with susceptibility to body ownership manipulations
83 (Tajadura-Jimenez, Longo, Coleman, & Tsakiris, 2012; Tajadura-Jimenez & Tsakiris, 2014;
84 Tsakiris, Tajadura-Jimenez, & Costantini, 2011) and self-objectification (Ainley & Tsakiris,
85 2013). High interoceptive accuracy may thus have benefits for emotional well-being. Yet it is
86 important to note that heightened interoceptive ability may have positive as well as negative
87 consequences, since it may produce anxiety (Domschke, Stevens, Pfliegerer, & Gerlach,
88 2010). This is thought to be due to a learning process by which the awareness of the
89 interoceptive signal (e.g., heartbeat) may trigger the awareness of a prospective aversive body
90 state (e.g., panic attack) and therefore enhance anxiety and worrisome thoughts (Paulus &
91 Stein, 2010). In this context it has been suggested that high interoceptive accuracy might have
92 benefits for emotional well-being only in conjunction with a high interoceptive awareness
93 (Garfinkel et al., 2016).

94 Perceptual accuracy of interoceptive signals varies considerably across individuals and
95 is only moderate in the general population. The few available studies that have sought to
96 identify groups of individuals who may display higher interoceptive accuracy have failed to
97 demonstrate evidence of higher interoceptive accuracy in groups where such higher
98 interoceptive accuracy might be expected due to expertise in the perception of bodily signals
99 as a result of their specific training; e.g., in yoga practitioners and meditators (Daubenmier,
100 Sze, Kerr, Kemeny, & Mehling, 2013; Farb, Segal, & Anderson, 2013; Khalsa et al., 2008;

101 Melloni et al., 2013). These groups show a higher interoceptive *awareness* (i.e., they know
102 how good or bad they are at accurately estimating their heart rate), but not a higher
103 interoceptive accuracy.

104 An important exception in this literature, is a recent study examining interoceptive
105 accuracy in professional musicians (string players and singers), who showed a higher
106 interoceptive accuracy as compared to controls (Schirmer-Mokwa et al., 2015). Whilst pre-
107 existing personality differences may contribute to heightened interoceptive ability and
108 emotion comprehension skills in experts, the authors suggest that this difference can be
109 explained by the fact that musical training includes training in multisensory integration. Also
110 interoception implies multisensory integration; it is a perceptual activity which integrates
111 multiple signals from the body to one coherent percept of the state of the body.

112 We here propose that also another aspect of professional arts training is likely to be a
113 significant factor for the heightened IAcc in musicians; the expressive training they receive.
114 An artist's professional training involves daily practice in the craftsmanship of their
115 discipline, which involves a *dual* action: it includes the elicitation of bodily states (e.g., via
116 autobiographical memory elicitation or imagery e.g., Karin, Christensen, & Haggard, 2016)
117 *and* the immediate expression of these states (e.g., emotions, intentions, etc.), directly
118 through the body (e.g., dance, music, acting), or indirectly (e.g., writing, painting). Because
119 of this dual action of eliciting autonomic states and expressing these in behaviour (which the
120 artist carefully monitors and practices), expertise in the arts might be a type of training which
121 increases interoceptive accuracy (to remember: yoga and other meditative practices
122 specifically encourage individuals to disregard or to 'let go' of bodily states, emotions and
123 other cognitive states, rather than to generate and express them). A full account of this 'dual'
124 hypothesis of arts practice will require a series of systematic studies that examine the practice
125 effect in a number of converging ways. The approach taken in this paper is to operationalise

126 'practice' as a between-groups and cross-sectional manipulation of years of dance training.
127 Given the recent observations in relation to musicians, we here aim to extend the empirical
128 characterization of interoceptive expertise in artists by investigating interoceptive accuracy in
129 professional ballet dancers. In addition, to explore the influence of visual art experience, a
130 general 'art experience' questionnaire was administered. According to the above rationale
131 regarding training in the arts, any arts training would correlate positively with interoceptive
132 accuracy.

133 Regarding dance training in particular, long-term dance training results in significant
134 changes in behaviour, brain function and structure. For example, dancers have an enhanced
135 perceptual sensitivity to body movement which is illustrated by increased sensorimotor
136 response when they watch familiar body movements (Calvo-Merino, Glaser, Grèzes,
137 Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard,
138 2006; Cross, Hamilton, & Grafton, 2006; Fink, Graif, & Neubauer, 2009; Jang & Pollick,
139 2011; Orgs, Dombrowski, Heil, & Jansen-Osmann, 2008), and enhanced exteroceptive skills
140 (Bläsing, Tenenbaum, & Schack, 2009). Structural neural differences are evidenced by an
141 augmented cortical thickness of sensorimotor regions in dancers' brain, as compared to
142 controls (Hänggi, Koeneke, Bezzola, & Jancke, 2010). Ballet dancers also have higher trait
143 emotional intelligence than controls (Petrides, Niven, & Mouskounti, 2006), and are more
144 sensitive to the expressive qualities of others' affective body language (Bojner Horwitz,
145 Lennartsson, Theorell, & Ullen, 2015; Christensen, Gomila, Gaigg, Sivarajah, & Calvo-
146 Merino, 2016). The present experiment is the first to compare interoceptive abilities in
147 professional ballet dancers with those of a matched control group on an interoceptive
148 accuracy task.

149 The heart beat tracking method is emerging as the most widely used test of an
150 individuals' interoceptive accuracy (Ainley, Tajadura-Jiménez, Fotopoulou, & Tsakiris,

151 2012; Tsakiris, Tajadura-Jiménez, & Constantini, 2011). In this task, participants are
152 instructed to feel and count their own heartbeats over fixed time periods (e.g., between 20 –
153 100 seconds), without physically taking their pulse. The subjectively reported count is then
154 compared to the objectively recorded number of heartbeats (recorded with electrocardiogram;
155 ECG). The difference between estimated and actual heart beats serves as an index of the
156 participant’s level of interoceptive accuracy (Ainley et al., 2012; Tsakiris, Tajadura-Jiménez,
157 et al., 2011). In the study by Schirmer-Mokwa et al. (2015) described earlier, which
158 demonstrated superior IAcc in musicians than non-musicians, the Whitehead task was used to
159 measure interoceptive accuracy (Whitehead & Drescher, 1980). This task requires the
160 participants to judge whether rhythmically presented auditory cues are in synchrony with
161 their own heartbeats or not. This task obliges the individual to integrate interoceptive and
162 exteroceptive signals which is something musicians and dancers might be particularly good at
163 given their expertise in synchronizing their movements with sounds in their environment.
164 Therefore, we choose Schandry’s heart beat perception task, because this one solely relies on
165 interoceptive information. It is a well-validated measure, has a good test–retest reliability,
166 and it discriminates well between individuals (Mussgay, Klinkenberg, & Rüdell, 1999;
167 Werner et al., 2013).

168 Recent studies have also explored which individual difference factors might modulate
169 interoceptive accuracy by using questionnaire measures. While some studies have not found
170 associations between interoceptive accuracy and emotion and empathy questionnaire
171 measures (Ainley, Maister, & Tsakiris, 2015; Garfinkel et al., 2015), recent evidence suggests
172 a link between interoceptive sensibility questionnaires measuring alexithymia and
173 interoceptive accuracy (Cook, Brewer, Shah, & Bird, 2013; Gaigg, Cornnell, & Bird, 2016).
174 Therefore, in order to investigate the link between these individual differences in
175 interoceptive accuracy further, we administered a battery of questionnaires tapping into the

176 dimension of interoceptive sensibility (emotion, empathy and alexithymia questionnaires).
177 Finally, to explore whether also general training in the arts might be related to interoceptive
178 accuracy, as suggested above and by previous work on musicians (Schirmer-Mokwa et al.,
179 2015), participants filled in an art experience questionnaire (Chatterjee, Widick, Sternschein,
180 Smith II, & Bromberger, 2010).

181

182 **2. Method**

183 *2.1. Participants*

184 Twenty female ballet dancers (in professional training or working professionally with
185 Ballet as their main dance style) (age Dancers: $M = 25.35$; $SD = 4.57$) participated in
186 exchange for a small time reimbursement (£8/h). Twenty female undergraduate students with
187 no formal dance experience (age Controls: $M = 24.25$; $SD = 3.86$) participated in exchange
188 for course credits. The sample size was determined based on previous work. Schirmer-
189 Mokwa et al., (2015) reported a large effect size (Cohen's $d = 1.01$)¹ for the IAcc advantage
190 of musicians over non-musicians. Sample size calculations using *GPower* 3.1. (Faul,
191 Erdfelder, Lang, & Buchner, 2007) indicate that groups of 15 dancers and 15 controls would
192 be sufficient to detect a similar effect with a power of 85%. To protect against the possibility
193 that the effect might be somewhat weaker in dancers, groups of 20 were recruited for the
194 current study. The two groups of participants were matched in terms of age. Participants gave
195 informed consent. The study was approved by the City, University of London Research
196 Ethics Committee.

197

198 *2.2. Materials and procedure*

¹ Schirmer-Mokwa et al., (2015) report results separately for two sub-groups of musicians compared to controls. The effect size here refers to the comparison of the combined group of musicians vis-a-vis the control group as derived from the data set out in Table 1 of Schirmer-Mokwa et al., (2015).

199 A number of emotion-related individual difference variables that may be associated with
200 interoceptive accuracy were measured. The selection of self-report measures was based on
201 prior work using these in the context of interoception research, including empathy and
202 alexithymia measures (Ainley, Maister, & Tsakiris, 2015; Shah, Hall, Catmur, & Bird, 2016).
203 The selected measures included: 1) the *Interpersonal Reactivity Index* (IRI) (Davis, 1983),
204 which comprises 28 questions about a person's propensity for perspective taking, fantasy,
205 empathic concern and personal distress. Answers are given on a 5-point Likert scale with
206 total scores ranging from 0 – 140; 2) the questionnaire of Emotional Empathy (EE)
207 (Mehrabian & Epstein, 1972), which comprises 33 questions about a person's empathic
208 tendency. Answers are given on a 9-point Likert scale from -4 to +4; 3) the *Emotional*
209 *Intensity Scale* (EIS) (Bachorowski & Braaten, 1994), which includes 30 items probing a
210 person's propensity for reacting emotionally in both positive and negative interpersonal
211 settings. Answers are given on a 5-point Likert scale with total scores ranging from 30 - 150;
212 4) the *Toronto Alexithymia Scale* (TAS) (Bagby, Parker, & Taylor, 1994a), which includes 20
213 items that ask about a person's difficulty in identifying and describing their own feelings, and
214 their tendency for externally-focussed thinking. Answers are given on a 5-point Likert scale
215 with total scores ranging from 20 – 100; 5) the *Bermond-Vorst Alexithymia Questionnaire*
216 (BVAQ) (Bermond, Oosterveld, & Vorst, 1994; Bermond, Vorst, Vingerhoets, & Gerritsen,
217 1999), which includes 20 items that probe a person's difficulties in identifying, describing
218 and understanding their own emotions and their propensity to react emotionally to situations
219 and to fantasizing. Answers are given on a 5-point Likert scale with total scores ranging from
220 20 - 100; and finally, 6) the art experience screening questionnaire probed for number of arts
221 classes and of regular visits to art galleries and museums etc. (Chatterjee et al., 2010). Eight
222 items enquire about a person's art experience on 6 and 7-point Likert scales that ask about the
223 quantity and frequency of art enjoyment (e.g., museum visits, classes, hourly training, etc.).

224 The total score is made up of the sum of the answers to all items. On the Art Experience
225 Questionnaire, scores between 0–14 designate artistically naïve individuals, while artistically
226 experienced individuals have scores above 14. The questionnaire data for the two groups,
227 along with demographic characteristics are set out in Table 1.

228 **Insert table 1 about here***

229

230 A heartbeat perception task was used to measure participants' interoceptive accuracy
231 (Garfinkel et al., 2015; Schandry, 1981). Participants were asked to count their own
232 heartbeats during four time intervals of 25, 35, 45 and 100 seconds respectively, specifically,
233 without physically taking their pulse. The order of presentation of these intervals was
234 counterbalanced across participants, who were not informed about their specific durations.
235 The experiment was programmed in the stimulus presentation programme *E-prime* (version
236 E-Studio, v. 2.0.8.90; www.pstnet.com). Participants were instructed to press the <Enter>
237 button to start each trial. The word “start” then appeared and after each interval (25, 35, 45 or
238 100 seconds) the word “stop” appeared. For the duration of the interval a heart (5x10cm) was
239 displayed on the screen. To make the counting as precise as possible participants were
240 instructed to count specifically only for as long the heart was on the screen (and not at the
241 words “start” and “stop”). See figure 1 for the trial structure and table 1 for the two groups'
242 interoceptive accuracy.

243

244 **Insert figure 1 about here***

245

246 Participants' heart rate was recorded throughout the experiment with *ADInstruments*
247 *PowerLab System* (ML845) including a Bioelectrical signal amplifier (ML408 with
248 MLA2540 and MLA2505 5-lead shielded Bio Amp cables). Self-adhesive electrodes were

249 attached to participants' abdomen, and a ground electrode to the elbow. *LabChart 7* (v.7.3.1.
250 1994-2004; www.adiinstruments.com) was used to record and analyse the ECG signal from
251 which heart rate was derived. A trigger was sent from *E-prime* to the ECG trace to demarcate
252 the onset and offset of each trial.

253 The experimental session was structured as follows: Upon arrival participants read an
254 information sheet about the purpose of the study and provided written consent for their
255 participation. The actual task was then explained and a practice trial was carried out to
256 familiarize the participant with the task. Then followed the 4 intervals of the task. After the
257 heart beat perception task, to explore participants' confidence in their interoceptive
258 awareness, the experimenter asked the participants 3 questions to report (i) on a scale from 1
259 to 10, where '1' is not very confident and '10' is very confident, how confident they were
260 that they had counted accurately, (ii) which body part they had focused on during the task,
261 and (iii) their estimate of their own resting heart rate in beats per minute (hereafter 'heart rate
262 estimate'). Finally, participants were asked to fill in the questionnaires outlined above and
263 were then debriefed and paid for their participation.

264

265 2.3. Data analyses

266 For each of the 4 trials, an accuracy score was obtained for each participant (these
267 values were entered into the ANOVA, see below). An average across the 4 trials was also
268 obtained for each participant. The latter value was used for the correlational analyses. We
269 employed the following commonly used formula: $1 - (nbeatsreal - nbeatsreported) / ((nbeatsreal + nbeatsreported) / 2)$ (Hart, McGowan, Minati, & Critchley,
270 2013). In this formula, the reported values (*nbeatsreported*) are included within the
271 denominator to protect against overestimating performance accuracy in people with high
272 variance between the four intervals (Garfinkel et al., 2015). As effect sizes in the following

274 analyses we report partial eta (η_p^2) where .01 is considered a small effect size, .06 a medium
275 effect and .14 a large effect, and Cohen's d where t-tests were performed (Cohen, 1988).

276 For one participant (control), there was data loss for one of the 4 intervals due to
277 recording error. We have calculated the average of the other 3 intervals of the participant's
278 accuracy score to fill in this missing value.

279

280 **3. Results**

281 **3.1. Interoceptive accuracy**

282 Figure 2 illustrates the IAcc data as a function of the four duration intervals (25, 35, 45,
283 100 seconds) and group (controls, dancers). A 4 (Duration) x 2 (Group) repeated measures
284 (RM) Analysis of Variance (ANOVA) of these data revealed a significant main effect of
285 Group ($F(1, 38) = 9.389, p = .004, \eta_p^2 = .198$, observed power = .848), with dancers exhibiting
286 a higher interoceptive accuracy ($m = .699; SE = .06$), than controls ($m = .446, SE = .06$). The
287 main effect of Duration was also significant ($F(3, 114) = 2.939; p = .036, \eta_p^2 = .072$), as was
288 the interaction between Duration and Group ($F(3, 114) = 3.156, p = .028, \eta_p^2 = .077$), which
289 was characterized by a quadratic ($F(1,38) = 6.891, p = .012, \eta_p^2 = .153$) but not a linear trend
290 ($F(1,38) = 1.676, p = .203, \eta_p^2 = .042$). Before we return to this interaction in more detail, the
291 following analyses will first consider a number of possible explanations for the group effect,
292 which is of most interest.

293

294 **Insert figure 2 about here***

295

296 It has been suggested that physical fitness influences heartbeat awareness (de Geus, van
297 Doornen, de Visser, & Orlebeke, 1990; Pollatos, Herbert, Kaufmann, Auer, & Schandry,
298 2007). A low resting HR is a proxy measure of fitness, and our data confirmed a correlation

299 between resting HR and IAcc across both groups ($r = -.342$, $p = .031$). Although this
300 correlation was not significant within each group separately (Dancers: $r = .187$, $p = .430$;
301 Controls: $r = -.357$, $p = .122$), the Dancers had a lower resting HR ($m = 61.171$; $SD = 9.650$;
302 $SE = 2.158$) than controls ($m = 75.443$; $SD = 11.804$; $SE = 2.640$) ($t(38) = 4.186$; $p > .001$,
303 Cohen's $d = 1.32$). It was therefore, important to rule out the possibility that group
304 differences in physical fitness could account for the superior IAcc of dancers observed in the
305 above analysis. Resting HR was therefore entered into the ANOVA as a covariate, which did
306 not affect the pattern of results reported above. Specifically, the main effect of group
307 remained significant ($F(1,37) = 4.377$, $p = .043$; $\eta_p^2 = .106$), with dancers exhibiting higher
308 interoceptive accuracy than controls, while there was no main effect of resting HR ($F(1,37) =$
309 $.467$, $p = .498$, $\eta_p^2 = .012$). Although, there was no main effect of Duration ($F(3, 111) =$
310 1.313 ; $p = .274$, $\eta_p^2 = .034$), the interaction between duration and group remained significant
311 ($F(3, 111) = 3.683$, $p = .014$, $\eta_p^2 = .091$) and maintained the quadratic trend ($F(1,37) = 9.737$,
312 $p = .003$, $\eta_p^2 = .208$).

313 Another possibility for the superior IAcc of dancers is that individuals with a resting HR
314 naturally close to 60bpm may artificially appear more accurate in heart rate perception tasks
315 because of familiarity with the 60 second counts of a minute (Knapp-Kline & Kline, 2005).
316 Because dancers' resting HR was closer to 60 than controls, this possible confound was
317 examined by calculating the absolute difference between 60 and each participants' resting HR
318 (i.e., $ABS(60-HR)$). This difference score was indeed marginally correlated with IAcc across
319 both groups ($r = -.307$, $p = .054$), confirming that individuals whose resting HR deviated the
320 most from 60 had the lowest IAcc. However, when this difference score was entered as a
321 covariate in the ANOVA, the general pattern of results again remained unchanged. The main
322 effect of group remained significant ($F(1,37) = 5.376$, $p = .026$; $\eta_p^2 = .127$), with no
323 significant effect of the difference score ($F(1,37) = .580$; $p = .451$, $\eta_p^2 = .015$). And the

324 interaction between duration and group also remained significant ($F(3,111) = 4.258$; $p = .007$;
325 $\eta_p^2 = .133$), with a quadratic ($F(1,37) = 10.421$, $p = .003$, $\eta_p^2 = .220$) but not a linear trend (p
326 $= .407$).

327 A third explanation for the enhanced IAcc of dancers vs. controls could be that dancers
328 generally have greater knowledge about their own resting HR (Dunn et al., 2010a; Filippetti
329 & Tsakiris, 2017). In other words, dancers may not be better at tracking their heart beats, they
330 may simply know what their resting HR is. Given the data set out in Table 1, this explanation
331 seemed unlikely since dancers overestimated their resting HR by as much as controls
332 underestimated theirs (note that for 2 dancers HR estimates were not available). Moreover,
333 participants' estimates of their resting HR did not correlate with IAcc, either across both
334 groups combined ($r = .287$; $p = .072$) or each group individually (Dancers: $r = .038$, $p = .875$;
335 Controls: $r = .317$; $p = .173$). Finally, when HR estimates were entered as a covariate to the
336 ANOVA, the main effect of group again remained significant ($F(1,37) = 12.835$, $p = .001$; η_p^2
337 $= .268$), with dancers exhibiting higher interoceptive accuracy than controls. There was no
338 main effect of 'heart rate estimate' ($F(1,35) = 1.232$, $p = .275$, $\eta_p^2 = .034$), nor a main effect
339 of Duration ($F(3, 105) = .720$; $p = .542$, $\eta_p^2 = .020$), or interaction between duration and
340 group ($F(3, 105) = 1.819$, $p = .148$, $\eta_p^2 = .049$) in this analysis, although the quadratic trend in
341 this interaction again remained significant ($F(1,37) = 4.481$, $p = .041$; $\eta_p^2 = .108$)².

342 Finally, it is possible that dancers demonstrated superior IAcc than controls due to group
343 differences in emotion-related traits that are thought to be associated with interoceptive
344 ability, including emotional sensitivity, empathy and alexithymia. However, as the data set
345 out in Table 1 indicates, dancers and controls did not differ on the total scores of any of the

² Replacing the 2 missing values with the group mean did not alter the results: The main effect of group remained significant ($F(1,37) = 6.361$, $p = .016$; $\eta_p^2 = .147$), with dancers exhibiting higher interoceptive accuracy than controls, while there was also no main effect of 'heart rate estimate' ($F(1,37) = .894$, $p = .350$, $\eta_p^2 = .024$). There was no main effect of Duration ($F(3, 111) = .719$; $p = .543$, $\eta_p^2 = .019$) and no interaction between duration and group ($F(3, 111) = 2.144$, $p = .099$, $\eta_p^2 = .055$).

346 emotion, empathy and alexithymia questionnaires (see table 1 for the statistical comparisons
347 of the differences). Furthermore, as shown in Table 2, none of the questionnaire measures
348 correlated with the average interoceptive accuracy score (averaged across the 4 intervals)
349 (range $r = -.116$ to $.221$; range $p = .171$ to $.835$).

350

351 **Insert table 2 about here***

352

353 Turning now to the Duration*Group interaction, it is interesting that this interaction
354 was characterized by a consistent quadratic trend in all of the above analyses. The
355 implications of this interaction are not entirely clear. A linear trend in the data (i.e., the
356 shortest interval having the highest accuracy scores, and the longest interval having the
357 lowest) would indicate that participants might have used a counting strategy (Ring, Brener,
358 Knapp, & Mailloux, 2015). This is crucial to rule out especially in the dancer group, as
359 dancers are said to have particularly good counting skills. Following the suggestion of
360 Schauder, Mask, Bryant, and Cascio (2015), the accuracy on the shortest (25s) and longest
361 (100s) intervals was compared within each group to establish whether general counting
362 abilities may be playing a role in task performance. The rationale here is that a paced
363 counting strategy would lead to greater error on longer than shorter intervals, however in both
364 groups there was no such difference between the two durations (Controls: $t(19) = 2.006$; $p =$
365 $.059$, Cohen's $d = .273$; Dancers: $t(19) = .981$, $p = .339$, Cohen's $d = .099$). Moreover, when
366 the ANOVA was computed, separately within each group, the factor 'duration' was not
367 significant in the dancer group, neither in isolation (linear: $p = .315$; quadric: $p = .148$), nor
368 when the covariate resting HR was included (linear: $p = .321$; quadric: $p = .319$), nor when
369 both the covariates resting HR and 'heart rate estimate' were included (linear: $p = .644$;
370 quadric: $p = .078$). In the control group, there were linear and quadratic trends for the factor

371 ‘duration’ (linear: $p = .031$; quadric: $p = .043$). If anything, this would suggest that controls
372 may have relied on a counting strategy, however, neither the linear nor the quadratic trends
373 remained significant in this group when the covariate resting HR was included (linear: $p =$
374 $.767$; quadric: $p = .266$), and when both the covariates resting HR and ‘heart rate estimate’
375 were included (linear: $p = .941$; quadric: $p = .354$).

376

377 ***3.2. Effect of dance experience on interoceptive accuracy***

378 The analyses thus far confirm that dancers demonstrate superior IAcc than non-dancers.
379 To test whether years of experience within the group of dancers would further corroborate an
380 effect of dance training on interoceptive accuracy, ‘years of dance training’ was correlated
381 with interoceptive accuracy in the dancer group. One dancer had an interoceptive accuracy of
382 4.5 SD below the mean of the remaining dancers and was therefore excluded from this
383 correlation analysis. A directional one-tailed parametric correlation revealed a significant
384 relationship between the two variables ($r = .477$; $p = .019$)³. To explore this effect further and
385 given the relatively small sample size for correlation analyses, we followed the rationale set
386 out in (Kandasamy et al., 2016, p.3), creating groups with different levels of dance expertise.
387 A median split was performed on the variable ‘years of dance experience’ (median = 17.5;
388 range: 8 – 30 years). Junior dancers ($n = 10$) had a mean of 14.1 years of dance experience
389 (SD = 3.28), and senior dancers ($n = 10$) had a mean of 23 years of dance experience (SD =
390 4.45). The outlier was again removed from this analysis (junior dancers: $n = 9$). A One-Way
391 ANOVA was computed with the average ‘interoceptive accuracy’ as the dependent variable
392 and ‘level of dance experience’ as a between subjects variable (Controls, Junior Dancers,
393 Senior Dancers). Figures 3 and 4 illustrate the data. There was a significant main effect of
394 ‘level of dance experience’ $F(2) = 10.322$, $p < .001$. To follow-up this significant effect,

³ Results with inclusion of the outlier in the correlation: $r = .324$; $p = .080$.

395 independent t-tests were carried out. Controls' interoceptive accuracy ($m = .45$; $SD = .27$)
396 and Junior Dancers' interoceptive accuracy ($m = .66$; $SD = .13$) differed significantly ($t(27) =$
397 -2.256 ; $p = .032$, Cohen's $d = 0.99$), and there was also a significant difference both between
398 Controls' and Senior Dancers' interoceptive accuracy ($m = .82$; $SD = .14$), ($t(28) = -4.037$, p
399 $< .001$, Cohen's $d = 1.72$, Cohen's $d = 1.08$), and between Junior and Senior Dancers'
400 interoceptive accuracy ($t(27) = -2.574$, $p = .020$), suggesting that 'years of dance experience'
401 has an impact on interoceptive accuracy.⁴ To rule out any effect of 'age' in the division into
402 junior and senior dance groups, the full RM ANOVA was run, with the factors Group
403 (controls, junior dancers, senior dancers) and Duration (25, 35, 45, 100), including 'age' as a
404 co-variate. The results of this 3 X 4 RM ANOVA showed that the main effect of Group
405 remained significant $F(36) = 7.129$, $p = .002$, $\eta^2 = .284$), while the factor 'age' was not
406 significant ($F(1) = .458$, $p = .503$, $\eta^2 = .013$).

407

408 **Insert figure 3 about here***

409 **Insert figure 4 about here***

410

411 **3.3. General art expertise and interoceptive accuracy**

412 In addition to the evidence for a specific association between dance expertise and
413 enhanced IAcc outlined above, the data also revealed a significant correlation between
414 general art experience (i.e., the score on the Art Experience Questionnaire) and IAcc across
415 both groups ($r = .359$; $p = .023$). Figure 5 illustrates this association and it is worth noting that
416 the correlation rises to ($r = .552$; $p < .001$) if the obvious outlier to the top left of Figure 5 is

⁴ Including the outlier altered the results very slightly. As before, there was a significant main effect of 'level of dance experience' $F(2) = 7.373$, $p = .002$. To follow-up this significant effect, independent t-tests were carried out. Controls' interoceptive accuracy ($m = .45$; $SD = .27$) and Junior Dancers' interoceptive accuracy ($m = .58$; $SD = .28$) did not differ significantly ($t(28) = -1.255$; $p = .220$, Cohen's $d = .47$), while there was a significant difference both between Controls' and Senior Dancers' interoceptive accuracy ($m = .82$; $SD = .14$), ($t(28) = -4.037$, $p < .001$, Cohen's $d = 1.72$, Cohen's $d = 1.08$), and between Junior and Senior Dancers' interoceptive accuracy ($t(18) = -2.375$, $p = .029$).

417 excluded (this Dancer's IAcc is 4.5 SD below the mean of the remaining dancers). Moreover,
418 the correlation is primarily driven by the group of Dancers ($r = .551$; $p < .001$; excluding the
419 outlier) with no association in controls ($r = -.172$; $p = .47$).

420

421 **Insert figure 5 about here***

422

423 The variable 'general art experience' might be confounded with dance experience
424 because the Art Experience Questionnaire is focused on measuring exposure to visual art and
425 aesthetics. Visual aesthetics is an integral part of classical dance education and dancers work
426 with theatrical designers and artists. Therefore, we tested whether years of dance training and
427 general interest in visual arts might be correlated. The correlation between years of dance
428 experience and arts experience was marginally non-significant ($r = .407$; $p = .075$) in the
429 dancer group, although the moderate effect size suggests that in a larger sample this
430 relationship would be reliable. We therefore controlled for years of dance experience in a
431 partial correlation, which showed that a moderately strong association between general art
432 experience and IAcc remained in dancers ($r = .421$; $p = .082$; excluding the outlier).

433

434 ***3.4. Interoceptive awareness: subjective report-objective accuracy correspondence***

435 In addition to their enhanced interoceptive accuracy, dancers were also more confident in
436 their ability to perceive their heartbeat accurately. Although confidence ratings were not
437 collected at each of the 4 trials to calculate the ROC score as suggested by Garfinkel et al.
438 (2015), participants were asked to rate their confidence across all four intervals at the end of
439 all trials (ratings were not available for 2 of the dancers who were therefore excluded from
440 this analysis). Dancers reported significantly higher confidence scores ($m = 6.11$; $SD = 1.53$)
441 than Controls ($m = 4.90$; $SD = 1.77$; $t(36) = -2.241$, $p = .030$, Cohen's $d = .73$), and across

442 both groups confidence ratings were marginally correlated with IAcc ($r = .307$; $p = .061$).
443 However, a linear regression analysis with IAcc as dependent variable and Group and
444 confidence score as predictors revealed that, while the model was significant overall ($F(2,37$
445 $= 9.165$; $p > .001$) and explained 34.4% of the variance ($R^2 = .344$), only the factor Group
446 was significant as a predictor ($t = 3.647$, $p = .001$), while confidence rating was not ($t = .825$;
447 $p = .415$). This result did not change when all questionnaire measures were added as
448 predictors to the model. Specifically, the model remained significant overall ($F(2,37 = 2.771$;
449 $p = .025$), explaining 40.1% of the variance ($R^2 = .401$), with only the factor Group as a
450 significant predictor ($t = 2.686$, $p = .012$). Table 3 sets out the full details of this analysis.

451

452

Insert table 3 about here*

453

454

455 **4. Discussion**

456 Professional dancers showed a higher interoceptive accuracy as compared to control
457 participants. Importantly, this effect was independent of lower heart rates (a proxy measure of
458 physical fitness), of overall counting abilities (no difference in accuracy between the shortest
459 and longest intervals within each group; Schauder, Mash, Bryant, & Cascio, 2015), and of
460 knowledge about resting HR. Follow-up comparisons suggested that training in dance might
461 enhance interoceptive accuracy because senior dancers (with 18-30 years of dance
462 experience) had a higher interoceptive accuracy than both junior dancers (with 8 – 17 years
463 of experience) and control participants (with 0 years of dance experience). The latter did not
464 differ significantly between each other. Furthermore, in keeping with the idea that training in
465 any art might be related to heightened interoceptive accuracy, a correlation analysis revealed
466 that across groups, general art experience (questionnaire measure) correlated positively with
467 interoceptive accuracy. Conversely, no correlations were found between objective

468 interoceptive accuracy and subjective questionnaire measures of empathy, emotional
469 sensitivity, and alexithymia. These findings make an important contribution to the empirical
470 characterization of interoception. They suggest which activities and practices might
471 potentially enhance interoceptive accuracy. Pre-existing personality differences may also be a
472 factor (i.e., that individuals with a high interoceptive accuracy are particularly prone to
473 becoming dancers). Previous and current results suggest –at least– an interesting future
474 avenue of testing, to establish whether it might be the particular training in music (Schirmer-
475 Mokwa et al., 2015) in dance or in the arts more generally which results in high interoceptive
476 accuracy.

477 Before discussing the implications of these observations in more detail, it is important to
478 briefly comment on the unexpected group by duration interaction. Previous studies rarely
479 report data on the heart rate perception task as a function of the duration of the intervals (e.g.,
480 Kandasamy, et al., 2016; Shah et al., 2016), but this was important here to rule out that
481 higher IAcc in dancers would be the result of a counting strategy that would be evident as
482 linear decreases in performance as a function of increasing interval durations. Although no
483 such decreases were evident in the performance profile of dancers, the control participants'
484 performance was characterised by linear as well as quadratic changes in performance over the
485 four intervals. In the absence of previous observations that could speak to this finding, the
486 interpretation is unclear and it is possible that this pattern merely represents non-specific
487 individual differences. Given how frequently the heart beat perception task is used to estimate
488 IAcc in the literature, however, the observation merits further scrutiny in larger samples and
489 with a greater range of intervals. Future studies including dancer and musician groups might
490 also want to include a task to measure participants' time estimation skills, as recommended
491 by Ring and Brener (1996) (such as in Shah et al., 2016), or use a interoceptive awareness
492 task where the influence of time estimation skills is minimized (such as in Azevedo, Ainley,

493 Tsakiris, 2016). Furthermore, a regression analysis exploring the unique contribution of both
494 participants' HR estimation skills and their actual resting HR is a recommendable strategy to
495 account for the confound of knowledge about HR influencing participants' HR counts,
496 highlighted by Ring and Brener (1996). In our study, we were able to address this concern by
497 showing that, in fact, the dancers' counted HR was not related to their HR estimates, but to
498 their actual resting HR.

499 In accordance with the *dual* hypothesis set out in the introduction we suggest that
500 interoceptive accuracy may be acquired through engagement with any training involving *both*
501 (i) elicitation of- and attention to- bodily signals (such as heart beats, sweat response, muscle
502 contraction), *as well as* (ii) the use of these signals for the expression of states and
503 'emotions'. These two aspects are common in musical and dance training. Moreover, the
504 exploratory correlation between general art experience and interoceptive accuracy might
505 suggest a general effect also of visual arts training on interoceptive accuracy.

506 A growing body of empirical research emphasizes a possible link between interoceptive
507 accuracy and emotional function (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Herbert,
508 Muth, Pollatos, & Herbert, 2012; Herbert, Pollatos, & Schandry, 2007; Werner, Peres,
509 Duschek, & Schandry, 2010). Previous work has shown that dancers and other artists are
510 better than controls at identifying emotional expressions in others and are more responsive to
511 those expressions at the psychophysiological level (Christensen et al., 2016; Goldstein,
512 Bloom, 2011; Goldstein, Winner, *in press*; Lima & Castro, 2011). This is important
513 considering that several prominent theories propose bodily routes to emotional function;
514 either via a peripheral mechanism (James, 1894; Lange, 1885; Porges, 1995, 1997), an
515 embodied sensorimotor mirror neuron mechanism (Gallese, 2005; Gallese, Fadiga, Fogassi,
516 & Rizzolatti, 1996; Vittorio Gallese, Keysers, & Rizzolatti, 2004; Wicker et al., 2003;
517 Wilson, 2002), or a limbic introspective predictive coding mechanism (Barrett & Simmons,

518 2015; Craig, 2002, 2003; Critchley, 2005; Seth, 2013; Seth & Critchley, 2013). Regardless of
519 the particular route, these models converge in suggesting that we understand the emotions,
520 intentions and states of both ourselves and of others through our own bodies (Damasio,
521 1999a; de Vignemont & Singer, 2006; Gallese, 2005; Gallese et al., 2004; Hurley, 2008;
522 Niedenthal, 2007; Rizzolatti, Fogassi, & Gallese, 2001; Uddin, Iacoboni, Lange, & Keenan,
523 2007); through the perception of our own bodily sensations (Cameron, 2001; Craig, 2009;
524 Critchley, 2009; Damasio, 1994, 1999c; Laird & Lacasse, 2014; Niedenthal, 2007). An
525 enhancement of interoceptive accuracy through arts training might thus increase desirable
526 interpersonal attributes of emotional function.

527 Regarding the lack of correlation between interoceptive accuracy and the emotion and
528 empathy questionnaires, our results are in accordance with previous literature (Ainley et al.,
529 2015). The absence of such correlations on the one hand, alongside evidence of an
530 association between interoceptive accuracy and people's emotional function as just outlined
531 on the other, suggests that subjectively participants may not be able to accurately report their
532 interpersonal emotional and empathic skills. In other words, actual empathic skills and
533 emotional function as observed in people's behaviour or neural responses vis-a-vis the
534 emotions of others (e.g., Ernst et al., 2013; Fukushima et al., 2011) may be associated with
535 interoceptive accuracy without either being related to participant's beliefs about their
536 emotional skills as expressed on questionnaires. This would be in line with the suggestion
537 that there is a fundamental distinction between people's abilities and their beliefs about their
538 abilities in the domain of personal and interpersonal emotional experiences (Garfinkel et al.,
539 2015). In this context, it is interesting that previous studies have reported an association
540 between interoceptive accuracy and people's beliefs about their ability to describe and
541 identify their own emotions as measured by self-report alexithymia questionnaires (Shah,
542 Hall, Catmur, & Bird, 2016). Our results did not replicate these findings, which may be due

543 to the more modest sample size in the current study. Future studies might seek to further
544 clarify the relation between interoceptive accuracy, alexithymia and interpersonal emotional
545 functioning (e.g., empathy) and further develop causal models of their interaction during
546 emotional experiences and over the course of development (see e.g., Craig, 2009; Damasio,
547 1999a).

548 We have performed several important control analyses to rule out potential variables that
549 might have confounded the group difference. These included participants' counting abilities
550 (Ring et al., 2015), inter-individual differences in heart rate at rest (Knapp-Kline & Kline,
551 2005), participants' knowledge about heart rate (Dunn et al., 2010a; Filippetti & Tsakiris,
552 2017), and their confidence in their own estimates (Garfinkel et al., 2015). However, it is
553 recommendable that future studies in this domain would counteract these potential pitfalls of
554 the method by introducing a counting task in the procedure (as in e.g., Shah et al., 2016) and
555 ask participants to provide their Body Mass Index to be able to match the groups according to
556 this physical variable (Pollatos et al., 2016). Besides, participants should be asked to provide
557 a confidence value after each estimation interval, to be able to calculate interoceptive
558 awareness using the ROC analysis (Garfinkel, Seth, Barrett, Suzujum, & Critchley, 2015).

559 We have suggested that dance training might enhance interoceptive accuracy. However, it
560 is equally possible that individuals with greater interoceptive accuracy may respond better to
561 dance training, and persist in this field longer due to their success. In other words, dance
562 training may in fact do more to 'weed out' individuals with lower interoception than to train
563 interoception *per se*. The fact that we found an increase in interoceptive accuracy between
564 groups of increasing level of dance training is a strong argument in favour of a training-based
565 explanation of the group difference. However, longitudinal assessments will be required to
566 establish this with certainty.

567 If dance, music and general arts training indeed enhance interoceptive accuracy, the next
568 pertinent question would be which aspects of the training cause this increase. Our main
569 explanatory avenue for the higher interoceptive accuracy in dancers is the dual-action
570 hypothesis set out in the introduction (elicitation of bodily states *and* the immediate
571 expression of these states (e.g., emotions, intentions, etc), directly or indirectly through the
572 body). However, a different or complementary explanatory avenue might be that from very
573 early in life a professional artist's training involves an strong focus on attention to bodily
574 signals. This has been suggested for musicians (Zamorano et al., 2015), and is also true for
575 dancers (Tajet-Foxell & Rose, 1995). Furthermore, this links with an explanation worded
576 elsewhere that high interoceptive accuracy might be the result of an artist's specific training
577 in multisensory integration (Schirmer-Mokwa et al., 2015). Intensive music and dance
578 training involves multisensory integration, particularly auditory-motor integration. Only
579 future studies addressing the different relevant components might find convincing answers to
580 tease apart the contribution of the dual emotion action, attention to bodily signals and
581 multisensory integration to high interoceptive accuracy measures. Finally, the relationship
582 between general art experience and interoceptive accuracy needs to be confirmed with a
583 larger sample, preferably in a between-group comparison. The current study used a moderate
584 sample size as the recruitment of a specialist population (expert dancers) places certain
585 constraints on achievable sample sizes. Besides, ideally, control participants would be
586 compared with different groups of visual artists who have visual art experience only –to rule
587 out confounds of the potential contributions of the different art forms to interoceptive
588 accuracy.

589 Unravelling the neurocognitive mechanisms of objective interoceptive ability and
590 emotional function will inform the applied sciences. If it turns out that the arts can be used to
591 increase healthy emotional functioning and to scaffold difficulties in those with emotional

592 dysfunction this holds large opportunities for many segments of society. For example, current
593 art therapy interventions do not reliably provide improvements and the only measureable
594 effect is usually enhanced ‘well-being’ (Meekums, Karkou & Nelson, 2015; Xia, 2009). The
595 likely reason for this lack of conclusive results is that the art intervention programs are still
596 too unspecific. If interoceptive accuracy might be a mechanism to specifically target, two
597 important questions need to be assessed in future work: the quantity of training needed (i.e.,
598 whether professional training is required to provide durable results) and the importance of
599 dosage; ‘hyper emotionality’ might be equally detrimental as ‘hypo-emotionality’.

600

601 **5. References**

- 602 Ainley, V., Maister, L., & Tsakiris, M. (2015). Heartfelt empathy? No association between
603 interoceptive awareness, questionnaire measures of empathy, reading the mind in the
604 eyes task or the director task. *Frontiers in Psychology, 6*, 554.
605 doi:10.3389/fpsyg.2015.00554
- 606 Ainley, V., Tajadura-Jiménez, A., Fotopoulou, A., & Tsakiris, M. (2012). Looking into
607 myself: Changes in interoceptive sensitivity during mirror self-observation.
608 *Psychophysiology, 49*, 1504-1508.
- 609 Ainley, V., & Tsakiris, M. (2013). Body Conscious? Interoceptive Awareness, Measured by
610 Heartbeat Perception, Is Negatively Correlated with Self-Objectification. *Plos One*,
611 8(2), e55568. doi:10.1371/journal.pone.0055568
- 612 Azevedo, R. T., Ainley, V., & Tsakiris, M. (2016). Cardio-visual integration modulates the
613 subjective perception of affectively neutral stimuli. *Int J Psychophysiol, 99*, 10-17.
614 doi:10.1016/j.ijpsycho.2015.11.011

- 615 Bachorowski, J. A., & Braaten, E. B. (1994). Emotional Intensity - Measurement and
616 Theoretical Implications. *Personality and Individual Differences*, *17*(2), 191-199.
617 doi:10.1016/0191-8869(94)90025-6
- 618 Bagby, R. M., Parker, J. D. A., & Taylor, G. J. (1994a). The twenty-item Toronto
619 Alexithymia Scale-I. Item selection and cross-validation of the factor structure.
620 *Journal of Psychosomatic Research*, *38*, 23-32.
- 621 Bagby, R. M., Parker, J. D. A., & Taylor, G. J. (1994b). The twenty-item Toronto
622 Alexithymia Scale-I. Item selection and cross-validation of the factor structure.
623 *Journal of Psychosomatic Research*, *38*, 23-32.
- 624 Barrett, L. F., Quigley, K. S., Bliss-Moreau, E., & Aronson, K. R. (2004). Interoceptive
625 sensitivity and self-reports of emotional experience. *Journal Personality Social*
626 *Psychology*, *87*. doi:10.1037/0022-3514.87.5.684
- 627 Barrett, L. F., & Simmons, W. K. (2015). Interoceptive predictions in the brain. *Nature*
628 *Review Neuroscience*, *16*(7), 419-429. doi:10.1038/nrn3950
629 <http://www.nature.com/nrn/journal/v16/n7/abs/nrn3950.html> - supplementary-
630 information
- 631 Bermond, B., Oosterveld, P., & Vorst, H. C. M. (1994). Bermond-Vost Alexithymia
632 Questionnaire; construction, reliability, validity and uni-dimensionality. *Internal*
633 *Report. University of Amsterdam: Faculty of Psychology. Department of*
634 *Psychological Methods*.
- 635 Bermond, B., Vorst, H. C. M., Vingerhoets, A. J. J. M., & Gerritsen, W. (1999). The
636 Amsterdam Alexithymia Scale: its psychometric values and correlations with other
637 personality traits. *Psychotherapy and psychosomatics*, *68*, 241-251.

- 638 Bojner Horwitz, E., Lennartsson, A. K., Theorell, T. P., & Ullen, F. (2015). Engagement in
639 dance is associated with emotional competence in interplay with others. *Front*
640 *Psychol*, 6, 1096. doi:10.3389/fpsyg.2015.01096
- 641 Bläsing, B., Tenenbaum, G., & Schack, T. (2009). The cognitive structure of movements in
642 classical dance. *Psychology of Sport and Exercise*, 10(3), 350-360.
643 doi:10.1016/j.psychsport.2008.10.001
- 644 Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action
645 observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral*
646 *Cortex*, 15(8), 1243-1249. doi:10.1093/cercor/bhi007
- 647 Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing
648 or doing? Influence of visual and motor familiarity in action observation (vol 16, pg
649 1905, 2006). *Current Biology*, 16(22), 2277-2277. doi:10.1016/j.cub.2006.10.065
- 650 Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E. R., & Haggard, P. (2005). The
651 influence of visual and motor familiarity during action observation: An fMRI study
652 using expertise. *Journal of Cognitive Neuroscience*, 115-115.
- 653 Cameron, O. G. (2001). *Visceral sensory neuroscience: Interoception*. New York: USA:
654 Oxford University Press.
- 655 Chatterjee, A., Widick, P., Sternschein, R., Smith II, W. B., & Bromberger, B. (2010). The
656 Assessment of Art Attributes. *Empirical Studies of the Arts*, 28, 207-222.
- 657 Christensen, J. F., Gomila, A., Gaigg, S. B., Sivarajah, N., & Calvo-Merino, B. (2016).
658 Dance Expertise Modulates Behavioral and Psychophysiological Responses to
659 Affective Body Movement. *Journal of Experimental Psychology: Human Perception*
660 *and Performance*. doi:10.1037/xhp0000176

- 661 Cook, R., Brewer, R., Shah, P., & Bird, G. (2013). Alexithymia, not autism, predicts poor
662 recognition of emotional facial expressions. *Psychological Science*, *24*(5), 723-732.
663 doi:10.1177/0956797612463582
- 664 Craig, A. D. (2002). How do you feel? Interoception: the sense of the physiological condition
665 of the body. *Nature Review Neuroscience*, *3*, 655-666.
- 666 Craig, A. D. (2003). Interoception: the sense of the physiological condition of the body.
667 *Current Opinion in Neurobiology*, *13*(4), 500-505.
- 668 Craig, A. D. (2009). How do you feel - now? The anterior insula and human awareness.
669 *Nature Reviews Neuroscience*, *10*(1), 59-70. doi:10.1038/nrn2555
- 670 Critchley, H. D. (2005). Neural mechanisms of autonomic, affective, and cognitive
671 integration. *Journal of Comparative Neurology*, *493*(1), 154-166.
672 doi:10.1002/cne.20749
- 673 Critchley, H. D. (2009). Psychophysiology of neural, cognitive and affective integration:
674 fMRI and autonomic indicants. *International Journal of Psychophysiology*, *73*(2), 88-
675 94. doi:10.1016/j.ijpsycho.2009.01.012
- 676 Critchley, H. D., Wiens, S., Rotshtein, P., Ohman, A., & Dolan, R. J. (2004). Neural systems
677 supporting interoceptive awareness. *Nature Neuroscience*, *7*(2), 189–195.
678 doi:dx.doi.org/10.1038/Nn1176
- 679 Cross, E. S., Hamilton, A. F. d. C., & Grafton, S. T. (2006). Building a motor simulation de
680 novo: Observation of dance by dancers. *Neuroimage*, *31*(3), 1257-1267.
- 681 Damasio, A. R. (1994). *Descartes' Error: Emotion, Reason, and the Human Brain*: Nature
682 Publishing Group.
- 683 Damasio, A. R. (1999a). *The Feeling of What Happens: Body and Emotion in the Making of*
684 *Consciousness*: Harcourt Brace.

- 685 Damasio, A. R. (1999b). *The Feeling of What Happens: Body and Emotion in the Making of*
686 *Consciousness*: Nature Publishing Group.
- 687 Damasio, A. R. (1999c). How the brain creates the mind. *Scientific American*, *281*(6), 112-
688 117.
- 689 Daubenmier, J., Sze, J., Kerr, C. E., Kemeny, M. E., & Mehling, W. (2013). Follow your
690 breath: Respiratory interoceptive accuracy in experienced meditators.
691 *Psychophysiology*, *50*(8), 777-789. doi:10.1111/psyp.12057
- 692 Davis, M. H. (1983). Measuring individual-differences in empathy - evidence for a
693 multidimensional approach. *Journal of Personality and Social Psychology*, *44*(1),
694 113-126.
- 695 de Geus, E. J., van Doornen, L. J., de Visser, D. C., & Orlebeke, J. F. (1990). Existing and
696 training induced differences in aerobic fitness: their relationship to physiological
697 response patterns during different types of stress. *Psychophysiology*, *27*(4), 457-478.
- 698 de Vignemont, F., & Singer, T. (2006). The empathic brain: how, when and why? *Trends in*
699 *Cognitive Sciences*, *10*(10), 435-441. doi:10.1016/j.tics.2006.08.008
- 700 Dunn, B. D., Galton, H. C., Morgan, R., Evans, D., Oliver, C., Meyer, M., . . . Dalgleish, T.
701 (2010a). Listening to your heart. How interoception shapes emotion experience and
702 intuitive decision making. *Psychological Science*, *21*(12), 1835-1844.
703 doi:10.1177/0956797610389191
- 704 Domschke, K., Stevens, S., Pfleiderer, B., & Gerlach, A. L. (2010). Interoceptive sensitivity
705 in anxiety and anxiety disorders: an overview and integration of neurobiological
706 findings. *Clin Psychol Rev*, *30*(1), 1-11. doi:10.1016/j.cpr.2009.08.008
- 707 Dunn, B. D., Galton, H. C., Morgan, R., Evans, D., Oliver, C., Meyer, M., . . . Dalgleish, T.
708 (2010b). Listening to your heart. How interoception shapes emotion experience and

- 709 intuitive decision making. *Psychological Science*, *21*.
- 710 doi:10.1177/0956797610389191
- 711 Farb, N. A., Segal, Z. V., & Anderson, A. K. (2013). Mindfulness meditation training alters
712 cortical representations of interoceptive attention. *Social Cognitive and Affective
713 Neurosci*, *8*. doi:10.1093/scan/nss066
- 714 Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). GPower 3: A flexible statistical
715 power analysis program for the social, behavioral, and biomedical sciences. *Behavior
716 Research Methods*, *39*, 175–191.
- 717 Ferri, F., Ardizzi, M., Ambrosecchia, M., & Gallese, V. (2013). Closing the Gap between the
718 inside and the outside: Interoceptive Sensitivity and Social Distances. *Plos One*,
719 *8*(10), e75758. doi:10.1371/journal.pone.0075758
- 720 Filippetti, M. L., & Tsakiris, M. (2017). Heartfelt embodiment: Changes in body-ownership
721 and self-identification produce distinct changes in interoceptive accuracy. *Cognition*,
722 *159*, 1-10. doi:http://dx.doi.org/10.1016/j.cognition.2016.11.002
- 723 Fink, A., Graif, B., & Neubauer, A. C. (2009). Brain correlates underlying creative thinking:
724 EEG alpha activity in professional vs. novice dancers. *Neuroimage*, *46*(3), 854-862.
725 doi:10.1016/j.neuroimage.2009.02.036
- 726 Fukushima, H., Terasawa, Y., & Umeda, S. (2011). Association between interoception and
727 empathy: evidence from heartbeat-evoked brain potential. *International Journal of
728 Psychophysiology*, *79*(2), 259-265. doi:10.1016/j.ijpsycho.2010.10.015
- 729 Gaigg, S. B., Cornell, A. S. F., & Bird, G. (2016). The psychophysiological mechanisms of
730 Alexithymia in Autism Spectrum Disorder.
- 731 Gallese, V. (2005). Embodied simulation: From neurons to phenomenal experience.
732 *Phenomenology and the Cognitive Sciences*, *4*(1), 23-48. doi:10.1007/s11097-005-
733 4737-z

- 734 Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the
735 premotor cortex. *Brain, 119*, 593-609.
- 736 Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social
737 cognition. *Trends in Cognitive Sciences, 8*(9), 396-403.
738 doi:<http://dx.doi.org/10.1016/j.tics.2004.07.002>
- 739 Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzujum J., & Critchley, H. (2015). Knowing
740 your own heart: Distinguishing interoceptive accuracy from interoceptive awareness.
741 *Biological Psychology, 104*, 65-74.
- 742 Garfinkel, S. N., Manassei, M. F., Hamilton-Fletcher, G., In den Bosch, Y., Critchley, H. D.,
743 & Engels, M. (2016). Interoceptive dimensions across cardiac and respiratory axes.
744 *Philosophical Transactions of the Royal Society B: Biological Sciences, 371*(1708).
745 doi:[10.1098/rstb.2016.0014](https://doi.org/10.1098/rstb.2016.0014)
- 746 Goldstein, T. R., Bloom, P. (2011). The Mind on stage: Why Cognitive Scientists Should
747 Study Acting. *Trends in Cognitive Sciences, 15*(141-142).
- 748 Goldstein, T. R., Winner, E. (in press). Enhancing Empathy and Theory of Mind. *Journal of*
749 *Cognition and Development*.
- 750 Haase, L., Stewart, J. L., Youssef, B., May, A. C., Isakovic, S., Simmons, A. N., . . . Paulus,
751 M. P. (2016). When the brain does not adequately feel the body: Links between low
752 resilience and interoception. *Biological Psychology, 113*, 37-45.
753 doi:<http://dx.doi.org/10.1016/j.biopsycho.2015.11.004>
- 754 Hänggi, J., Koeneke, S., Bezzola, L., & Jancke, L. (2010). Structural Neuroplasticity in the
755 Sensorimotor Network of Professional Female Ballet Dancers. *Human Brain*
756 *Mapping, 31*(8), 1196-1206. doi:[10.1002/hbm.20928](https://doi.org/10.1002/hbm.20928)

- 757 Hart, N., McGowan, J., Minati, L., & Critchley, H. D. (2013). Emotional regulation and
758 bodily sensation: Interoceptive awareness is intact in borderline personality disorder.
759 *Journal of Personality Disorders*, 27(4), 506-518.
- 760 Herbert, B. M., Muth, E. R., Pollatos, O., & Herbert, C. (2012). Interoception across
761 Modalities: On the Relationship between Cardiac Awareness and the Sensitivity for
762 Gastric Functions. *Plos One*, 7(5), e36646. doi:10.1371/journal.pone.0036646
- 763 Herbert, B. M., Pollatos, O., Flor, H., Enck, P., & Schandry, R. (2010). Cardiac awareness
764 and autonomic cardiac reactivity during emotional picture viewing and mental stress.
765 *Psychophysiology*, 47(2), 342-354. doi:10.1111/j.1469-8986.2009.00931.x
- 766 Herbert, B. M., Pollatos, O., & Schandry, R. (2007). Interoceptive sensitivity and emotion
767 processing: an EEG study. *International Journal of Psychophysiology*, 65(3), 214-
768 227. doi:10.1016/j.ijpsycho.2007.04.007
- 769 Hurley, S. (2008). The shared circuits model (SCM): How control, mirroring, and simulation
770 can enable imitation, deliberation, and mindreading. *Behavioral and Brain Sciences*,
771 31(01), 1-22. doi:doi:10.1017/S0140525X07003123
- 772 James, W. (1894). Discussion: The physical basis of emotion. *Psychological Review*, 1, 516-
773 529. doi:http://dx.doi.org/10.1037/h0065078
- 774 Jang, S. H., & Pollick, F. E. (2011). Experience Influences Brain Mechanisms of Watching
775 Dance. *Dance Research Journal*, 29(2), 352-377.
- 776 Kandasamy, N., Garfinkel, S. N., Page, L., Hardy, B., Critchley, H. D., Gurnell, M., &
777 Coates, J. M. (2016). Interoceptive Ability Predicts Survival on a London Trading
778 Floor. *Scientific Reports*, 6, 32986. doi:10.1038/srep32986
- 779 Karin, J., Christensen, J. F., & Haggard, P. (Fall 2016, in press). Mental Training. In V.
780 Wilmerding & D. Krasnow (Eds.), *Dancer Wellness*. Champaign Canada: Human
781 Kinetics.

- 782 Khalsa, S. S., Rudrauf, D., Damasio, A. R., Davidson, R. J., Lutz, A., & Tranel, D. (2008).
783 Interoceptive awareness in experienced meditators. *Psychophysiology*, *45*(4), 671–
784 677. doi:dx.doi.org/10.1111/j.1469-8986.2008.00666.x
- 785 Knapp-Kline, K., & Kline, J. P. (2005). Heart rate, heart rate variability, and heartbeat
786 detection with the method of constant stimuli: slow and steady wins the race. *Biol*
787 *Psychol*, *69*(3), 387-396. doi:10.1016/j.biopsycho.2004.09.002
- 788 Laird, J. D., & Lacasse, K. (2014). Bodily influences on emotional feelings: Accumulating
789 evidence and extensions of William James's theory of emotion. *Emotion Review*, *6*,
790 27-34. doi:http://dx.doi.org/10.1177/1754073913494899
- 791 Lange, C. (1885). *The Emotions*: Nature Publishing Group.
- 792 Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: musical expertise enhances
793 the recognition of emotions in speech prosody. *Emotion*, *11*(5), 1021-1031.
794 doi:10.1037/a0024521
- 795 Meekums, B., Karkou, V., & Nelson, E. (2015). Dance movement therapy for depression.
796 *Cochrane Database of Systematic Reviews*, *2*. doi:10.1002/14651858.CD009895.pub2
- 797 Mehling, W. E., Price, C., Daubenmier, J. J., Acree, M., Bartmess, E., & Stewart, A. (2012).
798 The Multidimensional Assessment of Interoceptive Awareness (MAIA). *Plos One*,
799 *7*(11), e48230. doi:10.1371/journal.pone.0048230
- 800 Mehrabian, A., Epstein, N. (1972). A measure of emotional empathy. *Journal of Personality*,
801 *40*(4), pp. 525-543. 10.1111/j.1467-6494.1972.tb00078.x
- 802 Melloni, M., Sedeño, L., Couto, B., Reynoso, M., Gelormini, C., Favaloro, R., . . . Ibanez, A.
803 (2013). Preliminary evidence about the effects of meditation on interoceptive
804 sensitivity and social cognition. *Behavioral and Brain Functions*, *9*(1), 1-6.
805 doi:10.1186/1744-9081-9-47

- 806 Mussgay L., Klinkenberg N., & Rüdell, H. (1999). Heart beat perception in patients with
807 depressive, somatoform, and personality disorders. *Journal of Psychophysiology*, *13*,
808 27-36. doi:10.1027//0269-8803.13.1.27
- 809 Niedenthal, P. M. (2007). Embodying Emotion. *Science*, *316*(5827), 1002-1005.
810 doi:10.1126/science.1136930
- 811 Orgs, G., Dombrowski, J. H., Heil, M., & Jansen-Osmann, P. (2008). Expertise in dance
812 modulates alpha/beta event-related desynchronization during action observation.
813 *European Journal of Neuroscience*, *27*(12), 3380-3384. doi:10.1111/j.1460-
814 9568.2008.06271.x
- 815 Paulus, M. P., & Stein, M. B. (2010). Interoception in anxiety and depression. *Brain Struct*
816 *Funct*, *214*(5-6), 451-463. doi:10.1007/s00429-010-0258-9
- 817
- 818 Petrides, K. V., Niven, L., & Mouskounti, T. (2006). The trait emotional intelligence of ballet
819 dancers and musicians. *Psicothema*, *18*, 101-107.
- 820 Pollatos, O., Herbert, B. M., Kaufmann, C., Auer, D. P., & Schandry, R. (2007).
821 Interoceptive awareness, anxiety and cardiovascular reactivity to isometric exercise.
822 *International Journal of Psychophysiology*, *65*(2), 167-173
823 doi:10.1016/j.ijpsycho.2007.03.005
- 824 Pollatos, O., Herbert, B. M., Berberich, G., Zaudig, M., Krauseneck, T., & Tsakiris, M.
825 (2016). Atypical Self-Focus Effect on Interoceptive Accuracy in Anorexia Nervosa.
826 *Frontiers in Human Neuroscience*, *10*, 484. doi:10.3389/fnhum.2016.00484
- 827 Porges, S. (1993). Body Perception Questionnaire: Nature Publishing Group.
- 828 Porges, S. W. (1995). Orienting in a defensive world: mammalian modifications of our
829 evolutionary heritage. A Polyvagal Theory. *Psychophysiology*, *32*(4), 301-318.

- 830 Porges, S. W. (1997). Emotion: an evolutionary by-product of the neural regulation of the
831 autonomic nervous system. *Annual Review of the New York Academy of Sciences*,
832 807, 62-77.
- 833 Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying
834 the understanding and imitation of action. *Nature Review Neuroscience*, 2(9), 661-
835 670. doi:10.1038/35090060
- 836 Ring, C., Brener, J. (1996). Influence of beliefs about heart rate and actual heart rate on
837 heartbeat counting. *Psychophysiology*, 33(5), pp.541-546. 10.1111/j.1469-
838 8986.1996.tb02430.x
- 839 Ring, C., Brener, J., Knapp, K., & Mailloux, J. (2015). Effects of heartbeat feedback on
840 beliefs about heart rate and heartbeat counting: a cautionary tale about interoceptive
841 awareness. *Biol Psychol*, 104, 193-198. doi:10.1016/j.biopsycho.2014.12.010
- 842 Schandry, R. (1981). Heart beat perception and emotional experience. *Psychophysiology*,
843 18(4), 483-488. doi:dx.doi.org/10.1111/j.1469-8986.1981.tb02486.x
- 844 Schauder, K. B., Mash, L. E., Bryant, L. K., & Cascio, C. J. (2015). Interoceptive ability and
845 body awareness in autism spectrum disorder. *Journal of Experimental Child*
846 *Psychology*, 131, 193-200. doi:10.1016/j.jecp.2014.11.002
- 847 Scherer, K. (2009). The dynamic architecture of emotion: evidence for the component
848 process model. *Cognition & Emotion*, 23(7), 1307-1351.
- 849 Schirmer-Mokwa, K. L., Fard, P. R., Zamorano, A. M., Finkel, S., Birbaumer, N., & Kleber,
850 B. A. (2015). Evidence for Enhanced Interoceptive Accuracy in Professional
851 Musicians. *Frontiers in Behavioral Neuroscience*, 9, 349.
852 doi:10.3389/fnbeh.2015.00349
- 853 Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in*
854 *Cognitive Sciences*, 17(11), 565-573. doi:10.1016/j.tics.2013.09.007

- 855 Seth, A. K., & Critchley, H. D. (2013). Extending predictive processing to the body: Emotion
856 as interoceptive inference. *Behavioral and Brain Sciences*, *36*(3), 227–228.
857 doi:dx.doi.org/10.1017/S0140525X12002270Seth
- 858 Shah, P., Hall, R., Catmur, C., & Bird, G. (2016). Alexithymia, not autism, is associated with
859 impaired interoception. *Cortex*, *81*, 215-220.
860 doi:http://dx.doi.org/10.1016/j.cortex.2016.03.021
- 861 Tajadura-Jimenez, A., Longo, M. R., Coleman, R., & Tsakiris, M. (2012). The person in the
862 mirror: using the enfacement illusion to investigate the experiential structure of self-
863 identification. *Conscious and Cognition*, *21*(4), 1725-1738.
864 doi:10.1016/j.concog.2012.10.004
- 865 Tajadura-Jimenez, A., & Tsakiris, M. (2014). Balancing the "inner" and the "outer" self:
866 interoceptive sensitivity modulates self-other boundaries. *Journal of Experimental*
867 *Psychology: General*, *143*(2), 736-744. doi:10.1037/a0033171
- 868 Tajet-Foxell, B., & Rose, F. D. (1995). Pain and pain tolerance in professional ballet dancers.
869 *British Journal of Sports Medicine*, *29*(1), 31-34.
- 870 Tsakiris, M. (2016). The multisensory basis of the self: From body to identity to others. *The*
871 *Quarterly Journal of Experimental Psychology*, 1-13.
872 doi:10.1080/17470218.2016.1181768
- 873 Tsakiris, M., Tajadura-Jiménez, A., & Constantini, M. (2011). Just a heartbeat away from
874 one's body: interoceptive sensitivity predicts malleability of body-representations.
875 *Proceedings of the Royal Society: Biological Sciences*, 1-6.
- 876 Tsakiris, M., Tajadura-Jimenez, A., & Costantini, M. (2011). Just a heartbeat away from
877 one's body: interoceptive sensitivity predicts malleability of body-representations.
878 *Proceedings of the Biological Sciences*, *278*(1717), 2470-2476.
879 doi:10.1098/rspb.2010.2547

- 880 Uddin, L. Q., Iacoboni, M., Lange, C., & Keenan, J. P. (2007). The self and social cognition:
881 the role of cortical midline structures and mirror neurons. *Trends in Cognitive*
882 *Sciences, 11*(4), 153-157. doi:10.1016/j.tics.2007.01.001
- 883 Weng, H. Y., Fox, A. S., Shackman, A. J., Stodola, D. E., Caldwell, J. Z. K., Olson, M. C., . .
884 . Davidson, R. J. (2013). Compassion Training Alters Altruism and Neural Responses
885 to Suffering. *Psychological Science, 24*(7), 1171-1180.
886 doi:10.1177/0956797612469537
- 887 Werner, N. S., Jung, K., Duschek, S., & Schandry, R. (2009). Enhanced cardiac perception is
888 associated with benefits in decision-making. *Psychophysiology, 46*(6), 1123-1129.
889 doi:10.1111/j.1469-8986.2009.00855.x
- 890 Werner, N. S., Peres, I., Duschek, S., & Schandry, R. (2010). Implicit memory for emo-tional
891 words is modulated by cardiac perception. *Biological Psychology, 85*(3), 370–376.
892 doi:dx.doi.org/10.1016/j.biopsycho.2010.08.008
- 893 Werner, N. S., Schweitzer, N., Meindl, T., Duschek, S., Kambeitz, J., & Schandry, R. (2013).
894 Interoceptive awareness moderates neural activity during decision-making. *Biological*
895 *Psychology, 94*(3), 498-506. doi:10.1016/j.biopsycho.2013.09.002
- 896 Whitehead, W. E., Drescher, V., & Heiman, P. (1977). Relation of heart rate control to
897 heartbeat perception. *Biofeedback Self Regul, 2*. doi:10.1007/bf00998623
- 898 Whitehead, W. E., & Drescher, V. M. (1980). Perception of Gastric Contractions and Self-
899 Control of Gastric Motility. *Psychophysiology, 17*(6), 552-558. doi:10.1111/j.1469-
900 8986.1980.tb02296.x
- 901 Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of
902 us disgusted in My Insula: The common neural basis of seeing and feeling disgust.
903 *Neuron, 40*(3), 655-664.

- 904 Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin Review*, 9(4),
905 625-636.
- 906 Wölk, J., Sütterlin, S., Koch, S., Vögele, C., & Schulz, S. M. (2014). Enhanced cardiac
907 perception predicts impaired performance in the Iowa Gambling Task in patients with
908 panic disorder. *Brain and Behavior*, 4(2), 238-246. doi:10.1002/brb3.206
- 909 Xia, J., Grant, T.J. (2009). Dance therapy for schizophrenia. *Cochrane Reviews*, 2009(1).
- 910 Zamorano, A. M., Riquelme, I., Kleber, B., Altenmüller, E., Hatem, S. M., & Montoya, P.
911 (2015). Pain sensitivity and tactile spatial acuity are altered in healthy musicians as in
912 chronic pain patients. *Frontiers in Human Neuroscience*, 8(1016).
913 doi:10.3389/fnhum.2014.01016
- 914
- 915
- 916
- 917
- 918
- 919
- 920
- 921
- 922
- 923
- 924
- 925
- 926
- 927
- 928

929 Table 1

930 *Participant characteristics. Shown are means (SD), and associated effect sizes for the*
 931 *between group comparisons. “Other dance styles” include Step Dance, Jazz Dance, Jazz*
 932 *Ballet, Burlesque, Lyrical and Commercial Dance. Groups differ significantly in the relevant*
 933 *variables “years of dance experience”, “hours of dance/week” and “art experience”. The*
 934 *questionnaire measures are the Interpersonal Reactivity Index (IRI), the questionnaire of*
 935 *Emotional Empathy (EE), the Emotional Intensity Scale (EIS), the TAS, the BVAQ, years of*
 936 *dance experience (DE) and The Art Experience Questionnaire (AE). Resting heart rate (HR),*
 937 *Interoceptive Accuracy, Estimated HR and Confidence ratings refer to the participant’s HR*
 938 *at rest, their ability to estimate their own HR, their estimate of how many heart beats they*
 939 *have per minute and the confidence with which they performed the interoceptive accuracy*
 940 *task (1 = not confident at all; 10 = very confident).*

Measure	GROUP		p -value	Effect size (Cohen’s d)
	Controls	Dancers		
Age	24.25 (3.86)	25.35 (4.57)	.416	.26
Years of Dance experience	0.75 (3.35)	18.5 (5.94)	< .001	3.68
Hours of Dance / week	0	24.10 (15.01)	< .001	2.11
Art Experience	7.25 (6.86)	41.00 (9.91)	< .001	3.96
IRI total	70.40 (9.28)	66.70 (11.99)	.282	.35
EE tendency score	69.95 (15.71)	69.85 (18.90)	.986	.01
EIS total	106.05 (10.18)	106.60 (9.91)	.863	.05
TAS total	45.05 (9.96)	49.75 (10.54)	.155	.46
BVAQ total	46.85 (10.19)	47.35 (7.71)	.862	.06
Resting HR	75.44 (11.80)	61.17 (9.65)	< .001	1.37
Interoceptive Accuracy	0.45 (0.27)	0.70 (0.25)	.004	.96
Estimated HR	63.75 (15.21)	77.89 (22.18)	.024	.74
Confidence rating	4.90 (1.77)	6.11 (1.45)	.023	.75

941

942 Table 2

943 *Correlations between Interoceptive Accuracy (IAcc) and all questionnaire measures across*
 944 *groups, including the Interpersonal Reactivity Index (IRI), the questionnaire of Emotional*
 945 *Empathy (EE), the Emotional Intensity Scale (EIS), the TAS, the BVAQ, years of dance*
 946 *experience (DE) and the Art Experience Questionnaire (AE).*

947 *Correlations*

Measure	IAcc	IRI	EE	EIS	TAS	BVAQ	DE	AE
Interoceptive accuracy (IAcc)	1	-.116	-.053	.221	.055	.034	.503**	.359
Interpersonal Reactivity Index (IRI)	-.116	1	.512**	.361*	-.119	-.354*	-.216	-.152
Emotional Empathy (EE)	-.053	.512**	1	.535**	-.156	-.506**	-.030	-.98
Emotional Intensity Scale (EIS)	.221	.361*	.525**	1	-.132	-.403**	-.085	-.067
TAS total score	.055	-.119	-.156	-.132	1	.690**	.194	.087
BVAQ total score	.034	-.354*	-.506**	-.403**	.690**	1	-.020	-.037
Dance Experience (DE) (years)	.503**	-.216	-.030	-.085	.194	-.020	1	.843**
Art Experience (AE) (score)	.359*	-.151	-.098	-.067	.087	-.037	.843**	1

Note: * $p < .05$; ** $p < .001$

948

949

950

951

952

953

954

955

956

957

958

959 Table 3

960 *Linear regression table. Interoceptive accuracy was the DV. Predictors included Group,*
961 *Confidence ratings and all questionnaire measures. Interpersonal Reactivity Index (IRI), the*
962 *questionnaire of Emotional Empathy (EE), the Emotional Intensity Scale (EIS), the TAS, the*
963 *BVAQ, years of dance experience (DE) and the Art Experience Questionnaire (AE).*

964 *Regression*

Predictor variable	B	SE B	β
Constant	-0.466	0.694	
Group	0.252	0.94	.469*
Confidence rating	0.028	0.27	.178
Interpersonal Reactivity Index score	-0.001	0.004	-.045
Emotional Empathy score	-0.001	0.003	-.095
Emotional Intensity Scale	0.008	0.005	.293
TAS total score	0.002	0.006	.064
BVAQ total score	0.001	0.008	.029

* Note: $R^2 = .401$; $\Delta R^2 = .401$; * $p = .012$

965

966

967

968

969

970

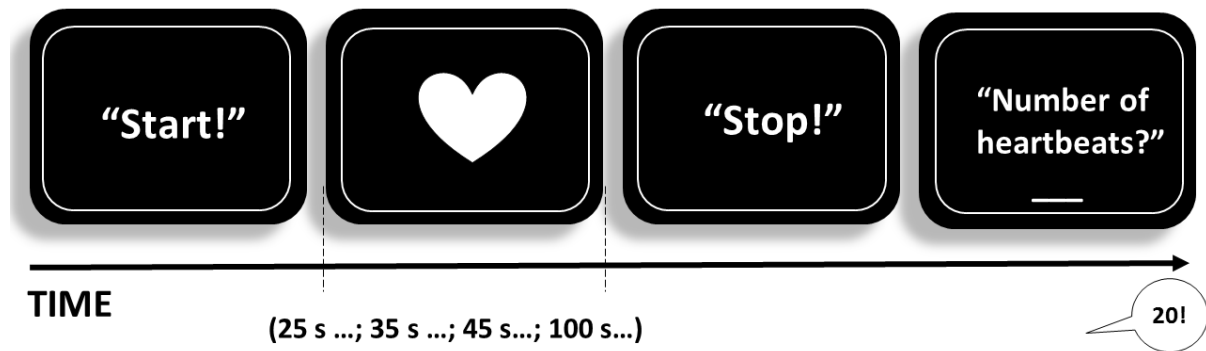
971

972

973

974

975



976

977 *Figure 1.* Trial structure. The 4 intervals for counting the heartbeats were 25 seconds (s), 35
978 s, 45s and 100s. Participants reported their subjectively counted heart beats at the end of each
979 trial with the keyboard (e.g., '20!').

980

981

982

983

984

985

986

987

988

989

990

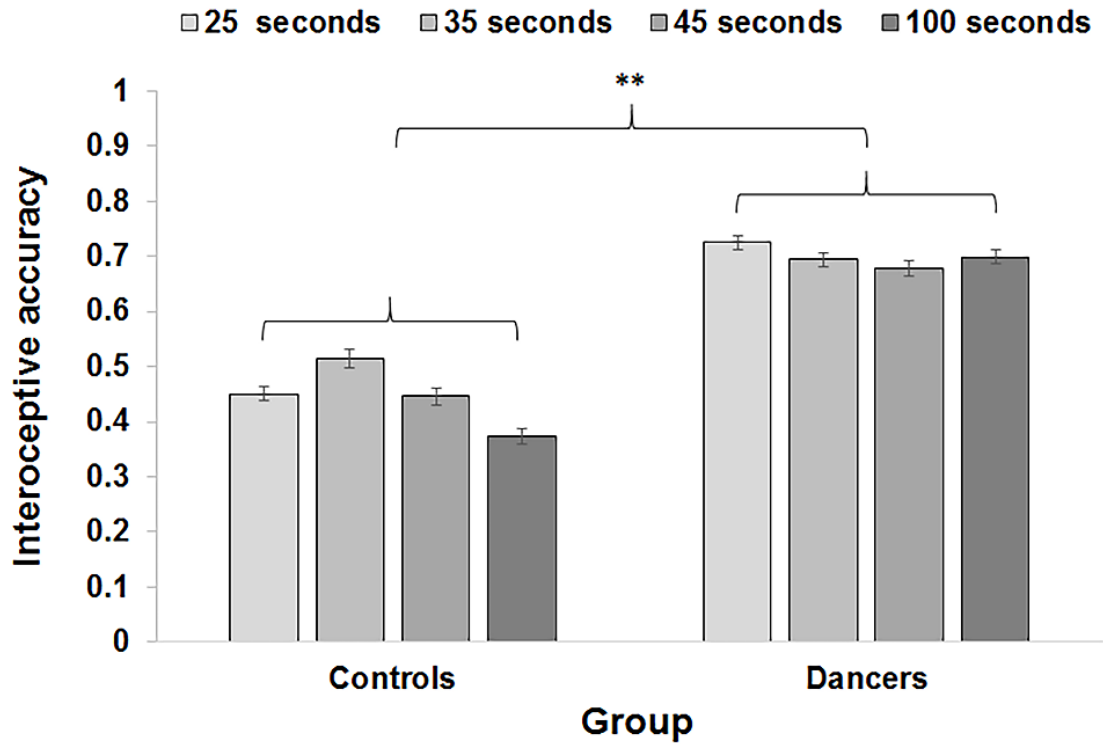
991

992

993

994

995



996

997 *Figure 2.* Illustration of the main effect of group. Error bars indicate S.E.M. ** $p < .001$

998

999

1000

1001

1002

1003

1004

1005

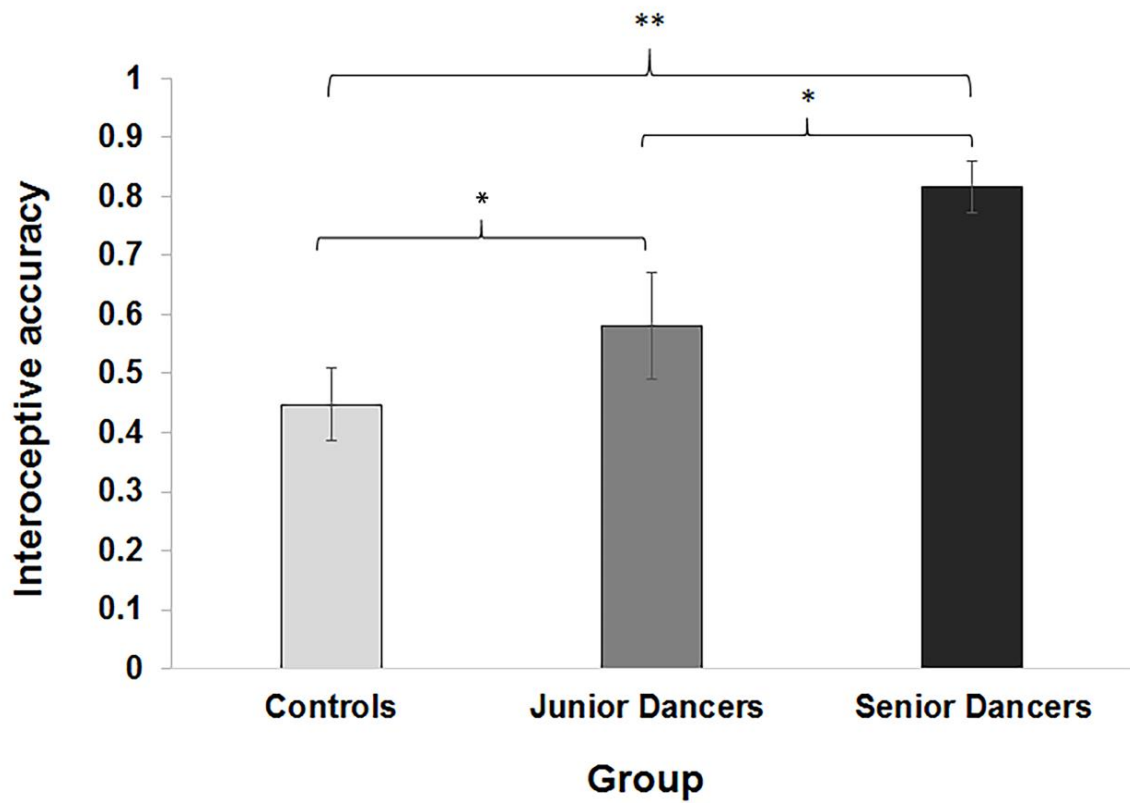
1006

1007

1008

1009

1010



1011

1012 *Figure 3.* Illustration of the main effect of group and of follow-up t-tests. Error bars indicate

1013 S.E.M. ** $p < .001$

1014

1015

1016

1017

1018

1019

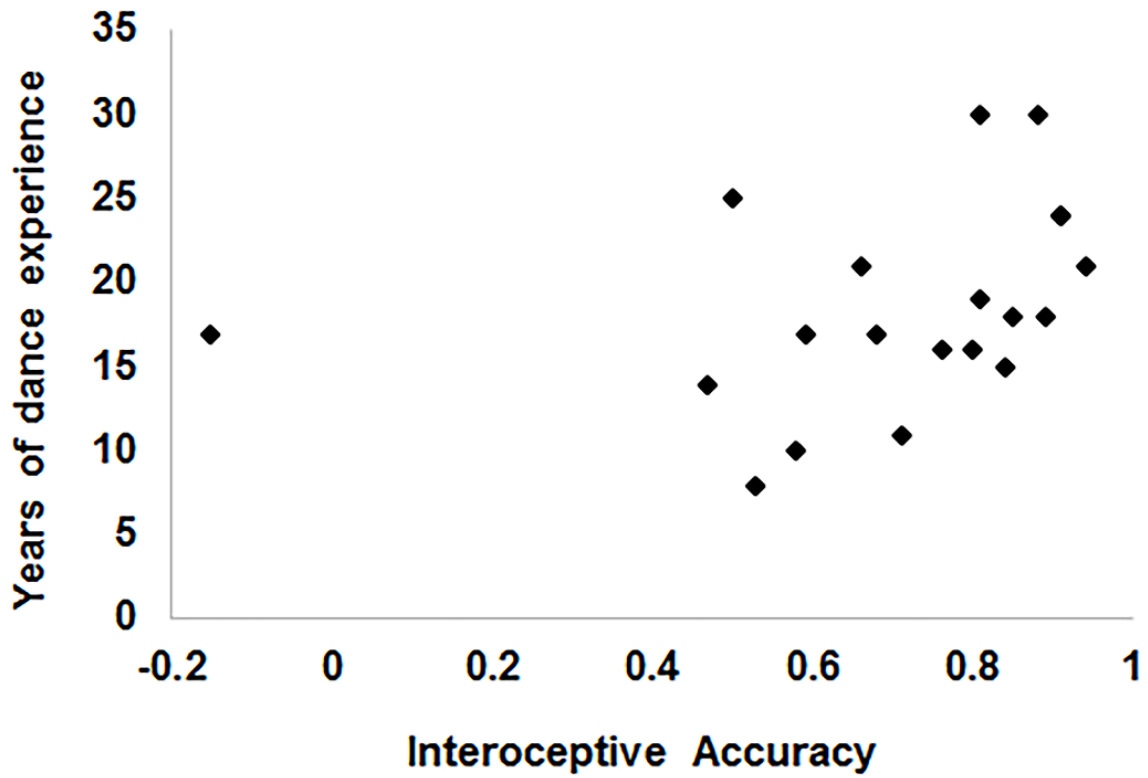
1020

1021

1022

1023

1024



1025

1026 *Figure 4.* Scatter dot illustration of the correlation between overall interoceptive accuracy and
1027 years of dance experience (in the dancer group).

1028

1029

1030

1031

1032

1033

1034

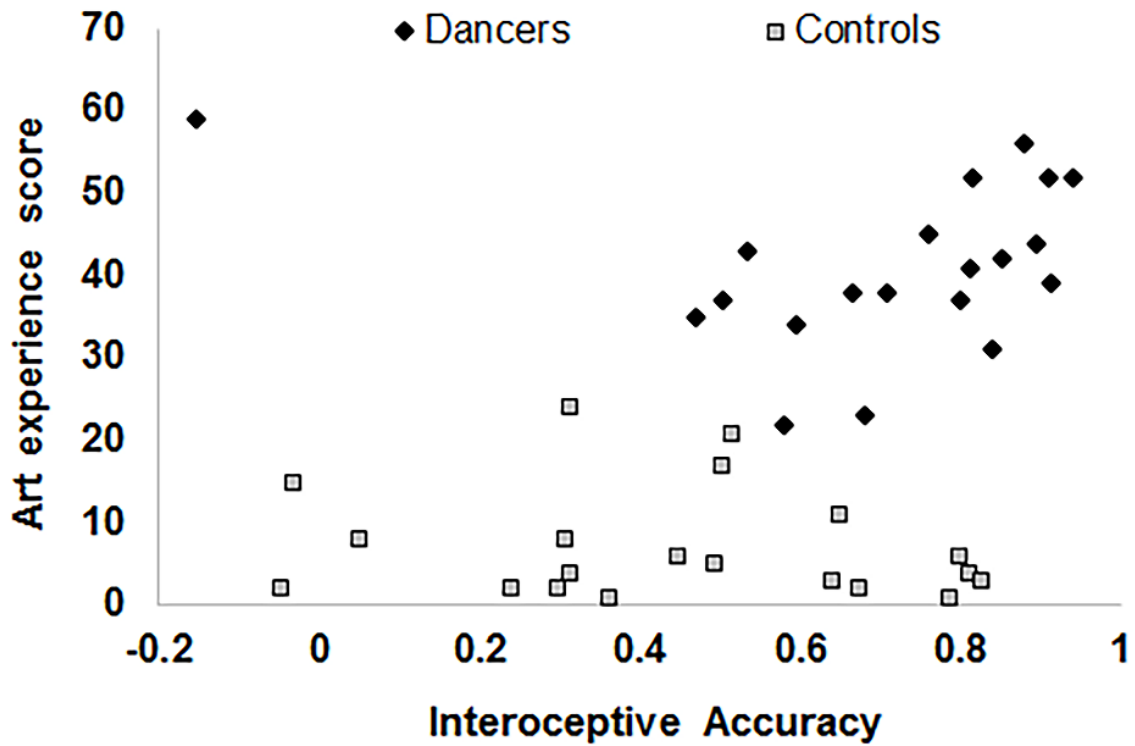
1035

1036

1037

1038

1039



1040

1041 *Figure 5.* Scatter dot illustration of the correlation between overall interoceptive accuracy and
1042 the art expertise questionnaire score. Squares represent the control group; rhombi represent
1043 the dancer group.

1044