I can feel my heartbeat: Dancers have increased interoceptive accuracy

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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

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1. Introduction

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

Current empirical traditions measure interoception along 3 main dimensions (Garfinkel, Seth, Barrett, Suzujum, & Critchley, 2015); (1) *interoceptive accuracy* (IAcc; objective accuracy of perceiving bodily signals, e.g., heart rate (HR), gastric activity; Schandry, 1981; Whitehead, Drescher, & Heiman, 1977; Whitehead & Drescher, 1980), (2) *interoceptive sensibility* (self-rated tendency to focus on internal bodily signals as reported on questionnaires; Bagby, Parker, & Taylor, 1994b; Mehling et al., 2012; Porges, 1993); and (3) *interoceptive awareness* (meta-cognitive awareness of interoceptive accuracy; Receiver Operating Characteristic; ROC curve; Garfinkel et al., 2015). These 3 dimensions are commonly found to be uncorrelated (Garfinkel et al., 2015) and it is specifically *interoceptive accuracy* (i.e., the objective accuracy of perceiving and reporting bodily signals as they occur) that has been the most widely used in studies on self-awareness and emotional experience. Specifically, interoceptive accuracy correlates positively with emotional sensitivity (Dunn et al., 2010b), empathy (Fukushima, Terasawa, & Umeda, 2011; Herbert, Pollatos, Flor, Enck, & Schandry, 2010), interpersonal sensitivity (Ferri, Ardizzi, Ambrosecchia, & Gallese, 2013), altruistic behaviour (Weng et al., 2013), emotional resilience (Haase et al., 2016), efficient decision-making under risk (Kandasamy et al., 2016; Werner, Jung, Duschek, & Schandry, 2009; Werner et al., 2013; Wölk, Sütterlin, Koch, Vögele, & Schulz, 2014), and inversely with susceptibility to body ownership manipulations (Tajadura-Jimenez, Longo, Coleman, & Tsakiris, 2012; Tajadura-Jimenez & Tsakiris, 2014; Tsakiris, Tajadura-Jimenez, & Costantini, 2011) and self-objectification (Ainley & Tsakiris, 2013). High interoceptive accuracy may thus have benefits for emotional well-being. Yet it is important to note that heightened interoceptive ability may have positive as well as negative consequences, since it may produce anxiety (Domschke, Stevens, Pfleiderer, & Gerlach, 2010). This is thought to be due to a learning process by which the awareness of the interoceptive signal (e.g., heartbeat) may trigger the awareness of a prospective aversive body state (e.g., panic attack) and therefore enhance anxiety and worrisome thoughts (Paulus & Stein, 2010). In this context it has been suggested that high interoceptive accuracy might have benefits for emotional well-being only in conjunction with a high interoceptive awareness (Garfinkel et al., 2016).

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

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

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

We here propose that also another aspect of professional arts training is likely to be a significant factor for the heightened IAcc in musicians; the expressive training they receive. An artist's professional training involves daily practice in the craftsmanship of their discipline, which involves a *dual* action: it includes the elicitation of bodily states (e.g., via autobiographical memory elicitation or imagery e.g., Karin, Christensen, & Haggard, 2016) *and* the immediate expression of these states (e.g., emotions, intentions, etc.), directly through the body (e.g., dance, music, acting), or indirectly (e.g., writing, painting). Because of this dual action of eliciting autonomic states and expressing these in behaviour (which the artist carefully monitors and practices), expertise in the arts might be a type of training which increases interoceptive accuracy (to remember: yoga and other meditative practices specifically encourage individuals to disregard or to 'let go' of bodily states, emotions and other cognitive states, rather than to generate and express them). A full account of this 'dual' hypothesis of arts practice will require a series of systematic studies that examine the practice effect in a number of converging ways. The approach taken in this paper is to operationalise 'practice' as a between-groups and cross-sectional manipulation of years of dance training. Given the recent observations in relation to musicians, we here aim to extend the empirical characterization of interoceptive expertise in artists by investigating interoceptive accuracy in professional ballet dancers. In addition, to explore the influence of visual art experience, a general 'art experience' questionnaire was administered. According to the above rationale regarding training in the arts, any arts training would correlate positively with interoceptive accuracy.

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

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

Recent studies have also explored which individual difference factors might modulate interoceptive accuracy by using questionnaire measures. While some studies have not found associations between interoceptive accuracy and emotion and empathy questionnaire measures (Ainley, Maister, & Tsakiris, 2015; Garfinkel et al., 2015), recent evidence suggests a link between interoceptive sensibility questionnaires measuring alexithymia and interoceptive accuracy (Cook, Brewer, Shah, & Bird, 2013; Gaigg, Crornell, & Bird, 2016). Therefore, in order to investigate the link between these individual differences in interoceptive accuracy further, we administered a battery of questionnaires tapping into the dimension of interoceptive sensibility (emotion, empathy and alexithymia questionnaires). Finally, to explore whether also general training in the arts might be related to interoceptive accuracy, as suggested above and by previous work on musicians (Schirmer-Mokwa et al., 2015), participants filled in an art experience questionnaire (Chatterjee, Widick, Sternschein, Smith II, & Bromberger, 2010).

2. Method

2.1. Participants

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

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).

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

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

Insert table 1 about here*

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

Insert figure 1 about here*

Participants' heart rate was recorded throughout the experiment with *ADInstruments PowerLab System* (ML845) including a Bioelectrical signal amplifier (ML408 with MLA2540 and MLA2505 5-lead shielded Bio Amp cables). Self-adhesive electrodes were attached to participants' abdomen, and a ground electrode to the elbow. *LabChart* 7 (v.7.3.1. 1994-2004; www.adiinstruments.com) was used to record and analyse the ECG signal from which heart rate was derived. A trigger was sent from *E-prime* to the ECG trace to demarcate the onset and offset of each trial.

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

2.3. Data analyses

For each of the 4 trials, an accuracy score was obtained for each participant (these values were entered into the ANOVA, see below). An average across the 4 trials was also obtained for each participant. The latter value was used for the correlational analyses. We employed the following commonly used formula: $1 - (|nbeatsreal - nbeatsreported|)/((nbeatsreal + nbeatsreported)/2)$ (Hart, McGowan, Minati, & Critchley, 2013). In this formula, the reported values (*nbeatsreported*) are included within the denominator to protect against overestimating performance accuracy in people with high variance between the four intervals (Garfinkel et al., 2015). As effect sizes in the following analyses we report partial eta ($\eta_p{}^2$) where .01 is considered a small effect size, .06 a medium effect and .14 a large effect, and Cohen's *d* where t-tests were performed (Cohen, 1988).

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

3. Results

3.1. Interoceptive accuracy

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

*Insert figure 2 about here**

It has been suggested that physical fitness influences heartbeat awareness (de Geus, van Doornen, de Visser, & Orlebeke, 1990; Pollatos, Herbert, Kaufmann, Auer, & Schandry, 2007). A low resting HR is a proxy measure of fitness, and our data confirmed a correlation between resting HR and IAcc across both groups (r = -.342, p = .031). Although this correlation was not significant within each group separately (Dancers: r = .187, p = .430; Controls: r = -.357, p = .122), the Dancers had a lower resting HR (m = 61.171; SD = 9.650; SE = 2.158) than controls (m = 75.443; SD = 11.804; SE = 2.640) (t(38) = 4.186; p > .001, Cohen's d = 1.32). It was therefore, important to rule out the possibility that group differences in physical fitness could account for the superior IAcc of dancers observed in the above analysis. Resting HR was therefore entered into the ANOVA as a covariate, which did not affect the pattern of results reported above. Specifically, the main effect of group remained significant (F(1,37) = 4.377, p = .043; η_p^2 = .106), with dancers exhibiting higher interoceptive accuracy than controls, while there was no main effect of resting HR (F(1,37) = .467, p = .498, η_p^2 = .012). Although, there was no main effect of Duration (F(3, 111) = 1.313; p = .274, η_p^2 = .034), the interaction between duration and group remained significant (F(3, 111) = 3.683, p = .014, η_p^2 = .091) and maintained the quadratic trend (F(1,37) = 9.737, p = .003, η_p^2 = .208).

Another possibility for the superior IAcc of dancers is that individuals with a resting HR naturally close to 60bpm may artificially appear more accurate in heart rate perception tasks because of familiarity with the 60 second counts of a minute (Knapp-Kline & Kline, 2005). Because dancers' resting HR was closer to 60 than controls, this possible confound was examined by calculating the absolute difference between 60 and each participants' resting HR (i.e., ABS(60-HR)). This difference score was indeed marginally correlated with IAcc across both groups (r = -.307, p = .054), confirming that individuals whose resting HR deviated the most from 60 had the lowest IAcc. However, when this difference score was entered as a covariate in the ANOVA, the general pattern of results again remained unchanged. The main effect of group remained significant (F(1,37) = 5.376, p = .026; η_p^2 = .127), with no significant effect of the difference score (F(1,37) = .580; p = .451, η_p^2 = .015). And the interaction between duration and group also remained significant (F(3,111) = 4.258; p = .007; η_p^2 = .133), with a quadratic (F(1,37) = 10.421, p = .003, η_p^2 = .220) but not a linear trend (p = .407).

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

Finally, it is possible that dancers demonstrated superior IAcc than controls due to group differences in emotion-related traits that are thought to be associated with interoceptive ability, including emotional sensitivity, empathy and alexithymia. However, as the data set 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; ηp^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, ηp^2 = .024). There was no main effect of Duration (F(3, 111) = .719; p = .543, ηp^2 = .019) and no interaction between duration and group (F(3, 111) = 2.144, p = .099, ηp^2 = .055).

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

Insert table 2 about here*

Turning now to the Duration*Group interaction, it is interesting that this interaction was characterized by a consistent quadratic trend in all of the above analyses. The implications of this interaction are not entirely clear. A linear trend in the data (i.e., the shortest interval having the highest accuracy scores, and the longest interval having the lowest) would indicate that participants might have used a counting strategy (Ring, Brener, Knapp, & Mailloux, 2015). This is crucial to rule out especially in the dancer group, as dancers are said to have particularly good counting skills. Following the suggestion of Schauder, Mask, Bryant, and Cascio (2015), the accuracy on the shortest (25s) and longest (100s) intervals was compared within each group to establish whether general counting abilities may be playing a role in task performance. The rationale here is that a paced counting strategy would lead to greater error on longer than shorter intervals, however in both groups there was no such difference between the two durations (Controls: t(19) = 2.006; p = .059, Cohen's d = .273; Dancers: t(19) = .981, p = .339, Cohen's d = .099). Moreover, when the ANOVA was computed, separately within each group, the factor 'duration' was not significant in the dancer group, neither in isolation (linear: p = .315; quadric: p = .148), nor when the covariate resting HR was included (linear: p = .321; quadric: p = .319), nor when both the covariates resting HR and 'heart rate estimate' were included (linear: p = .644; quadric: p = .078). In the control group, there were linear and quadratic trends for the factor 'duration' (linear: $p = .031$; quadric: $p = .043$). If anything, this would suggest that controls may have relied on a counting strategy, however, neither the linear nor the quadratic trends remained significant in this group when the covariate resting HR was included (linear: $p = .767$; quadric: $p = .266$), and when both the covariates resting HR and 'heart rate estimate' were included (linear: $p = .941$; quadric: $p = .354$).

3.2. Effect of dance experience on interoceptive accuracy

The analyses thus far confirm that dancers demonstrate superior IAcc than non-dancers. To test whether years of experience within the group of dancers would further corroborate an effect of dance training on interoceptive accuracy, 'years of dance training' was correlated with interoceptive accuracy in the dancer group. One dancer had an interoceptive accuracy of 4.5 SD below the mean of the remaining dancers and was therefore excluded from this correlation analysis. A directional one-tailed parametric correlation revealed a significant relationship between the two variables ($r = .477$; $p = .019$)[3]. To explore this effect further and given the relatively small sample size for correlation analyses, we followed the rationale set out in (Kandasamy et al., 2016, p.3), creating groups with different levels of dance expertise. A median split was performed on the variable 'years of dance experience' (median = 17.5; range: 8 – 30 years). Junior dancers ($n = 10$) had a mean of 14.1 years of dance experience ($SD = 3.28$), and senior dancers ($n = 10$) had a mean of 23 years of dance experience ($SD = 4.45$). The outlier was again removed from this analysis (junior dancers: $n = 9$). A One-Way ANOVA was computed with the average 'interoceptive accuracy' as the dependent variable and 'level of dance experience' as a between subjects variable (Controls, Junior Dancers, Senior Dancers). Figures 3 and 4 illustrate the data. There was a significant main effect of '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: $r = .324$; $p = .080$.

independent t-tests were carried out. Controls' interoceptive accuracy (m = .45; SD = .27) and Junior Dancers' interoceptive accuracy (m = .66; SD = .13) differed significantly (t(27) = -2.256; p = .032, Cohen's d = 0.99), and there was also 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(27) = -2.574, p = .020), suggesting that 'years of dance experience' has an impact on interoceptive accuracy.[4] To rule out any effect of 'age' in the division into junior and senior dance groups, the full RM ANOVA was run, with the factors Group (controls, junior dancers, senior dancers) and Duration (25, 35, 45, 100), including 'age' as a co-variate. The results of this 3 X 4 RM ANOVA showed that the main effect of Group remained significant F(36) = 7.129, p = .002, np2 = .284), while the factor 'age' was not significant (F(1) = .458, p = .503, np2 = .013).

Insert figure 3 about here*

Insert figure 4 about here*

3.3. General art expertise and interoceptive accuracy

In addition to the evidence for a specific association between dance expertise and enhanced IAcc outlined above, the data also revealed a significant correlation between general art experience (i.e., the score on the Art Experience Questionnaire) and IAcc across both groups (r = .359; p = .023). Figure 5 illustrates this association and it is worth noting that 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).

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

Insert figure 5 about here*

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

3.4.Interoceptive awareness: subjective report-objective accuracy correspondence

In addition to their enhanced interoceptive accuracy, dancers were also more confident in their ability to perceive their heartbeat accurately. Although confidence ratings were not collected at each of the 4 trials to calculate the ROC score as suggested by Garfinkel et al. (2015), participants were asked to rate their confidence across all four intervals at the end of all trials (ratings were not available for 2 of the dancers who were therefore excluded from this analysis). Dancers reported significantly higher confidence scores (*m* = 6.11; *SD* = 1.53) than Controls (*m* = 4.90; *SD* = 1.77; t(36) = -2.241, p = .030, Cohen's *d* = .73), and across both groups confidence ratings were marginally correlated with IAcc (r = .307; p = .061). However, a linear regression analysis with IAcc as dependent variable and Group and confidence score as predictors revealed that, while the model was significant overall (F(2,37 = 9.165; *p* > .001) and explained 34.4% of the variance (R^2 = .344), only the factor Group was significant as a predictor (*t* = 3.647, p = .001), while confidence rating was not (*t* = .825; *p* = .415). This result did not change when all questionnaire measures were added as predictors to the model. Specifically, the model remained significant overall (F(2,37 = 2.771; *p* = .025), explaining 40.1% of the variance (R^2 = .401), with only the factor Group as a significant predictor (*t* = 2.686, p = .012). Table 3 sets out the full details of this analysis.

Insert table 3 about here*

4. Discussion

Professional dancers showed a higher interoceptive accuracy as compared to control participants. Importantly, this effect was independent of lower heart rates (a proxy measure of physical fitness), of overall counting abilities (no difference in accuracy between the shortest and longest intervals within each group; Schauder, Mash, Bryant, & Cascio, 2015), and of knowledge about resting HR. Follow-up comparisons suggested that training in dance might enhance interoceptive accuracy because senior dancers (with 18-30 years of dance experience) had a higher interoceptive accuracy than both junior dancers (with 8 – 17 years of experience) and control participants (with 0 years of dance experience). The latter did not differ significantly between each other. Furthermore, in keeping with the idea that training in any art might be related to heightened interoceptive accuracy, a correlation analysis revealed that across groups, general art experience (questionnaire measure) correlated positively with interoceptive accuracy. Conversely, no correlations were found between objective interoceptive accuracy and subjective questionnaire measures of empathy, emotional sensitivity, and alexithymia. These findings make an important contribution to the empirical characterization of interoception. They suggest which activities and practices might potentially enhance interoceptive accuracy. Pre-existing personality differences may also be a factor (i.e., that individuals with a high interoceptive accuracy are particularly prone to becoming dancers). Previous and current results suggest –at least– an interesting future avenue of testing, to establish whether it might be the particular training in music (Schirmer-Mokwa et al., 2015) in dance or in the arts more generally which results in high interoceptive accuracy.

Before discussing the implications of these observations in more detail, it is important to briefly comment on the unexpected group by duration interaction. Previous studies rarely report data on the heart rate perception task as a function of the duration of the intervals (e.g., Kandasamy, et all., 2016; Shah et al., 2016), but this was important here to rule out that higher IAcc in dancers would be the result of a counting strategy that would be evident as linear decreases in performance as a function of increasing interval durations. Although no such decreases were evident in the performance profile of dancers, the control participants' performance was characterised by linear as well as quadratic changes in performance over the four intervals. In the absence of previous observations that could speak to this finding, the interpretation is unclear and it is possible that this pattern merely represents non-specific individual differences. Given how frequently the heart beat perception task is used to estimate IAcc in the literature, however, the observation merits further scrutiny in larger samples and with a greater range of intervals. Future studies including dancer and musician groups might also want to include a task to measure participants' time estimation skills, as recommended by Ring and Brener (1996) (such as in Shah et al., 2016), or use a interoceptive awareness task where the influence of time estimation skills is minimized (such as in Azevedo, Ainley, Tsakiris, 2016). Furthermore, a regression analysis exploring the unique contribution of both participants' HR estimation skills and their actual resting HR is a recommendable strategy to account for the confound of knowledge about HR influencing participants' HR counts, highlighted by Ring and Brener (1996). In our study, we were able to address this concern by showing that, in fact, the dancers' counted HR was not related to their HR estimates, but to their actual resting HR.

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

A growing body of empirical research emphasizes a possible link between interoceptive accuracy and emotional function (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Herbert, Muth, Pollatos, & Herbert, 2012; Herbert, Pollatos, & Schandry, 2007; Werner, Peres, Duschek, & Schandry, 2010). Previous work has shown that dancers and other artists are better than controls at identifying emotional expressions in others and are more responsive to those expressions at the psychophysiological level (Christensen et al., 2016; Goldstein, Bloom, 2011; Goldstein, Winner, *in press*; Lima & Castro, 2011). This is important considering that several prominent theories propose bodily routes to emotional function; either via a peripheral mechanism (James, 1894; Lange, 1885; Porges, 1995, 1997), an embodied sensorimotor mirror neuron mechanism (Gallese, 2005; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Vittorio Gallese, Keysers, & Rizzolatti, 2004; Wicker et al., 2003; Wilson, 2002), or a limbic interospective predictive coding mechanism (Barrett & Simmons, 2015; Craig, 2002, 2003; Critchley, 2005; Seth, 2013; Seth & Critchley, 2013). Regardless of the particular route, these models converge in suggesting that we understand the emotions, intentions and states of both ourselves and of others through our own bodies (Damasio, 1999a; de Vignemont & Singer, 2006; Gallese, 2005; Gallese et al., 2004; Hurley, 2008; Niedenthal, 2007; Rizzolatti, Fogassi, & Gallese, 2001; Uddin, Iacoboni, Lange, & Keenan, 2007); through the perception of our own bodily sensations (Cameron, 2001; Craig, 2009; Critchley, 2009; Damasio, 1994, 1999c; Laird & Lacasse, 2014; Niedenthal, 2007). An enhancement of interoceptive accuracy through arts training might thus increase desirable interpersonal attributes of emotional function.

Regarding the lack of correlation between interoceptive accuracy and the emotion and empathy questionnaires, our results are in accordance with previous literature (Ainley et al., 2015). The absence of such correlations on the one hand, alongside evidence of an association between interoceptive accuracy and people's emotional function as just outlined on the other, suggests that subjectively participants may not be able to accurately report their interpersonal emotional and empathic skills. In other words, actual empathic skills and emotional function as observed in people's behaviour or neural responses vis-a-vis the emotions of others (e.g., Ernst et al., 2013; Fukushima et al., 2011) may be associated with interoceptive accuracy without either being related to participant's beliefs about their emotional skills as expressed on questionnaires. This would be in line with the suggestion that there is a fundamental distinction between people's abilities and their beliefs about their abilities in the domain of personal and interpersonal emotional experiences (Garfinkel et al., 2015). In this context, it is interesting that previous studies have reported an association between interoceptive accuracy and people's beliefs about their ability to describe and identify their own emotions as measured by self-report alexithymia questionnaires (Shah, Hall, Catmur, & Bird, 2016). Our results did not replicate these findings, which may be due to the more modest sample size in the current study. Future studies might seek to further clarify the relation between interoceptive accuracy, alexithymia and interpersonal emotional functioning (e.g., empathy) and further develop causal models of their interaction during emotional experiences and over the course of development (see e.g., Craig, 2009; Damasio, 1999a).

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

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

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

Unravelling the neurocognitive mechanisms of objective interoceptive ability and emotional function will inform the applied sciences. If it turns out that the arts can be used to increase healthy emotional functioning and to scaffold difficulties in those with emotional dysfunction this holds large opportunities for many segments of society. For example, current art therapy interventions do not reliably provide improvements and the only measureable effect is usually enhanced ‘well-being’ (Meekums, Karkou & Nelson, 2015; Xia, 2009). The likely reason for this lack of conclusive results is that the art intervention programs are still too unspecific. If interoceptive accuracy might be a mechanism to specifically target, two important questions need to be assessed in future work: the quantity of training needed (i.e., whether professional training is required to provide durable results) and the importance of dosage; ‘hyper emotionality’ might be equally detrimental as ‘hypo-emotionality’.

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Table 1

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

Measure	GROUP		p -value	Effect size
	Controls	Dancers		(Cohen's d)
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

Table 2

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

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

Table 3

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

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

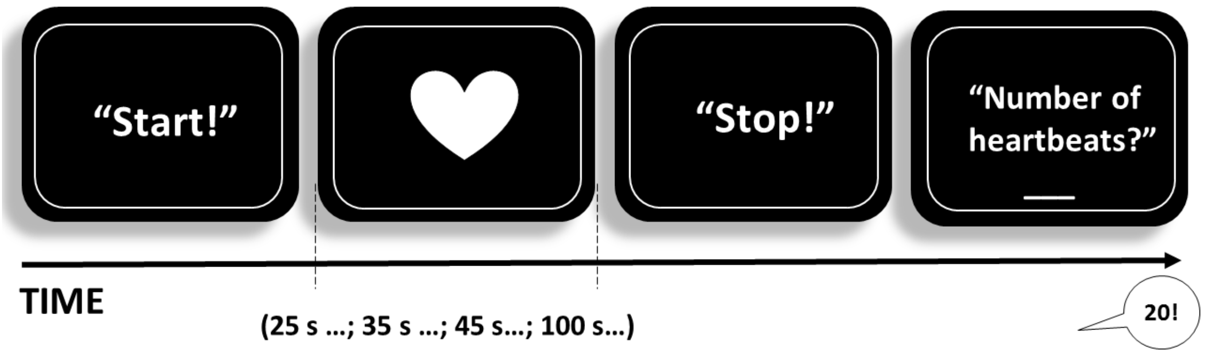

Figure 1. Trial structure. The 4 intervals for counting the heartbeats were 25 seconds (s), 35 s, 45s and 100s. Participants reported their subjectively counted heart beats at the end of each trial with the keyboard (e.g., '20!').

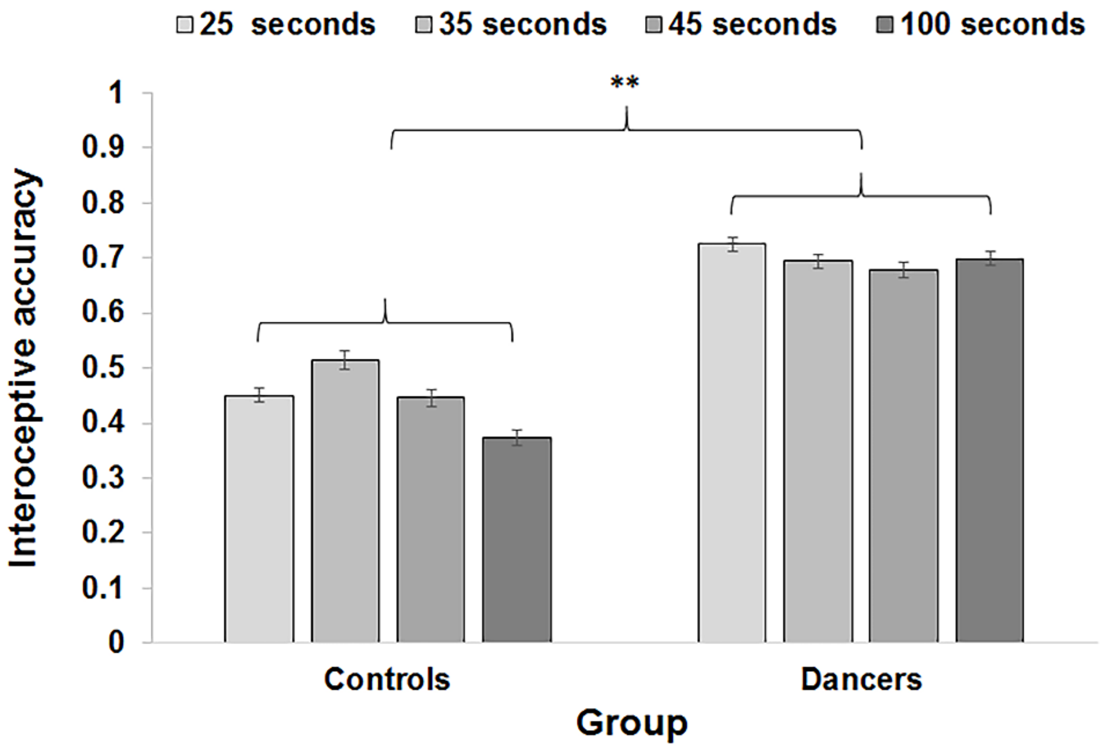

Figure 2. Illustration of the main effect of group. Error bars indicate S.E.M. ** p <.001

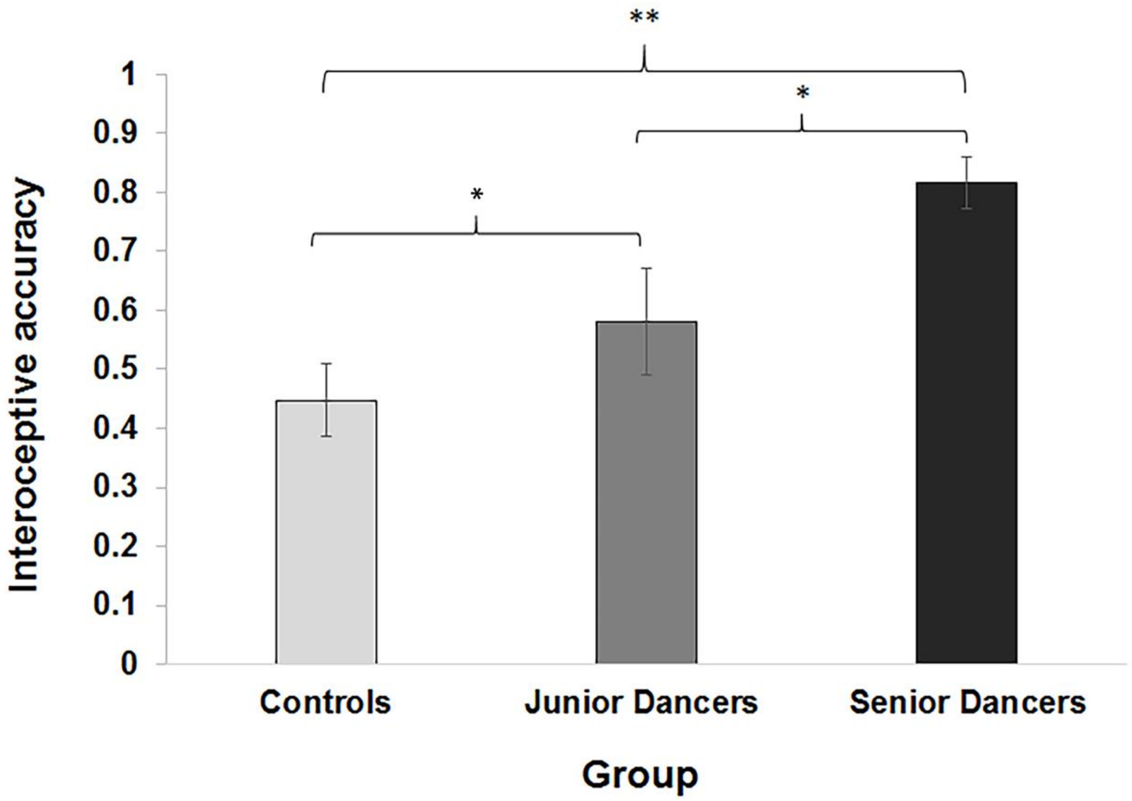

Figure 3. Illustration of the main effect of group and of follow-up t-tests. Error bars indicate S.E.M. ** $p < .001$

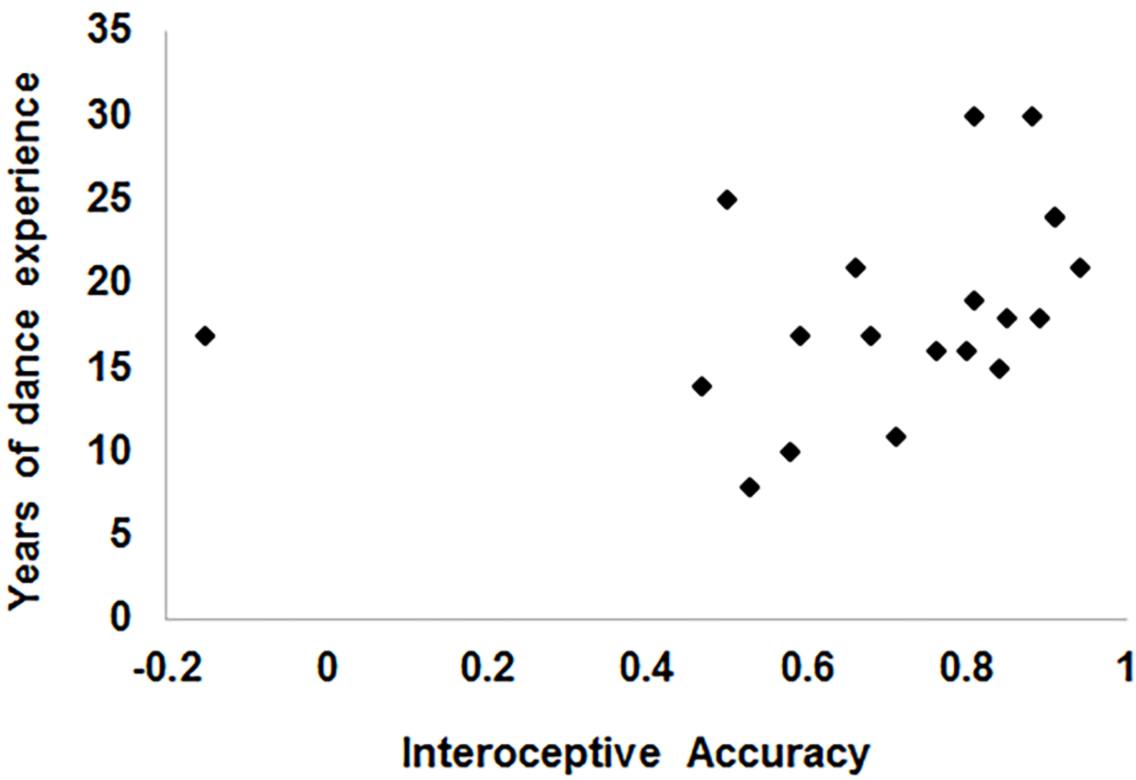

Figure 4. Scatter dot illustration of the correlation between overall interoceptive accuracy and years of dance experience (in the dancer group).

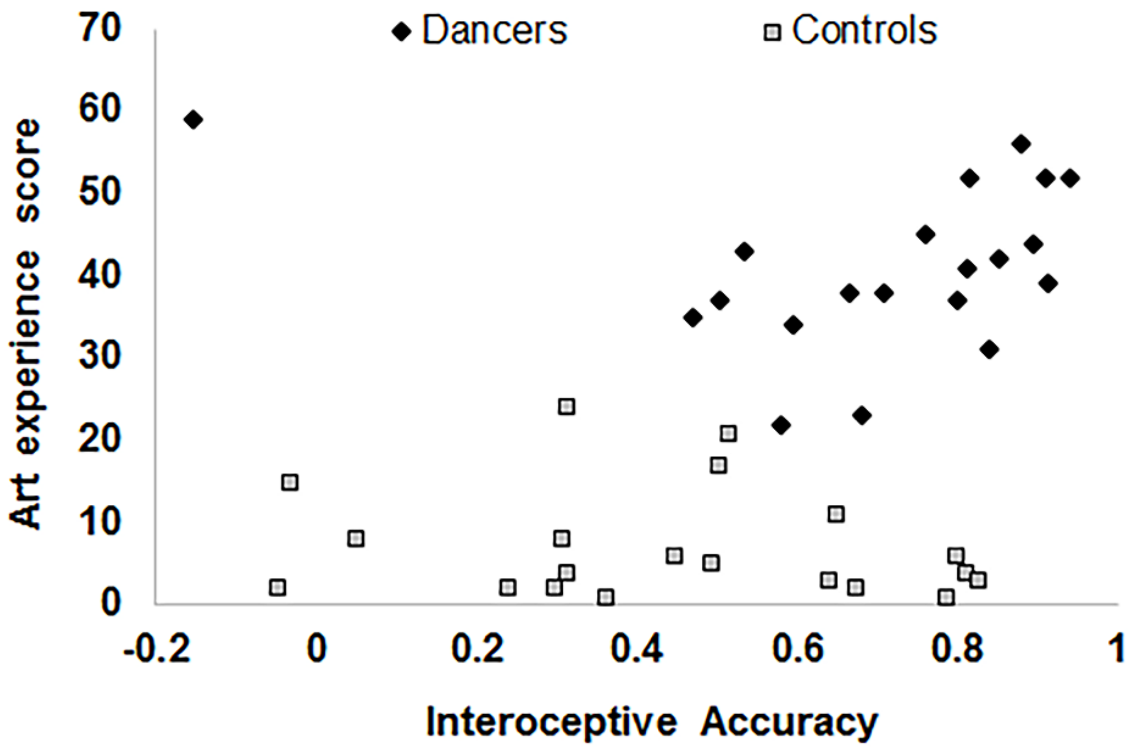

Figure 5. Scatter dot illustration of the correlation between overall interoceptive accuracy and the art expertise questionnaire score. Squares represent the control group; rhombi represent the dancer group.