



## Short communication

## I feel it in my finger: Measurement device affects cardiac interoceptive accuracy



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## ABSTRACT

In recent years, measures of cardiac interoceptive accuracy have been heavily scrutinised. The focus has been on potentially confounding physiological and psychological factors; little research has examined whether the device used to record objective heartbeats may influence cardiac interoceptive accuracy. The present studies assessed whether the device employed influences heartbeat counting (HCT) accuracy and the location from which heartbeats are perceived. In Study One, participants completed the HCT using a hard-clip finger pulse oximeter, electrocardiogram (ECG) and a smartphone application. In Study Two, an ECG, hard-clip and soft-clip oximeter were compared. Moderate-strong correlations were observed across devices, however, mean HCT accuracy and confidence varied as a function of device. Increased sensation in the finger when using a hard-clip pulse oximeter was related to increased accuracy relative to ECG. Results suggest that the device employed can influence HCT performance, and argue against comparing, or combining, scores obtained using different devices.

## 1. Introduction

With increased focus on interoception, the perception of the body's internal state (Craig, 2002; Khalsa et al., 2018), there is a growing need to scrutinise the methods used to quantify individual differences. Measures of cardiac interoceptive accuracy (e.g., the heartbeat counting task; HCT; Dale & Anderson, 1978; Schandry, 1981) remain the most commonly used. This is despite evidence that several factors (e.g., physiology; heart rate knowledge; Khalsa et al., 2009; Murphy et al., 2018; Ring et al., 2015) may influence performance on these tasks.

Despite scrutiny of cardiac interoception paradigms, it appears that only two studies have examined whether the use of different devices for quantifying objective heartbeats (e.g., pulse oximetry vs. electrocardiogram (ECG)) influences performance. These studies suggest that performance does not depend on the method used, whether one compares ECG versus wrist palpation or chest auscultation (Cali et al., 2015) or ECG versus a hard-clip finger pulse oximeter (Nicholson et al., 2018).

Whilst these studies suggest measurement device does not affect performance, both studies utilised between-participants designs. Given

large individual differences in HCT performance (e.g. Murphy et al., 2018), such designs likely lack sensitivity to detect an effect of measurement device. Furthermore, even if the device used does not influence performance, it may change the bodily location from which the heartbeat is perceived. Evidence suggests the heartbeat is most commonly perceived via the chest (Khalsa et al., 2009; Nummenmaa et al., 2018), but the use of a finger pulse oximeter may result in the heartbeat being perceived in the finger.

The present studies compared HCT performance, within-participants, using three measurement devices. In Study One, we compared an ECG, hard-clip pulse oximeter and a smartphone application (hereafter 'APP'). As well as accuracy, confidence and insight (interoceptive metacognition), we examined the influence of device on the location from which the heartbeat was perceived. Both the APP and pulse oximeter likely direct attention to the finger (as participants are aware that heartbeats are recorded from this location), but only the oximeter exerts pressure on the finger. We predicted that the finger pulse oximeter would increase intensity ratings at the finger, improving HCT accuracy. For any observed differences in accuracy, we aimed to quantify whether

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this resulted in a population-based change (a mean change in scores) or influenced participant rank-order (had a differential effect on scores across individuals). In Study Two, we compared ECG with hard-clip and soft-clip pulse oximeters to determine whether the effects observed in Study One could be replicated and would extend to soft-clip pulse oximeters.

## 2. Method

### 2.1. Participants

80 neurotypical adults took part. Due to equipment failure, 13 datasets were lost, resulting in 67 cases ( $M_{age} = 23.15$ ,  $SD_{age} = 6.05$ ; 38 Male). Three participants were missing one trial. For these, we averaged across valid trials or, for correlations, entered the mean score. For 'other ratings' (see Method) one participant rated multiple locations with differing intensities and this trial was removed. Ethical approval for both studies was granted by the local ethics subcommittee.

### 2.2. Procedure

During the 60-minute session, participants completed four trials of the HCT using each device (hard-clip pulse oximeter (CMSD50+; Contec, China), ECG (BIOPAC Systems, UK), and a custom-built smartphone application that recorded heartbeats using camera-driven photoplethysmography (BioBeats, UK). Interval duration (22,32,42,98 vs. 25,35,45,100 vs. 28,38,48,103, vs. 31,41,51,106 s) was latin-square counterbalanced, and interval order was randomised. Five participants completed the same interval duration for more than one device, and, due to randomisation issues, some participants completed the same interval order for more than one device. This did not influence the results (supplement [S2]). Half of participants completed the hard-clip pulse oximeter first, with the order of ECG vs. APP counterbalanced.

Prior to the HCT, participants were given detailed instructions (supplement [S1]). After each trial, participants rated their confidence (Total guess/no heartbeat awareness–Complete confidence/full perception of heartbeat) and how much/intensely they felt their heartbeat in 9 locations (chest, finger, neck, ears, stomach, legs, head, back, other; not at all–full perception), all on 0–10 scales.

## 3. Results

### 3.1. Scoring and analysis strategy

HCT accuracy per trial was scored using the equation  $((1 - (|Actual number of heartbeats - participant's estimate| / Actual number of heartbeats)) \times 100)$ . For each device, the average of the four trials completed was calculated. Insight was calculated by taking the absolute difference between accuracy (converted to a 0–10 scale) and confidence. The r-peaks of the ECG and hard-clip pulse oximeter waves were visually inspected and counted by two raters (inter-rater reliability was excellent;  $\tau_b = .973$ ,  $p < .001$ ; intraclass correlation = .998,  $F(129, 129) = 616.93$ ,  $p < .001$ ). All analyses were conducted in SPSS and JASP 10.2.0. Greenhouse-Geisser corrections were utilised where appropriate, with Bonferroni corrections employed for follow-up tests (corrected values are denoted by  $p_c$ ). Spearman correlations were used to establish whether the different devices resulted in a change in rank order for accuracy, confidence and insight. Kendall's Tau-b correlations were also used for all other correlations due to violations of normality. Data for both studies is available at [https://osf.io/9p2f5/?view\\_only=a345ed12a2514131b6ef07fc25604afe](https://osf.io/9p2f5/?view_only=a345ed12a2514131b6ef07fc25604afe).

### 3.2. Descriptive statistics and correlations

Descriptive statistics and Spearman correlations are presented in Table 1 and Fig. 3a–c.

### 3.3. Performance across devices

One-way repeated measures ANOVAs were used to compare accuracy, confidence and insight across devices (hard-clip pulse oximeter, ECG, APP). For accuracy, there was a main effect of device ( $F(2,132) = 23.80$ ,  $p < .001$ ,  $\eta^2 = .27$ ). Pairwise comparisons revealed that HCT accuracy was higher for the hard-clip pulse oximeter than the ECG ( $t(66) = 4.53$ ,  $p_c < .001$ ,  $d = .55$ ) and APP ( $t(66) = 6.07$ ,  $p_c < .001$ ,  $d = .74$ ), with accuracy also higher for the ECG than APP ( $t(66) = 2.63$ ,  $p_c = .032$ ,  $d = .32$ ). For confidence, a main effect of device was observed ( $F(2,132) = 20.62$ ,  $p < .001$ ,  $\eta^2 = .24$ ). HCT confidence was higher for the hard-clip pulse oximeter than the ECG ( $t(66) = 4.46$ ,  $p_c < .001$ ,  $d = .54$ ) and APP ( $t(66) = 5.33$ ,  $p_c < .001$ ,  $d = .65$ ). Confidence did not differ between the ECG and APP ( $t(66) = 1.60$ ,  $p_c > .250$ ,  $d = .20$ ). Insight did not differ across devices ( $F(2,132) = 1.541$ ,  $p > .20$ ,  $\eta^2 = .02$ ) (Fig. 1).

As heart rate varied across devices, we controlled for heart rate in additional analyses (supplement [S3]), which revealed the same pattern of results. The data were also examined for order effects. Simple effects revealed that the difference between the ECG and hard-clip pulse oximeter accuracy was only observed when the oximeter was completed last ( $p < .001$ ), not first ( $p > .250$ ; supplement [S7–S8]).

### 3.4. Perception of heartbeat intensity across locations and devices

A 3 (Device: hard-clip pulse oximeter, ECG, APP)  $\times$  9 (Location: chest, finger, neck, ears, stomach, legs, head, back, other) repeated measures ANOVA was used to examine whether intensity ratings differed across locations and devices. Significant main effects of device ( $F(2,132) = 13.72$ ,  $p < .001$ ,  $\eta^2 = .17$ ) and location ( $F(8,528) = 36.67$ ,  $p < .001$ ,  $\eta^2 = .36$ ) were observed, and a significant device  $\times$  location interaction ( $F(16,1056) = 17.10$ ,  $p < .001$ ,  $\eta^2 = .21$ ; Fig. 1). Follow-up ANOVAs revealed an effect of device for finger intensity ratings only ( $F(2,132) = 38.28$ ,  $p < .001$ ,  $\eta^2 = .37$ ). Pairwise comparisons revealed that finger intensity ratings were greater for the hard-clip pulse oximeter than ECG ( $t(66) = 7.22$ ,  $p_c < .001$ ,  $d = .88$ ) and APP ( $t(66) = 5.76$ ,  $p_c < .001$ ,  $d = .70$ ). No difference was found between ECG and APP ( $t(66) = 2.35$ ,  $p_c > .05$ ,  $d = .29$ ). See supplement [S5–S6] for further analysis of 'other' responses.

Task order (pulse oximeter first or last) did not affect the finding of increased sensation in the finger during the hard-clip pulse oximeter condition (supplement [S7, S9]).

### 3.5. The relationship between perceived bodily location of heartbeat and accuracy

To examine whether increased finger intensity ratings during the pulse oximeter condition contributed towards increased accuracy, we calculated hard-clip pulse oximeter-ECG and APP-ECG difference scores for accuracy, confidence, finger and chest intensity ratings. Increased accuracy during the hard-clip pulse oximeter condition, relative to ECG, correlated positively with increased finger intensity ratings during the hard-clip pulse oximeter condition, relative to ECG ( $\tau_b = .329$ ,  $p < .001$ ; but not the chest,  $\tau_b = -.093$ ,  $p > .250$ ). The same pattern of results was observed for confidence (finger:  $\tau_b = .466$ ,  $p < .001$ ; chest:  $\tau_b = -.081$ ,  $p > .250$ ) (Fig. 4). Bayesian follow-up analyses were completed to derive Bayes Factors indicating relative support for null ( $H_0$ ) and alternate ( $H_1$ ) hypotheses ( $BF_{10}$  denotes support for  $H_1$ ,  $BF_{01}$  denotes support for  $H_0$ ). These analyses suggested strong support for  $H_1$  in terms of the relationship between difference scores for finger ratings, accuracy and confidence ( $BF_{10}$  accuracy = 324.30, confidence = 665470.26). Moderate support for  $H_0$  was observed for the comparable analyses on chest rating difference scores ( $BF_{01}$  accuracy = 3.41; confidence = 3.97).

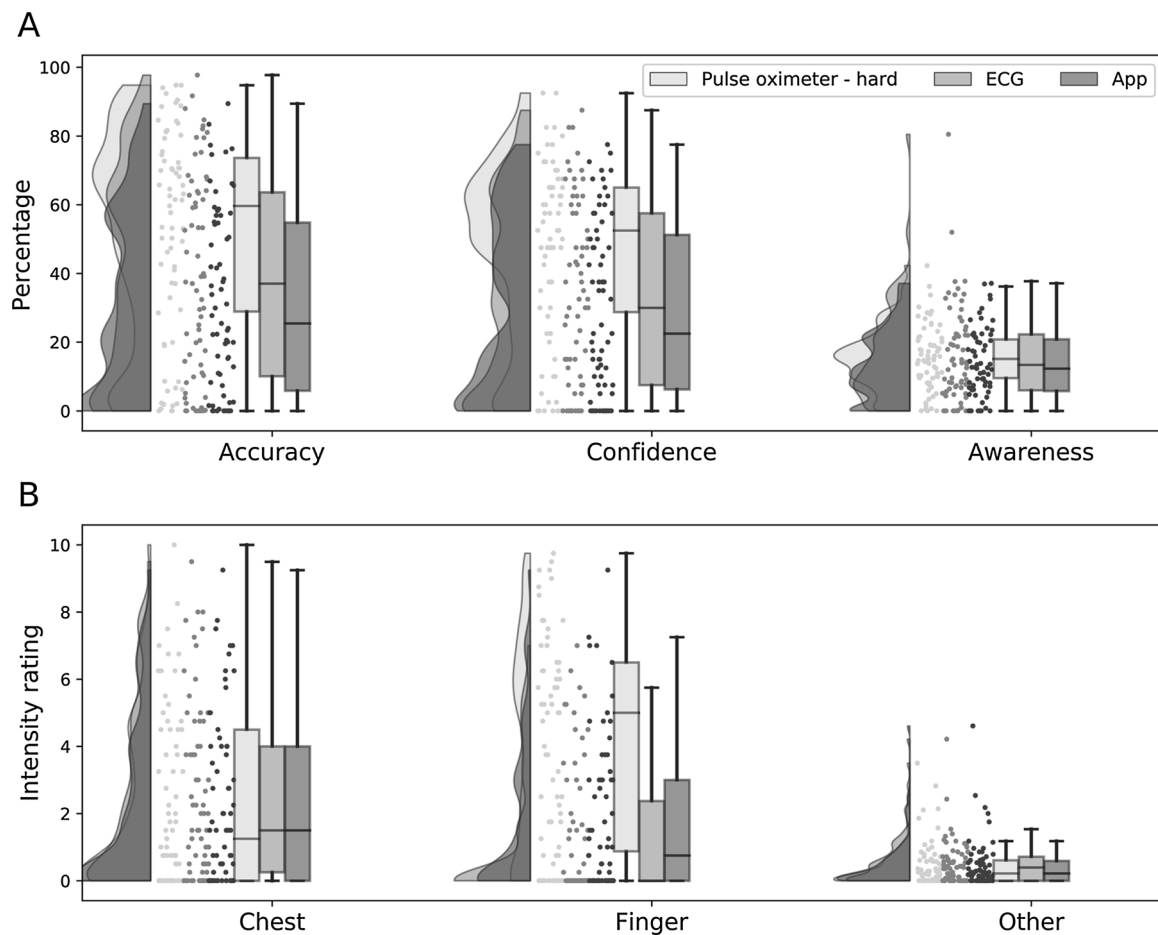
Comparable analyses of the APP-ECG difference scores revealed no association between difference scores for accuracy and finger ratings

**Table 1**

Study One: Descriptive statistics and spearman correlations for all heartbeat counting variables.

	Mean	SD	1	2	3	4	5	6	7	8
1. PO ACC	51.50	30.28	1							
2. ECG ACC	38.25	30.02	.668**	1						
3. APP ACC	31.38	26.37	.522**	.707**	1					
4. PO Confidence	4.66	2.61	.781**	.582**	.383**	1				
5. ECG Confidence	3.30	2.68	.460**	.770**	.686**	.544**	1			
6. APP Confidence	2.98	2.53	.429**	.600**	.848**	.478**	.782**	1		
7. PO Insight	1.54	0.93	.444**	.305*	.341**	.287*	0.218	.276*	1	
8. ECG Insight	1.60	1.44	.284*	.587**	.321**	.340**	.436**	.318**	.512**	1
9. APP Insight	1.33	1.01	.282*	.384**	.569**	.296*	.510**	.562**	.495**	.414**

\*denotes significant at  $p < .05$ ; \*\*denotes significant at  $p < .001$ . PO = Hard-clip Pulse Oximeter. ECG = Electrocardiogram. APP = Smartphone application. ACC = accuracy.



**Fig. 1.** A) Percentage accuracy, confidence and insight scores by device for Study One. Note that percentage scores are given for confidence and insight, calculated by multiplying scores on the 0–10 scale by 10. B) Intensity of perceived heartbeat ratings for the chest and finger by device. Error bars represent the minimum and maximum within 1.5 times the interquartile range of the lower and upper quartile. Lines represent the median. ECG = Electrocardiogram. Other = average ratings across all other bodily locations: neck, ears, stomach, legs, head, back, other (not listed). For a depiction of all bodily locations see supplementary results [S4]. Raincloud plots were created using tools detailed in Allen et al., (2019).

( $\tau_b = .109, p > .20$ ), however a significant correlation for chest ratings was observed ( $\tau_b = .185, p = .034$ ). For confidence, an association was observed for the finger ( $\tau_b = .195, p = .031$ ) with a trend observed for the chest ratings ( $\tau_b = .171, p = .056$ ). For accuracy, Bayes Factors suggested anecdotal support for H0 for finger ratings ( $BF_{01} = 2.73$ ) but weak evidence for H0 for chest ratings ( $BF_{01} = 0.57$ ). For confidence, support for H0 was weak for finger ratings ( $BF_{01} = 0.43$ ), with little evidence for H0 or H1 with respect to chest ratings ( $BF_{01} = 0.80$ ,  $BF_{10} = 1.24$ ).

#### 4. Study two

The results of Study One suggest that hard-clip pulse oximeters may influence accuracy and the bodily location from which heartbeats are perceived. What remains unclear is whether these results extend to soft-clip pulse oximeters, which may produce less sensation in the finger, as they exert less pressure on the finger. This question was addressed in Study Two.

## 5. Method

### 5.1. Participants

Power analyses (conducted in G\*Power) on the accuracy difference observed between the hard-clip pulse oximeter and ECG (Study One) suggested that 28 participants would provide > 80% power to replicate this effect (two-tailed). 31 neurotypical participants took part in exchange for a small honorarium ( $M_{age} = 32.48$ ,  $SD_{age} = 11.40$ , 12 Males).

### 5.2. Procedure

The procedure was identical to Study One except a soft-clip pulse oximeter was used in place of the APP ('soft' mount PureLight sensor; Nonin Medical Inc., MN, USA). 3 interval durations were utilised (25,35,45,100 vs. 28,38,48,103, vs. 31,41,51,106 s) that were counterbalanced across participants. Interval order was randomised and the order of conditions (hard-clip vs. soft-clip vs. ECG) was fully counterbalanced across participants. To determine if finger-sensations were related to finger size, the circumference of the finger under the cuticle was measured using a ring sizer.

## 6. Results

### 6.1. Scoring and analysis strategy

Recording during all conditions was completed using the ECG, with r-peaks scored using Acqknowledge software. All data were collected and visually inspected by one experimenter, with r-peaks manually counted to ensure accuracy. For participants reporting multiple locations for 'other' ratings ( $N = 6$ ), the average intensity rating was utilised. Scoring methods were otherwise identical to Study One.

### 6.2. Descriptive statistics and correlations

Descriptive statistics and Spearman correlations are presented in Table 2 and Fig. 3d–f.

### 6.3. Performance across devices

One-way repeated measures ANOVAs were used to compare accuracy, confidence and insight across devices (hard-clip pulse oximeter, ECG, soft-clip pulse oximeter). For accuracy, there was a main effect of device ( $F(2,60) = 9.34$ ,  $p < .001$ ,  $\eta^2 = .24$ ; Fig. 2). Pairwise comparisons revealed that HCT accuracy for the hard-clip pulse oximeter was higher than the ECG ( $t(30) = 3.85$ ,  $p_c = .002$ ,  $d = 1.0$ ) and the soft-clip pulse oximeter ( $t(30) = 3.67$ ,  $p_c = .003$ ,  $d = .66$ ). No difference was observed between the ECG and soft-clip pulse oximeter ( $t(30) = -.80$ ,  $p_c > .250$ ,  $d = .15$ ). For confidence, a main effect of device was observed ( $F(2,60) = 6.63$ ,  $p = .003$ ,  $\eta^2 = .18$ ). HCT confidence was

higher for the hard-clip pulse oximeter than the ECG ( $t(30) = 3.18$ ,  $p_c = .01$ ,  $d = .57$ ) and soft-clip pulse oximeter ( $t(30) = 2.88$ ,  $p_c = .022$ ,  $d = .52$ ). No difference was observed between the ECG and soft-clip pulse oximeter ( $t(30) = -.711$ ,  $p_c > .250$ ,  $d = .13$ ). Insight did not differ across devices ( $F(2,60) = 3.45$ ,  $p = .057$ ,  $\eta^2 = .10$ ).

Heart rate did not differ across devices ( $F(2,60) = .01$ ,  $p > .250$ ), and no interaction with order was observed for the above analyses (all interactions  $p > .250$ ).

### 6.4. Perception of heartbeat intensity across locations and devices

A 3 (Device: hard-clip pulse oximeter, ECG, soft-clip pulse oximeter)  $\times$  9 (Location: chest, finger, neck, ears, stomach, legs, head, back, other) repeated measures ANOVA was used to examine whether intensity ratings differed across locations and devices. A main effect of location was observed ( $F(8,240) = 23.66$ ,  $p < .001$ ,  $\eta^2 = .44$ ) but no main effect of device ( $F(2,60) = 2.34$ ,  $p = .11$ ,  $\eta^2 = .07$ ). Importantly, a significant device  $\times$  location interaction was observed ( $F(16,480) = 10.94$ ,  $p < .001$ ,  $\eta^2 = .27$ ). Follow-up ANOVAs revealed an effect of device for finger intensity ratings only ( $F(2,60) = 23.97$ ,  $p < .001$ ,  $\eta^2 = .44$ ; Fig. 2). Pairwise comparisons revealed that finger intensity ratings were greater for that hard-clip pulse oximeter than ECG ( $t(30) = 6.55$ ,  $p_c < .001$ ,  $d = 1.18$ ) and the soft-clip pulse oximeter ( $t(30) = 4.74$ ,  $p_c < .001$ ,  $d = .85$ ). No difference was found between ECG and soft-clip pulse oximeter ( $t(30) = -2.03$ ,  $p_c = .15$ ,  $d = .37$ ). See supplement [S11–S12] for further analysis of 'other' responses for Study Two.

A device  $\times$  location  $\times$  order ANOVA was also conducted, but no significant effects of order were observed (all  $ps > .15$ ). Finger intensity ratings were not correlated with finger size for either pulse oximeter (both  $p > .190$ ).

### 6.5. The relationship between perceived bodily location of heartbeat and accuracy

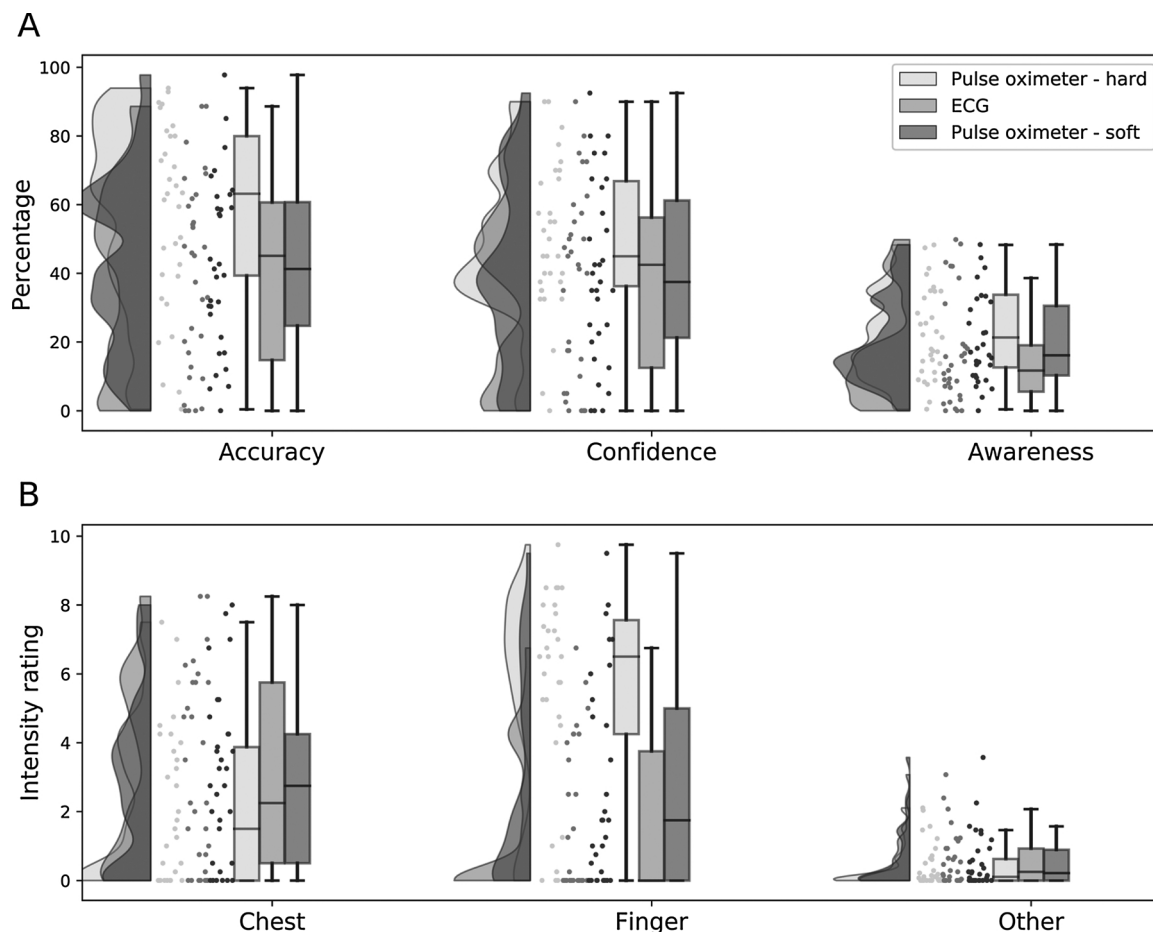
To examine whether increased finger intensity ratings during the hard-clip pulse oximeter condition contributed towards increased accuracy, we calculated hard-clip pulse oximeter-ECG and soft-clip pulse oximeter-ECG difference scores for accuracy, confidence, finger and chest intensity ratings. Increased accuracy during the hard-clip pulse oximeter condition, relative to the ECG condition, correlated positively with increased finger intensity ratings during the hard-clip pulse oximeter condition, relative to the ECG condition ( $\tau_b = .301$ ,  $p = .019$ ; but not the chest,  $\tau_b = -.015$ ,  $p > .250$ ). No significant correlation was observed for confidence ( $\tau_b = .217$ ,  $p = .094$ ; or the chest,  $\tau_b = .011$ ,  $p > .250$ ). Bayes Factors suggested moderate support for H1 in terms of the relationship between finger ratings for the hard-clip pulse oximeter and accuracy ( $BF_{10} = 3.54$ ). The comparable analysis for confidence ratings was equivocal ( $BF_{10} = 0.96$ ,  $BF_{01} = 1.04$ ). In contrast, moderate support for H0 was observed for chest ratings ( $BF_{01}$

**Table 2**

Study Two: Descriptive statistics and spearman correlations for all heartbeat counting variables.

	Mean	SD	1	2	3	4	5	6	7	8
1. Hard PO ACC	56.89	27.31	1							
2. ECG ACC	39.19	27.67	.520**	1						
3. Soft PO ACC	42.82	25.05	.640**	.605**	1					
4. Hard PO Confidence	4.95	2.21	.467**	.388*	.488**	1				
5. ECG Confidence	3.76	2.73	.271	.700**	.410*	.631**	1			
6. Soft PO Confidence	4.00	2.64	.307	.490**	.631**	.692**	.743**	1		
7. Hard PO Insight	2.24	1.29	.351	.166	.222	.045	−0.019	.109	1	
8. ECG Insight	1.65	1.55	.267	.597**	.268	.346	.521**	.350	.332	1
9. Soft PO Insight	2.02	1.27	.427*	.212	.375*	.256	.139	.261	.769**	.286

\*denotes significant at  $p < .05$ ; \*\*denotes significant at  $p < .001$ . Hard PO = Hard clip Pulse Oximeter. ECG = Electrocardiogram. Soft PO = Soft-clip pulse oximeter. ACC = accuracy.



**Fig. 2.** A) Percentage accuracy, confidence and insight scores by device for Study Two. Note that percentage scores are given for confidence and insight, calculated by multiplying scores on the 0–10 scale by 10. B) Intensity of perceived heartbeat ratings for the chest and finger by device. Error bars represent the minimum and maximum within 1.5 times the interquartile range of the lower and upper quartile. Lines represent the median. ECG = Electrocardiogram. Other = average ratings across all other bodily locations: neck, ears, stomach, legs, head, back, other (not listed). For a depiction of all bodily locations see supplementary results [S10]. Raincloud plots were created using tools detailed in Allen et al., (2019).

accuracy = 4.29, confidence = 4.30).

The same analyses were completed for the soft-clip pulse oximeter-ECG difference scores. Increased accuracy during the soft-clip pulse oximeter condition, relative to the ECG condition, was not significantly correlated with increased finger intensity ratings during the soft-clip pulse oximeter condition, relative to the ECG condition ( $\tau_b = .138$ ,  $p > .250$ ; nor for the chest,  $\tau_b = .009$ ,  $p > .250$ ) (see Fig. 5). The same pattern of significance was observed for confidence (finger:  $\tau_b = .054$ ,  $p > .250$ ; chest:  $\tau_b = .140$ ,  $p > .250$ ). Bayes Factors suggested anecdotal-moderate support for H0 in terms of the relationship with finger ratings ( $BF_{01}$  accuracy = 2.43, confidence = 3.96). Anecdotal-moderate support for H0 was observed for chest ratings ( $BF_{01}$  accuracy = 4.31, confidence = 2.40).

## 7. Discussion

This study investigated whether the device used to measure heartbeats in cardiac interoception tasks influences accuracy and the bodily location from which heartbeats are perceived. We aimed to quantify whether any observed effect of device resulted in a population-based change (change consistent across individuals), or a change in participant rank-order (differential change across individuals). Results across both studies showed that accuracy, confidence and insight scores across devices were correlated. In both studies, accuracy and confidence were higher when the hard-clip pulse oximeter was used. In Study One, accuracy for the ECG was also higher than the APP. In Study Two,

accuracy and confidence for the ECG and the soft-clip pulse oximeter were not significantly different. Across studies, differences in accuracy between the ECG and the hard-clip (but not soft-clip) pulse oximeter correlated with increased perception of heartbeat at the finger.

These data suggest that the use of different measurement devices results in a change in scores that is (relatively) consistent across individuals, as evidenced by moderate-strong correlations across all devices in both studies. As such, they argue against combining or comparing HCT scores across participants or groups where different measurement devices have been used (e.g., Nicholson et al., 2018). Overall, HCT accuracy scores for the ECG and APP (Study One) showed the strongest correspondence, with the soft-clip pulse oximeter (Study Two) also showing reasonable correspondence with the ECG. Pulse oximetry techniques that do not exert pressure on the finger may therefore be preferable where ECG methods are not available. Comparison of the APP and soft-clip pulse oximeter showed that the APP resulted in a lower percentage of the sample feeling sensation in their finger in terms of both raw scores (Soft Clip: 71%; App: 60%), and when compared to finger sensation in the ECG condition (Soft Clip: 58%; App: 42%).

As noted above, the HCT has been criticised due to its vulnerability to various psychological and physiological confounds (Khalsa et al., 2009; Murphy et al., 2018; Ring et al., 2015; see Murphy et al., 2018 for recent methodological recommendations). This short task was selected to enable a within-subjects design and allow measurements to be taken in a single session, given evidence of state effects on accuracy

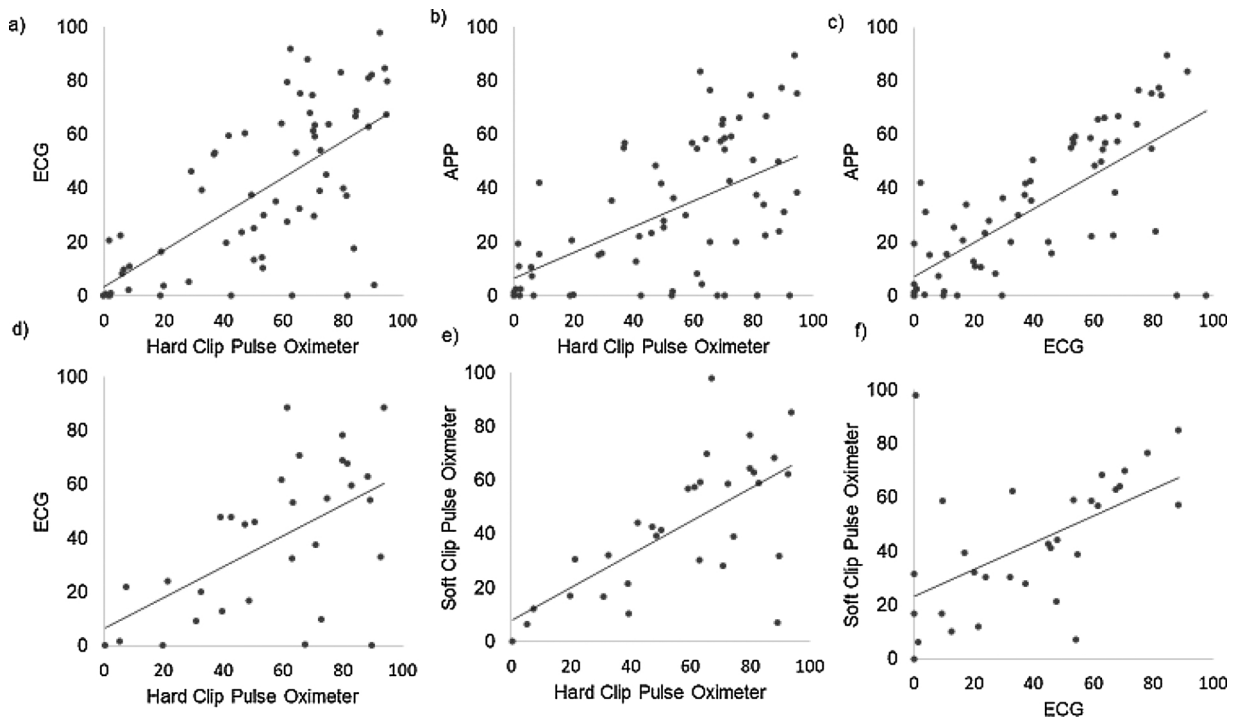


Fig. 3. Panels a–c present the correlations between accuracy scores obtained using the three different devices in Study One. Panels d–f present the correlations between accuracy scores obtained using the three different devices in Study Two. Significant correlations were observed in all cases.

(Wittkamp et al., 2018). Moreover, as these studies were conducted within-participants, several psychological and physiological factors impacting on performance (e.g., beliefs; Ring et al., 2015) were

controlled. Furthermore, there is no reason to suppose that these results would differ for any other measure of interoception requiring perception of heartbeats.

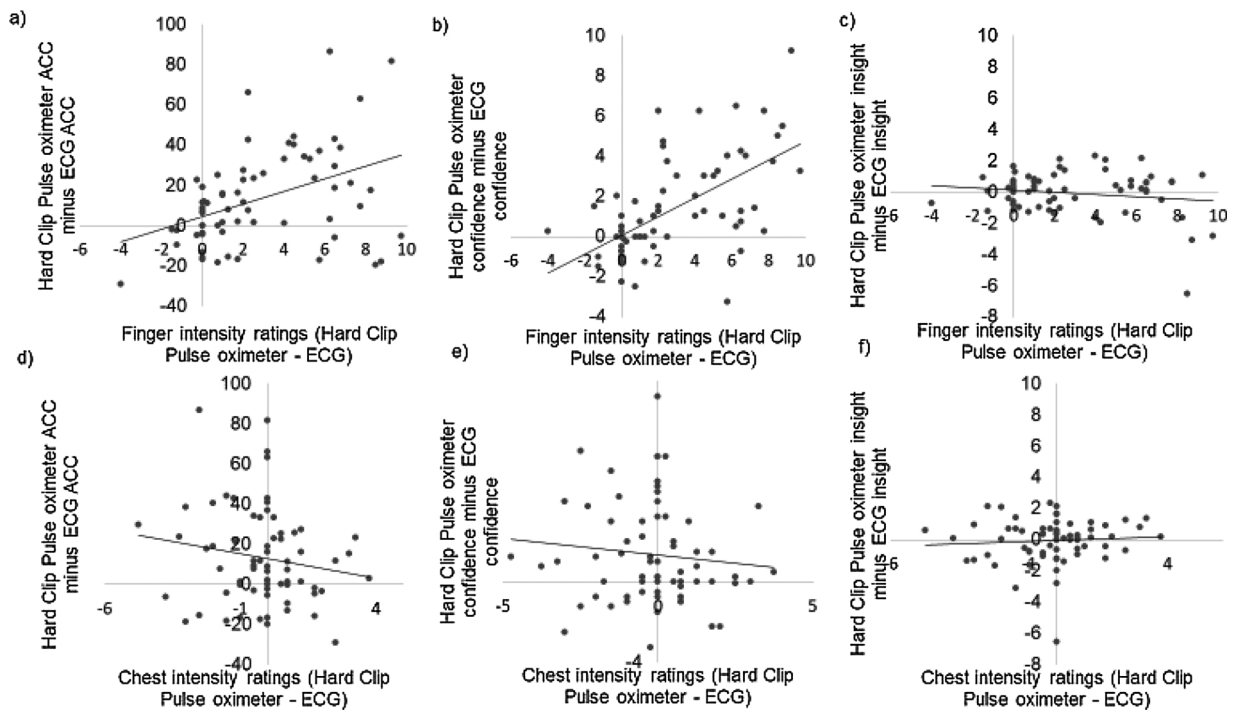
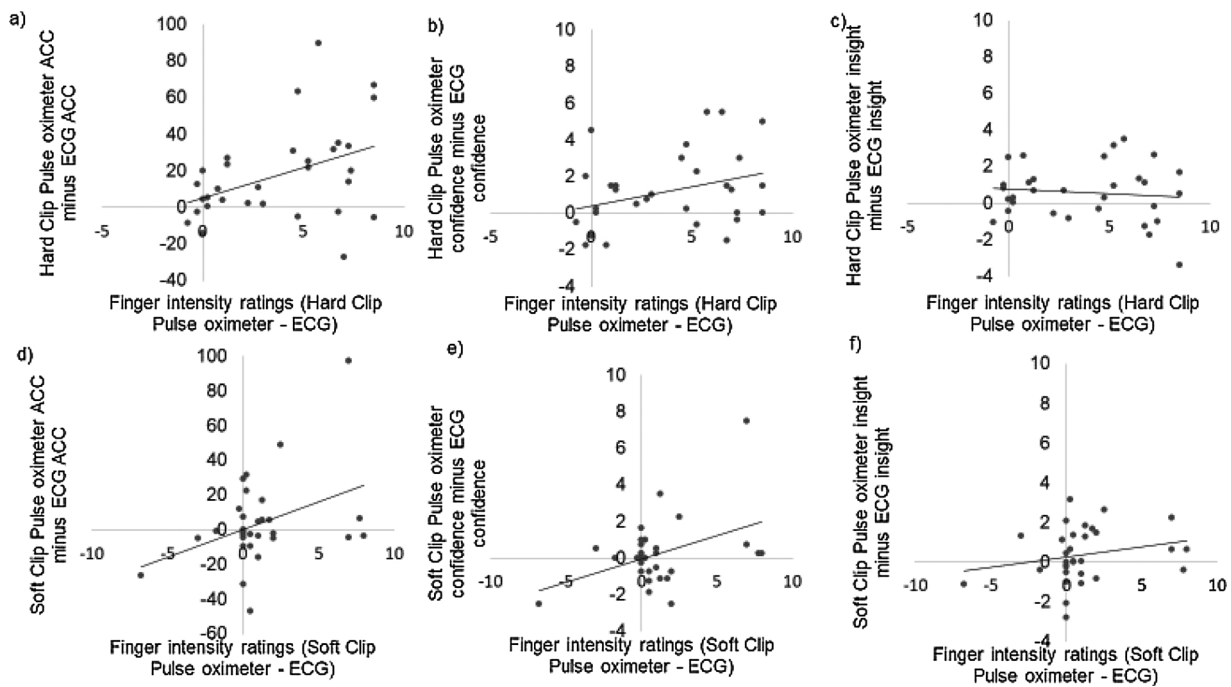


Fig. 4. Relationship between intensity ratings and performance in Study One. Panel a presents the relationship between difference scores for intensity ratings at the finger (hard-clip pulse oximeter minus ECG) and the difference scores between hard-clip pulse oximeter accuracy minus ECG accuracy. A significant correlation was observed. Panel b presents the relationship between difference scores for intensity ratings at the finger (hard-clip pulse oximeter minus ECG) and the difference scores between hard-clip pulse oximeter confidence minus ECG confidence. A significant correlation was observed. Panel c presents the relationship between difference scores for intensity ratings at the finger (pulse oximeter minus ECG) and the difference scores between pulse oximeter insight minus ECG insight. The correlation was not significant. Panels d–f present the same correlations for chest ratings. All correlations for chest ratings were non-significant. ECG = Electrocardiogram. ACC = accuracy.



**Fig. 5.** Relationship between intensity ratings and performance in Study Two. Panel a presents the relationship between difference scores for intensity ratings at the finger (hard-clip pulse oximeter minus ECG) and the difference scores between hard-clip pulse oximeter accuracy minus ECG accuracy. A significant correlation was observed. Panel b presents the relationship between difference scores for intensity ratings at the finger (hard-clip pulse oximeter minus ECG) and the difference scores between hard-clip pulse oximeter confidence minus ECG confidence. No significant relationship was observed. Panel c presents the relationship between difference scores for intensity ratings at the finger (hard-clip pulse oximeter minus ECG) and the difference scores between pulse oximeter insight minus ECG insight. The correlation was not significant. Panels d–f present the comparable analyses for the soft-clip pulse oximeter. No significant associations were observed. ECG = Electrocardiogram. ACC = accuracy.

These data suggest that the device used to record objective heartbeats in cardiac interoception tasks may influence accuracy and confidence, and the bodily location from which the heartbeat is felt. These data argue against combining or comparing scores across different devices and caution against the use of hard-clip pulse oximeters.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.biopsycho.2019.107765>.

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