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10 Being watched: The effect of social self-focus on interoceptive and exteroceptive  
11 somatosensory perception  
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47 **Abstract**

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49 We become aware of our bodies interoceptively, by processing signals arising from within the  
50 body, and exteroceptively, by processing signals arising on or outside the body. Recent  
51 research highlights the importance of the interaction of exteroceptive and interoceptive signals  
52 in modulating bodily self-consciousness. The current study investigated the effect of social self-  
53 focus, manipulated via a video camera that was facing the participants and that was either  
54 switched on or off, on interoceptive sensitivity (using a heartbeat perception task) and on tactile  
55 perception (using the Somatic Signal Detection Task (SSDT)). The results indicated a  
56 significant effect of self-focus on SSDT performance, but not on interoception. SSDT  
57 performance was not moderated by interoceptive sensitivity, although interoceptive sensitivity  
58 scores were positively correlated with false alarms, independently of self-focus. Together with  
59 previous research, our results suggest that self-focus may exert different effects on body  
60 perception depending on its mode (private versus social). While interoception has been  
61 previously shown to be enhanced by private self-focus, the current study failed to find an effect  
62 of social self-focus on interoceptive sensitivity, instead demonstrating that social self-focus  
63 improves exteroceptive somatosensory processing.

64

65 *Keywords:* Interoception; Exteroception; Heartbeat perception; Somatic signal detection; Self-  
66 focus

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89 **1. Introduction**

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91 Considerable research evidence supports the multi-level model of body perception and body  
92 awareness (Berlucchi & Aglioti, 2010). In order for us to be aware of, and have an accurate  
93 perception of our bodies we must co-perceive various sensory inputs, including interoceptive,  
94 exteroceptive, proprioceptive, vestibular, tactile, and visual signals (Neisser, 1993). For a large  
95 part, we become aware of our bodies interoceptively, by processing signals arising from within  
96 the body (e.g., heart beats, respiration, gastrointestinal functions), and exteroceptively by  
97 processing signals arising on (e.g., touch), or outside the body (e.g., vision). While research on  
98 multisensory integration delineates how exteroceptive signals are combined and then impact  
99 body-awareness (e.g., vision and touch, or vision and audition; see Tsakiris, 2010 for a review),  
100 little is known about the integration of signals across interoceptive and exteroceptive  
101 somatosensory modalities. Even though interoceptive and exteroceptive signals are processed  
102 separately in the brain (e.g., Farb, Segal, & Anderson, 2013; Hurliman, Nagode, & Pardo, 2005)  
103 the two modes of bodily perception are highly interconnected (Simmons et al., 2012) and need to  
104 be integrated to bring about body awareness (Craig, 2009). Recent empirical investigations  
105 demonstrate that combined interoceptive-exteroceptive signals can significantly alter ownership  
106 of a virtual hand (Suzuki, Garfinkel, Critchley, & Seth, 2013), as well as awareness of one's  
107 body in space (Aspell et al., 2013), providing behavioral evidence to suggest that interoceptive  
108 and exteroceptive signals are integrated to jointly shape body awareness and perception.

109 As body perception ultimately relies on the online integration of sensory signals across  
110 different modalities—a dynamic process strongly modulated by attention (e.g., Talsma &  
111 Woldorff, 2005)—state-dependent fluctuations in both interoceptive and exteroceptive  
112 somatosensory perception as a function of varying modes and degrees of attention to the self  
113 could be expected. Distinct modes of self-focus enhance aspects of the self directly related to the  
114 given focus-mode—for example, mirrors have been found to elicit a more private self-focus, by  
115 directing individuals' attention to inner aspects of the self, whereas video cameras have been  
116 found to elicit a more social self-focus by drawing individuals' attention to the external,  
117 observable to others aspects of the self (Carver & Scheier, 1981; Davies, 2005). Private self-  
118 focus has been found to enhance interoceptive sensitivity, as reflected by higher heartbeat  
119 perception accuracy when attending to pictures of self, self-referential words (Ainley, Maister,  
120 Brokfeld, Farmer, & Tsakiris, 2013) or reflection of self in a mirror (Ainley, Tajadura-Jimenez,  
121 Fotopoulou, & Tsakiris, 2012; Weisz, Balazs, & Adam, 1988). The way in which private self-  
122 focus affects exteroceptive somatosensory perception is less clear than in the case of  
123 interoception. A recent study by Mirams, Poliakoff, Brown, and Lloyd (2013) shows that body-  
124 scan meditation practice, in which participants are trained to attend to selective areas of the body  
125 one at a time while taking the time to notice any somatic sensations in a non-evaluative manner,  
126 is followed by an increase in sensitivity and decrease in false alarm rates on a tactile perception  
127 task, suggesting enhanced tactile perception following the meditation practice. The authors point  
128 out that their results contradict the findings from their previous study (Mirams, Poliakoff, Brown,  
129 & Lloyd, 2012) examining the effects of interoceptive versus exteroceptive attention on  
130 somatosensory processing, which found that interoceptive attention increases an individual's  
131 propensity to report feeling a tactile stimulus regardless of whether it has occurred or not. They  
132 conclude that bodily self-focus might have differential effects on somatosensory processing  
133 depending on the mode of attention (localized, non-mindful interoceptive attention versus  
134 generalized, mindful body-scan meditation). Consequently, further research is necessary to

135 delineate the way in which self-focus affects interoceptive and exteroceptive somatosensory  
136 processing.

137 While several studies have investigated effects of various modes of private self-focus on  
138 body perception, no study to date has examined how processing of bodily signals, both  
139 interoceptive and exteroceptive in nature, is affected by social self-focus. Social self-focus has  
140 been successfully elicited in experimental settings with a turned on video camera facing the  
141 participant as if s/he is being filmed (e.g., Burgio, Merluzzi, & Pryor, 1986; Duval & Lalwani,  
142 1999). As there is evidence that private self-focus and social self-focus can have distinct  
143 cognitive effects (Davies, 2005), it is possible that social self-focus might impact body  
144 awareness in a different manner than private self-focus. The aim of the present study was to  
145 investigate whether social self-focus evoked by a turned on video camera (self-focus condition:  
146 camera turned on and facing the participant; non self-focus condition: camera turned off and  
147 facing away from the participant) would affect interoceptive and/or exteroceptive somatosensory  
148 processing.

149 We assessed interoceptive somatosensory processing by measuring cardiac interoceptive  
150 sensitivity (IS), which is commonly quantified as an individual's heartbeat perception accuracy  
151 score, calculated by comparing the number of heartbeats the individual reports to the number of  
152 heartbeats that actually occurred in a given time interval, with better heart beat perception  
153 accuracy reflecting higher interoceptive sensitivity (Schandry, 1981). In order to measure  
154 exteroceptive somatosensory processing we used a modified Somatic Signal Detection Task  
155 (SSDT; Lloyd, Mason, Brown, & Poliakoff, 2008). The SSDT involves detecting the presence of  
156 a near-threshold tactile stimulus presented on 50% of the trials, while a simultaneous visual  
157 stimulus, such as an LED, also flashes on 50% of the trials, resulting in an increase in  
158 participants' hit rate and false alarm rate due to the flashing LED (Lloyd et al., 2008). A signal  
159 detection analysis is used to establish whether any observed change in responses is due to an  
160 effect of the manipulation on tactile sensitivity (i.e., ability to tell apart signal from noise),  
161 response criterion (i.e., propensity to report feeling a tactile stimulus), or both. Overall, higher  
162 sensitivity, higher hit rate, and lower false alarm rate suggest higher exteroceptive/tactile  
163 awareness of the body. We hypothesized that the self-focus condition would be associated with  
164 enhanced somatosensory processing. We predicted that the self-focus condition would bring  
165 about an increase in interoceptive sensitivity as reflected by better heartbeat perception accuracy  
166 in the "camera on" as opposed to "camera off" condition. We further hypothesized that the  
167 "camera on" condition would be associated with improved tactile perception and that this would  
168 be reflected by increased sensitivity on the SSDT, driven by increased hit rate and decreased  
169 false alarm rate in the "camera on" as opposed to the "camera off" condition. As significant  
170 differences in emotional and cognitive processing based on individuals' interoceptive sensitivity  
171 level have been found—for example, in regards to emotional experience (e.g., Pollatos, Herbert,  
172 Matthias, & Schandry, 2007), decision-making (e.g., Werner, Jung, Duschek, & Schandry,  
173 2009), and memory performance (e.g., Werner, Peres, Duschek, & Schandry, 2010)—we have  
174 also aimed to investigate potential modulation of SSDT performance by IS level. We expected  
175 individuals with higher IS to display more accurate tactile perception, as reflected by higher  
176 sensitivity, higher hit rate, and lower false alarm rate. Lastly, we also wanted to examine whether  
177 the effect of social self-focus on interoceptive and/or exteroceptive somatosensory processing  
178 would be moderated by IS level.

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## 180 **2. Material and methods**

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## 2.1 Participants

Fifty-seven (48 female; Mean age = 18.67 years; SD = .93 years) undergraduate psychology students at Royal Holloway, University of London took part in the experiment in compensation for course credit.

## 2.2 Experimental design

The experiment was a fully counterbalanced within-subject design. Participants completed the interoceptive sensitivity (IS) task and the Somatic Signal Detection Task (SSDT) two times each—one time with the video camera turned on and facing the participant (i.e., social self-focus condition), and one time with the video camera turned off and facing away from the participant (i.e., non-self-focus condition). The order of “camera on”/“camera off” conditions was counterbalanced across participants. The order of IS task and SSDT within each condition (“camera on”, and “camera off”) was also counterbalanced across participants. Together, there were 8 possible orders. The order in which a given participant completed the tasks was randomized.

## 2.3 Experimental Set-up

Participant was seated at a desk-chair about 1 m away from the wall. A black screen with a 10 mm red LED in the middle was attached directly to the wall. The LED was at eye-level of the seated participant and directly in front of him or her. A video camera was mounted on a tripod and placed about 75 cm directly in front of the participant. The LED was about 25 cm behind the video camera. The camera was slightly below eye-level of the participant in order not to interfere with the participant’s vision of the LED. However, when turned on and facing the participant, the camera lens was turned slightly upwards in order to capture participant’s face. When the camera was turned off and the lens was facing away from the participant, the tripod and the camera remained in the same position in front of the participant. Fig. 1 illustrates the experimental set up.

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Insert Figure 1  
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During the experiment, the lab was dark; a spotlight placed above the participant illuminated the area in which the participant was seated. The spotlight did not directly illuminate the wall on which the LED was situated in order not to reduce visibility of the flashing light during the SSDT.

## 2.4 Interoceptive sensitivity task

Interoceptive sensitivity was assessed via heartbeat perception, using the Mental Tracking Method (Schandry, 1981). Participants were instructed to mentally count their heartbeats from the moment they received an audio computer-generated cue signaling the start of the trial, until they received an otherwise identical cue signaling the end of the trial, and then to verbally report to the experimenter the number of heartbeats they had counted. Every participant

227 was first presented with a 10-s training trial (during the first assessment only), and then with a  
228 block of 25-s, 35-s, and 45-s trials presented in a random order. During the whole duration of the  
229 task, participants' true heart rate was monitored using a piezo-electric pulse transducer attached  
230 to the participant's right index finger (PowerLab 26T, AD Instruments, UK). Throughout the  
231 assessment, participants were not permitted to take their pulse, or to use any other strategy such  
232 as holding their breath. No information regarding the length of the individual trials or feedback  
233 regarding participants' performance was given. The task was programmed using Presentation  
234 software (Neurobehavioral Systems: <http://www.neurobs.com>).

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## 236 **2.5 Somatic Signal Detection Task**

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238 The Somatic Signal Detection Task (SSDT; Lloyd et al., 2008) measures somatic  
239 sensitivity and response bias in detecting whether a tactile stimulus at threshold intensity is  
240 present or absent, while an irrelevant LED flashes (at the same time as the occurrence of tactile  
241 stimulation) or not. The dependent variable is the participant's response: "definitely yes,"  
242 "maybe yes," "maybe no," "definitely no". It should be noted that in order to adapt the SSDT  
243 paradigm to the present investigation, we modified some aspects of the procedure. Specifically,  
244 we delivered the tactile stimuli to the cheek, as opposed to the hand as in the original paradigm.  
245 This adjustment was made to ensure that tactile stimulation occurred at a body-site that is the  
246 focus of attention during the video-camera manipulation—the face—as opposed to the hand,  
247 which is peripheral to the focus of attention during the manipulation. As we moved the site of  
248 tactile stimulation, we also needed to adjust the location of the LED. The light was positioned on  
249 eye-level, a meter away from the participant, in his or her central visual field, and slightly behind  
250 the video-camera to ensure that the light remained close enough to be salient, yet not too close as  
251 to interfere with the salience of the camera manipulation.

252 Tactile stimuli were delivered through a constant current electrical stimulator (DS7A,  
253 Digitimer). One couple of surface electrodes, placed on the participants' right cheek  
254 approximately 1 cm apart, delivered a single constant voltage rectangular monophasic pulse. The  
255 beginning of each trial was signaled by two brief audio tones. Then, a stimulus period of 1020  
256 ms followed. In the tactile-present trials a 0.05 ms tactile stimulus was presented after 500 ms. In  
257 tactile-absent trials an empty 1020 ms period took place. A single audio tone signaled the end of  
258 the trial, at which point participants were asked to report whether they perceived a tactile  
259 stimulus on their cheek or not. First, a staircase procedure was used to establish a threshold for  
260 each participant—the point at which participant reported feeling the tactile stimulus on 40–60%  
261 of the tactile-present trials. The threshold protocol consisted of 5 tactile-present and 5 tactile-  
262 absent trials, and the participant was asked to give a verbal response of "yes" or "no" to each  
263 trial. The thresholding procedure was repeated as many times as needed in order to establish the  
264 threshold, before the main experimental trials could take place.

265 The main experiment consisted of 2 blocks of 80 trials, with 20 trials for each of the four  
266 conditions (tactile present-light present, tactile present-light absent, tactile absent-light present,  
267 tactile absent-light absent) presented per block in a random order. In the light-present trials the  
268 LED was illuminated for 20 ms with a delay of 500 ms on either side. The light was either  
269 simultaneous with the tactile pulse (in the tactile present-light present trials) or occurred on its  
270 own (in the tactile absent-light present trials). Participants had to report whether they felt the  
271 tactile stimulus during the trial period by pressing one of four buttons on the response pad:  
272 "definitely yes," "maybe yes", "maybe no," "definitely no" (the order of the response

273 buttons was also reversed and random half of the participants responded in the above order,  
274 while the other half responded in the reverse order of: “definitely no,” “maybe no,” “maybe  
275 yes,” “definitely yes”). Participants were unaware of the significance of the light stimulus and  
276 were asked to report solely whether they felt a tactile stimulus. The stimuli were controlled via a  
277 PC running NI LabVIEW 2011 software, which was also used to record the responses. In  
278 between the two blocks, the thresholding procedure was repeated in order to re-establish the  
279 threshold before the second experimental block.

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## 282 **2.6 Procedure**

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284 Upon arrival to the lab participants were given information about the study that was  
285 essential to provide informed consent, but that did not reveal the real objectives of the  
286 experiment. After participants signed the informed consent form the experiment begun.  
287 Participants were seated at the desk-chair and 2 electrodes were attached to their right cheek with  
288 the use of surgical tape. Participants then completed the IS task and the SSDT in the “camera  
289 on” and “camera off” conditions (see ‘Experimental design’ section for information on  
290 counterbalancing of task order). Upon completion of the experiment participants were fully  
291 debriefed and informed about the real purpose of the study.

292

## 293 **2.7 Data analysis**

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### 295 **2.7.1 Interoceptive sensitivity scores**

296

297 Interoceptive sensitivity scores were calculated using the following formula:

298  $1/3 \sum (1 - (| \text{actual heartbeats} - \text{reported heartbeats} |) / \text{actual heartbeats})$ .

299 Individuals were categorized as high or low in IS using a median split on the camera off IS score  
300 (median = .590). The sample consisted of 29 low IS individuals (mean IS = .487, SD = .078),  
301 and 28 high IS individuals (mean IS = .794, SD = .125).

302

### 303 **2.7.2 Somatic Signal Detection Task data**

304

305 In accordance with the original SSDT paradigm (Lloyd et al., 2008), responses  
306 “definitely” and “maybe” were combined, and grouped into ‘yes’ and ‘no’ responses, which  
307 were then categorized as hits, misses, false alarms, and correct rejections. Hit rate and false  
308 alarm rate were calculated using the following formulas:

309

310 Hit rate = hits / (hits + misses)

311

312 False alarm rate = false alarms / (false alarms + correct rejections)

313

314 Sensitivity ( $d'$ ) and response criterion ( $c$ ) statistics were calculated using Statilite  
315 software (Version 1.05 developed by Chris Rorden:

316 <http://www.mccauslandcenter.sc.edu/mricro/stats/index.html>). Where false alarms were equal to  
317 zero, 1 was added to both false alarms and to correct rejections to calculate  $d'$  and  $c$  values.

318

319 **3. Results**

320

321 **3.1 Association between IS and Somatic Signal Detection Task performance**

322

323 Interoceptive sensitivity scores (across all participants) were correlated with SSDT  
324 outcome variables of hit rate, false alarm rate, sensitivity, and response criterion for the non-self-  
325 focus condition. As IS scores in this condition were not normally distributed, Spearman’s  $\rho$   
326 correlation coefficients were computed. IS scores were positively correlated with overall false  
327 alarms in the camera off condition ( $\rho = .299, p = .024$ ), which was driven by the significant  
328 positive association between IS and false alarms in the light present condition ( $\rho = .266, p =$   
329  $.046$ ), and a marginally significant positive relationship between IS and false alarms in the light  
330 absent condition ( $\rho = .239, p = .073$ ). IS scores were not significantly correlated with any other  
331 outcome measures on the SSDT in the camera off condition.

332

333 **3.2 Interoceptive sensitivity**

334

335 As interoceptive sensitivity scores in the non-self-focus condition were not normally  
336 distributed, non-parametric test statistics were used to investigate whether the camera  
337 manipulation had an effect on IS. A Wilcoxon Signed Rank Test revealed that interoceptive  
338 sensitivity scores did not differ between self-focus (“camera on”) and non-self-focus (“camera  
339 off”) conditions ( $Z = -1.148, p = .251$ ). No effect of camera remained when separately examining  
340 the low IS group ( $Z = -.876, p = .381$ ) or the high IS group ( $Z = -.638, p = .524$ ). There were no  
341 differences in heart rate between camera conditions ( $t(56) = -1.517, p = .135$ ).

342

343 **3.3 Somatic Signal Detection Task Results**

344

345 Sensitivity ( $d'$ ), hit rate, and response criterion ( $c$ ) were each submitted to a  $2 \times 2 \times 2 \times 4$   
346  $\times 2$  ANOVA with within subject factors of Light (present or absent) and Camera (on or off), and  
347 between subjects factors of Camera order (camera first or camera second), Task order (4 possible  
348 orders) and IS group (higher IS, lower IS). As there were no main effects of Camera order on  
349 sensitivity ( $F(1, 41) = .095, p = .760$ ), hit rate ( $F(1, 41) = .012, p = .913$ ), or response criterion  
350 ( $F(1, 41) = .004, p = .950$ ), and of Task order on sensitivity ( $F(3, 41) = .990, p = .407$ ), hit rate  
351 ( $F(3, 41) = .678, p = .571$ ), or response criterion ( $F(3, 41) = .286, p = .835$ ) these factors were  
352 removed from final analyses, and the dependent variables were analyzed in  $2$  (light)  $\times 2$  (camera)  
353  $\times 2$  (IS group) ANOVAs. As false alarms were not normally distributed, non-parametric test  
354 statistics were used to test for differences between groups and within conditions. A series of  
355 Mann-Whitney U tests and Kruskal-Wallis H tests revealed no group differences in any of the  
356 false alarm measures based on the between-subjects factors of Camera order and Task order,  
357 respectively—all values were above the significance level of  $\alpha = .05$ . Table 1 contains  
358 descriptive statistics for each outcome measure in each light condition.

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360 Insert Table 1  
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361

362 Sensitivity ( $d'$ ) was higher in the self-focus condition than in the non-self-focus condition  
363 ( $F(1, 55) = 5.866, p = .019, \eta^2_p = .096$ ). There was a significant main effect of light on sensitivity  
364 ( $F(1, 55) = 34.430, p < .001, \eta^2_p = .385$ ) with  $d'$  being significantly higher in light present trials

365 than in light absent trials. There was no interaction effect of camera and light on  $d'$ . There was  
366 no main effect of IS group on  $d'$ , nor interaction of IS group with camera or light on  $d'$ . In order  
367 to investigate the components of the increase in sensitivity, hit rate and false alarms across  
368 conditions were examined next.

369 Hit rate was analyzed in a 2 x 2 x 2 ANOVA, revealing a significant main effect of light  
370 ( $F(1, 55) = 87.801, p < .001, \eta^2_p = .615$ ), with hit rate being significantly higher in light-present  
371 than in light-absent trials, and a significant main effect of camera ( $F(1, 55) = 4.276, p = .043, \eta^2_p$   
372  $= .072$ ), with hit rate being significantly higher in camera-present trials than in camera-absent  
373 trials. There was a significant interaction of light and camera on hit rate ( $F(1, 55) = 4.304, p =$   
374  $.043, \eta^2_p = .073$ ). In order to probe the interaction, pairwise t-tests comparing hit rate in both  
375 camera conditions were conducted for each of the light conditions separately. The results  
376 revealed that the effect of camera on hit rate was driven by the difference in hit rate across  
377 camera conditions in light-absent trials ( $t(56) = -2.816, p = .007$ , Cohen's  $d = -.753$ ), as there  
378 was no difference in hit rate across camera conditions in light-present trials ( $t(56) = 2.096, p =$   
379  $.400$ ). To see whether the light had a smaller effect on hit rate in the self-focus condition—when  
380 the camera was on—than in the non-self-focus condition—when the camera was off—difference  
381 scores (hit rate light-present – hit rate light-absent) in each condition were compared. The light  
382 had a significantly smaller effect on hit rate in the self-focus condition (mean difference = 8.59  
383 (SD = 12.01)) than in the non-self-focus condition (mean difference = 13.25 (SD = 12.21)),  $t$   
384  $(56) = 2.096, p = .041$ , Cohen's  $d = .56$ . Figure 2 illustrates the effect of light and camera on hit  
385 rate. There was no main effect of IS group on hit rate, nor interaction of IS group with camera or  
386 light on hit rate.

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388 Insert Figure 2  
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390 As false alarms were not normally distributed, non-parametric test statistics were used to  
391 examine for significant differences in false alarms between conditions. A Wilcoxon Signed Rank  
392 Test showed a main effect of light on false alarm rates ( $Z = -2.739, p = .006$ ) with false alarm  
393 rates being higher in light-present than in light-absent trials, but no main effect of camera on  
394 false alarm rates ( $Z = -1.001, p = .317$ ). The main effect of light on false alarms was driven by  
395 the “camera off” condition where false alarms were higher in light-present trials ( $Z = -2.557, p =$   
396  $.011$ ), as opposed to the “camera on” condition where false alarms did not significantly differ  
397 between light-present and light-absent trials ( $Z = -1.699, p = .089$ ). However, the effect of light  
398 on false alarm rate in each condition, as compared using mean difference scores (false alarm rate  
399 light-present – false alarm rate light-absent), did not differ ( $Z = -.436, p = .663$ ). Figure 3  
400 illustrates the effect of light and camera on false alarm rate. Although the number of false alarms  
401 was higher in the high IS group than in the low IS group, the effect of IS group on false alarm  
402 rate was not statistically significant indicated by significance level values above .05 on a series  
403 of Mann-Whitney U tests investigating group differences in false alarm rates based on the  
404 between-subjects factor of IS group.

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406 Insert Figure 3  
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408 Response criterion ( $c$ ) was not affected by presence of the camera ( $F(1, 55) = 2.076, p =$   
409  $.155$ ), and there was only a main effect of light ( $F(1, 55) = 87.990, p < .001, \eta^2_p = .615$ ), with a  
410 significantly more liberal response criterion in light-present trials as opposed to light-absent

411 trials. There was no interaction effect of camera and light on the response criterion. There was no  
412 main effect of IS group, nor interaction of IS group with camera or light on the response  
413 criterion.

414

#### 415 **4. Discussion**

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417 The current study investigated interoceptive and exteroceptive somatosory perception  
418 under two conditions: self-focus and non-self-focus, as manipulated with a video camera being  
419 turned on or turned off, respectively. Contrary to our predictions, interoceptive somatosensation,  
420 as measured with a heartbeat perception accuracy task, was not significantly affected by the self-  
421 focus manipulation. However, exteroceptive somatosensation, measured with the Somatic Signal  
422 Detection Task (SSDT), differed significantly between the two self-focus conditions. In order to  
423 investigate our research question we needed to modify certain aspects of the SSDT paradigm—  
424 namely, the site of tactile stimulation, and respective position of the light in relation to the  
425 stimulated body part. Due to the strong automatic integration of visual and tactile sensory  
426 modalities, the light in our modified version of the SSDT, which, importantly, was in the central  
427 visual field of the participant, retained its salience, and as expected, and in accordance with the  
428 SSDT paradigm, in both conditions light occurrence enhanced tactile perception, as reflected by  
429 increased sensitivity and hit rate in light-present trials. Light presence also increased false alarm  
430 rate in the “camera off” condition and made participants more likely to report feeling a stimulus  
431 (as reflected by a more liberal response criterion in light-present as opposed to light-absent  
432 trials). Importantly, the presence of a switched on camera also enhanced tactile perception, as  
433 reflected by increased sensitivity and higher hit rate in the “camera on”, as opposed to “camera  
434 off” condition. Further, in the “camera on” condition, the light did not have an effect on false  
435 alarm rate as it did in the “camera off” condition, nor did the light increase hit rate as much in  
436 the “camera on” condition as it did in the “camera off” condition. Heartbeat perception  
437 accuracy was not a significant moderator of SSDT performance. The only significant association  
438 between heartbeat perception accuracy and SSDT measures was observed between heartbeat  
439 perception accuracy and false alarm rate in the “camera off”, non-self-focus condition.

440 To summarize, when the video camera was turned on, tactile perception was enhanced, as  
441 reflected by increased sensitivity and hit rate. Moreover, when it was turned on and recording,  
442 there was a lesser impact of light presence on hit rate and no effect of light on false alarm rate.  
443 The fact that the presence of the light improved hit rate to a larger degree when the camera was  
444 off than when the camera was on, as well as significantly increased false alarm rate only when  
445 the camera was off and not when it was on, suggests that the self-focus condition during which  
446 the camera was on was powerful enough to override the effect of light on tactile perception.  
447 Importantly, the self-focus condition with the camera turned on did not affect the response  
448 criterion, consequently eliminating the possibility that differences in performance on the SSDT  
449 were due to mere change in tendency to report feeling a tactile stimulus, instead likely reflecting  
450 an actual change in sensitivity due to the camera manipulation. It should be noted that the  
451 “camera on” condition might have diminished the effect of the light more easily as a result of an  
452 already weakened link between the visual and tactile sensory modalities (as compared to the  
453 original SSDT paradigm) brought about by a greater spatial distance between the sources of  
454 tactile and visual stimulation.

455 As false alarm rates were smaller in the present study than in the original SSDT paradigm, it is  
456 indeed likely that the magnitude of the light effect on tactile perception was smaller in the

457 present study than in the original SSDT study by Lloyd et al. (2008). Nevertheless, it should be  
458 noted that multisensory integration is not narrowly constrained by spatial correspondence and  
459 there is a large body of research demonstrating crossmodal integration also when the sensory  
460 stimulation from the two modalities occurs in distinct locations (see Spence, 2013 for a review).  
461 Overall, the light in our manipulation elicited the expected effect on tactile perception and the  
462 fact that this effect was diminished in the presence of the camera can be explained by the  
463 increase in tactile sensitivity due to heightened self-focus brought about by the turned on video  
464 camera. In interpreting our results, we suggest that the “camera on” condition evoked a  
465 cognitive shift from first to third person perspective in participants who, as a result of the  
466 “camera on” manipulation, were primed with a third person representation of the self as if one  
467 sees oneself from the outside, and particularly their face (which was the focus of the camera),  
468 which, consequently, might have contributed to the enhancement of tactile perception on the  
469 face. The visual enhancement of touch (VET) effect is a well-studied phenomenon, which  
470 demonstrates that viewing a given body region improves tactile perception in that skin region  
471 (e.g., Kennett, Taylor-Clarke, & Haggard, 2001), by influencing processing in the early  
472 somatosensory cortex (e.g., Fiorio & Haggard, 2005). While participants in the present study did  
473 not actually view their face, the video-camera being turned on might have primed thoughts of the  
474 face being viewed from the third person perspective (being previously told that the video  
475 recording of them performing the task could be watched by a third party), consequently,  
476 increasing sensitivity in detecting tactile stimuli in the “camera on”, but not the “camera off”  
477 condition through a mental imagery effect analogous to the VET.

478 Contrary to our predictions, the video-camera manipulation did not affect interoceptive  
479 somatosensory perception, as there was no difference in interoceptive sensitivity between the  
480 “camera on” and “camera off” conditions. Past research experiments by Ainley et al. (2012,  
481 2013) have found an increase in interoceptive sensitivity during both mirror, and still photograph  
482 self-observation—also used to increase self-focus. Of course, it is possible that interoceptive  
483 sensitivity was affected by mere presence of the video camera, which automatically enhanced  
484 self-focus, without much further difference between “camera on” and “camera off” conditions.  
485 The design of the present study, however, limits the conclusions we can draw from the data, as  
486 we did not have a third condition in which the camera would be absent, or an independent  
487 baseline measure, which would allow us to make such a comparison. Another possibility might  
488 be that the video camera manipulation did not elicit self-focus sufficiently to increase  
489 interoceptive sensitivity. We did not ask individuals whether they felt more focused on  
490 themselves, as we were not necessarily trying to evoke a conscious increase in self-focus, and the  
491 video camera is likely to increase self-focus in a way that the individual is not explicitly  
492 conscious of. Also, we assume our manipulation was potent as it did have a significant effect on  
493 tactile perception, as we anticipated. Consequently, we propose that a lack of an observed effect  
494 in the interoceptive domain is likely due to the mode of self-focus elicited by our manipulation,  
495 which was social rather than private in nature. While mirror presence has been found to direct  
496 individual’s attention to inner aspects of the self, video camera manipulations have been found to  
497 draw attention to external, or social aspects of one’s self that are observable to others (Carver &  
498 Scheier, 1981). Accordingly, while mirror presence can enhance an individual’s awareness of his  
499 or her inner body—a very private aspect of the self—a turned on video camera, on the other  
500 hand, might more selectively enhance tactile perception, which is the sensory modality through  
501 which individuals interact with the external world, hence, a sensory modality that is given a  
502 stronger weighting in the context of the social self-focus manipulation, thereby enhancing

503 information processing associated with that modality.

504 Finally, we investigated the relationship between interoceptive and exteroceptive  
505 somatosensory perception by examining our data for potential moderating effects of  
506 interoceptive sensitivity on SSDT performance, after splitting our participants into two groups:  
507 higher and lower heartbeat perception accuracy groups based on the sample median in the  
508 “camera off” condition. While we did not observe any modulation of tactile perceptual  
509 performance based on interoceptive sensitivity being higher or lower, it should be noted that our  
510 sample median was rather low, hence our groups did not represent individuals truly high and low  
511 in interoceptive sensitivity. Interestingly, we observed a positive correlation between  
512 interoceptive sensitivity and false alarm rate in the “camera off” condition. This relationship  
513 was not reflected in the independent sample comparison results—most likely due to the heavily  
514 skewed distribution of false alarms, which included many values of zero, which necessitated the  
515 use of non-parametric statistical tests likely lacking in power to detect the difference.

516 It has been proposed that increased attention to interoceptive stimuli might contribute to  
517 the occurrence of false alarms by increasing sensory noise, thereby making it more difficult for  
518 an individual to distinguish between signal and noise (sensations originating outside and inside  
519 the body, respectively) when detecting a tactile stimulus (Mirams et al., 2013; Silvia & Gendolla,  
520 2001). Mirams et al. (2012) found that directing individuals’ attention to pulse sensations in the  
521 fingertip increased individual propensity to report feeling a threshold tactile stimulus,  
522 nevertheless did not significantly affect sensitivity measures.  
523 Consequently, the results of that study suggest that interoceptive attention might bias individuals  
524 toward reporting tactile sensations in their absence, but do not entirely support the hypothesis  
525 that interoceptive attention contributes to individuals being less able to distinguish sensory noise  
526 from signal. It should be considered that in their experiment, Mirams et al. utilized an untypical  
527 interoceptive attention task in which they asked participants to focus their attention on pulse  
528 sensations in their fingertip. This methodology might account for an increased propensity to  
529 report having felt a tactile stimulus on the fingertip when completing the SSDT afterwards.  
530 Notably, in the present study, where we employed a classic version of the task, we did not find  
531 an effect of engaging in the heartbeat perception task on SSDT performance, as indicated by a  
532 lack of task order effects in our data. Importantly, while Mirams et al. investigated overall effects  
533 of interoceptive attention on SSDT performance, they left unexamined the question of whether  
534 inter-individual variability in baseline interoceptive sensitivity was related to tactile perception.  
535 While our results show that individuals with higher interoceptive sensitivity made more false  
536 alarms on the SSDT during the “camera off” condition, we did not observe any association  
537 between IS and sensitivity measures which would be more directly indicative of diminished  
538 ability to tell apart sensory signal from sensory noise. Even though false alarms on the SSDT  
539 have been associated with activity in the right insula and the anterior cingulate cortex (Poliakoff  
540 et al., in preparation, as cited in Mirams et al., 2013)—regions central to bodily attention and  
541 interoception (Craig, 2003; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004)—more  
542 empirical evidence is needed to test whether increased interoceptive sensitivity interferes with  
543 exteroceptive processing of bodily signals—especially, given the evidence for the contrary,  
544 where individuals with higher interoceptive sensitivity have been shown to be less susceptible to  
545 the Rubber Hand Illusion (Tsakiris, Tajadura-Jimenez, & Constantini, 2011). The Tsakiris et al.  
546 study suggests that individuals with higher  
547 interoceptive sensitivity are less susceptible to interference from exteroceptive signals in their  
548 perceptual experience. Nevertheless, individuals with higher interoceptive sensitivity would then

549 be expected to show enhanced exteroceptive somatosensory perception, and more specifically,  
550 increased sensitivity on the SSDT, which is also not supported by our data inasmuch as we did  
551 not observe any relationship between interoceptive sensitivity and tactile sensitivity measures.  
552 Consequently, further research is needed to establish the exact nature of the relationship between  
553 interoceptive and exteroceptive somatosensory processing.

#### 554 555 **4.1 Conclusions**

556  
557 To conclude, we investigated the effects of social self-focus on exteroceptive  
558 somatosensory processing, as measured with the Somatic Signal Detection Task, and  
559 interoceptive sensitivity, as measured with a heartbeat perception accuracy task. Our results  
560 show that when a video camera was turned on, it enhanced tactile perception, but did not affect  
561 heartbeat perception accuracy, relative to the “camera off” condition. Essentially, it can be  
562 concluded that social self-focus, as manipulated with a video camera being turned on or turned  
563 off, enhanced bodily perception in the exteroceptive tactile modality. Unlike mirrors, which have  
564 been found to evoke private self-focus by directing attention to private aspects of the self, video  
565 cameras have been found to direct attention to social aspects of the self that are external and  
566 observable to others (Davies, 2005). Therefore, the effect of social self-focus on tactile  
567 perception, and not on heartbeat perception, could be perhaps attributed to the inherently social  
568 aspect of tactile processing. Even though the effect of the switched on video camera on  
569 exteroceptive somatosensory processing was not modulated by interoceptive sensitivity, we  
570 observed heartbeat perception accuracy to be positively correlated with false alarms in the  
571 “camera off” condition. This finding is consistent with recent research showing that false alarm  
572 responses on the SSDT are associated with activity in the interoceptive centres of the brain—the  
573 right insula and the ACC (Poliakoff, in preparation, as cited in Mirams et al., 2013),  
574 nevertheless, our results do not shed further light on the nature of the relationship between  
575 interoceptive sensitivity and exteroceptive somatosensory processing such as tactile processing,  
576 as we failed to find significant correlations between heartbeat perception accuracy and any of the  
577 other SSDT outcome measures. Future research should delineate the relationship between  
578 interoceptive sensitivity and exteroceptive somatosensory processing, by taking into account the  
579 potential for modulating effects of various modes of attention to self on the way in which  
580 somatosensory processing of internally and externally originating bodily signals interacts in  
581 shaping body awareness and perception.

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686 **Tables and Figures**

687

688 Table 1.

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690 Mean sensitivity and response criterion in each camera and light condition.

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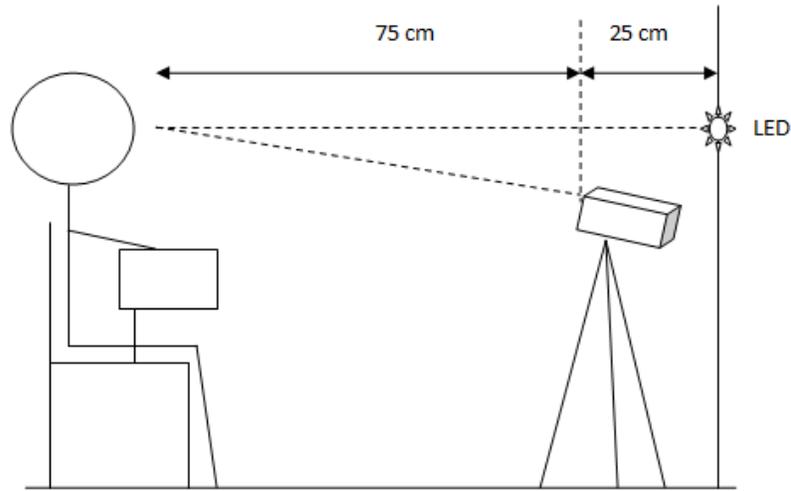
<b>Variable</b>	<b>Light condition</b>	<b>Camera condition</b>	
		<b>“Camera off” (NSF)</b>	<b>“Camera on” (SF)</b>
<i>d'</i>	No light	1.72 (.51)	2.01 (.50)
	Light	1.91 (.50)	2.13 (.52)
	<i>Overall</i>	1.86 (.46)	2.02 (.47)
<i>c</i>	No light	.87 (.28)	.66 (.26)
	Light	.78 (.26)	.65 (.27)
	<i>Overall</i>	.77 (.24)	.72 (.24)

692 *Note:* NSF = non self-focus; SF = self-focus; *d'* = sensitivity, *c* = response criterion. Standard  
 693 deviations in parentheses.

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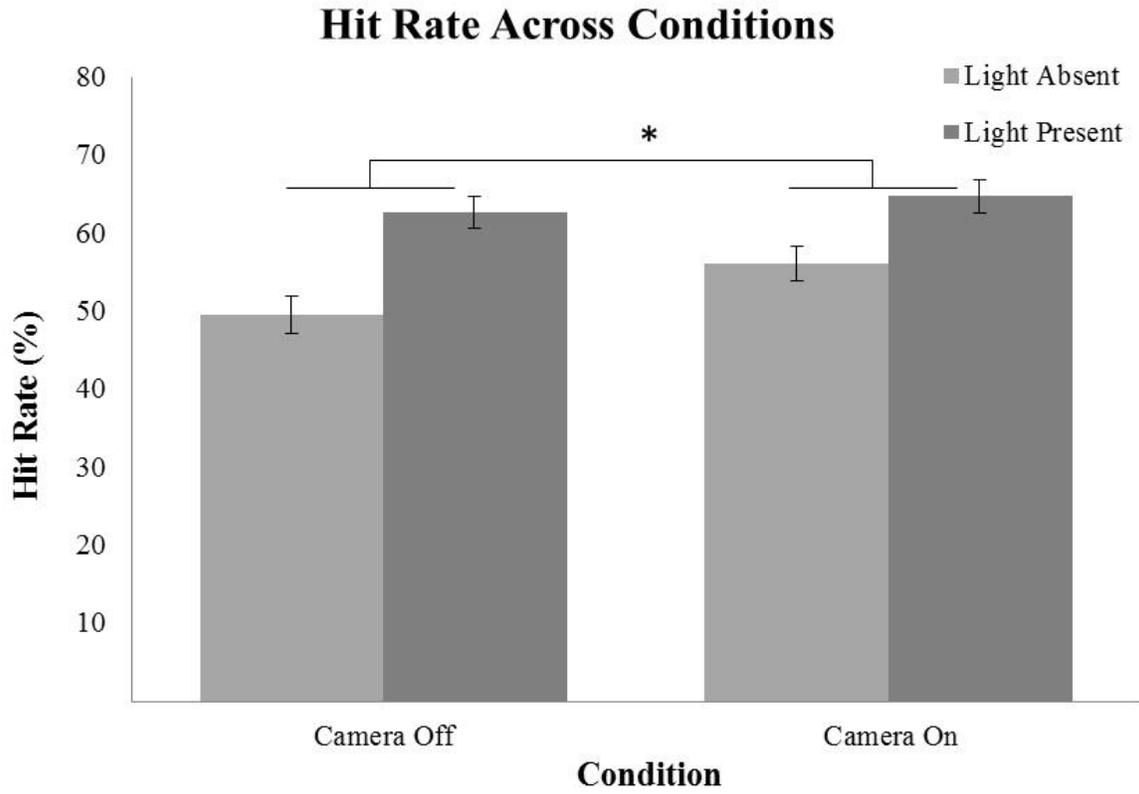
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696 Figure 1.  
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698 Experimental set-up.



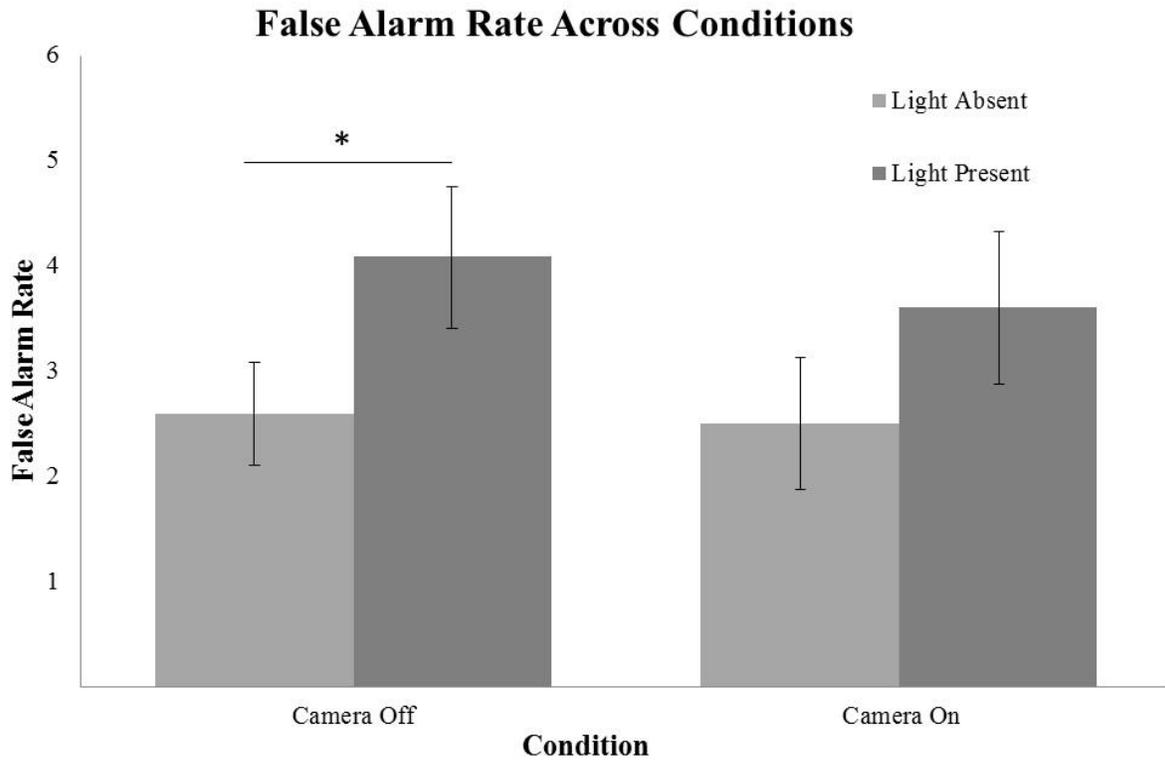
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729 Figure 2.  
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731 The effect of camera and light on hit rate.  
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734 Note: \*  $p < .05$   
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736 Figure 3.  
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738 The effect of camera and light on false alarm rate.  
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741 *Note: \*  $p < .05$*   
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