

No evidence for an effect of the distance between the hands on tactile temporal order judgments

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Abstract

Localizing somatosensory stimuli is an important process, since it allows us to spatially guide our actions towards the object entering in contact with the body. Accordingly, the positions of tactile inputs are coded according to both somatotopic and spatiotopic representations, the latter one considering the position of the stimulated limbs in external space. The spatiotopic representation has often been evidenced by means of temporal order judgment (TOJ) tasks. Participants' judgments about the order of appearance of two successive somatosensory stimuli are less accurate when the hands are crossed over the body midline than uncrossed, but also when participants' hands are placed close together as compared to farther away. Moreover, these postural effects might depend on the vision of the stimulated limbs. The aim of this study was to test the influence of seeing the hands, on the modulation of tactile TOJ by the spatial distance between the stimulated limbs. The results showed no influence of the distance between the stimulated hands on TOJ performance and prevent us from concluding whether vision of the hands affects TOJ performance, or whether these variables interact. The reliability of such distance effect to investigate the spatial representations of tactile inputs is questioned.

1 **1. Introduction**

2 Mapping somatosensory stimuli on the body surface is an important function as it
3 helps to identify which part of our body is in contact with external stimuli, but also to
4 locate these stimuli in the surrounding space. Ultimately, somatosensory mapping helps
5 to translate spatially-located perception of bodily contacts into spatially-guided motor
6 behaviors in order to finely tune manipulation with innocuous objects and, also,
7 defensive reaction to noxious external objects (Brozzoli, Ehrsson, & Farne, 2014;
8 Graziano & Cooke, 2006).

9 Somatotopy represents an almost point-by-point readout for the brain of the spatial
10 arrangement of the somatosensory receptors in the skin and in internal organs. More
11 exactly, it corresponds to the ordered projection of the afferent responses from the
12 receptors to spatially segregated groups of neurons in the brain (Penfield & Boldrey,
13 1937). However, as the body limbs, and consequently the somatosensory receptors, are
14 constantly moving in external space, such a spatial representation might be inefficient
15 to appropriately localize the contacting objects in external space and orient behaviors
16 towards their location. Therefore, the spatiotopic representation uses external space as
17 reference frame and considers the relative position of the body part on which the
18 stimulus is applied (e.g. Azañon & Soto-Faraco, 2008; Driver & Spence, 1998; Graziano,

19 Hu, & Gross, 1997; Shore, Spry, & Spence, 2002; Smania & Aglioti, 1995; Yamamoto &
20 Kitazawa, 2001). It thereby represents a crucial spatial representation of somatic
21 information as it anchors somatosensory perception in a representation of the body
22 posture and limb movements in external world, with the purpose of interacting with
23 objects in the environment close to the body (Brozzoli et al., 2014).

24 The ability to code somatosensory (tactile or nociceptive) information according to
25 spatiotopic reference has been assessed, among others, using temporal order judgment
26 (TOJ) tasks (Badde, Heed, & Röder, 2014; Badde, Roder, & Heed, 2015; Crollen, Albouy,
27 Lepore, & Collignon, 2017; Crollen, Lazzouni, et al., 2017; Crollen, Spruyt, Mahau,
28 Bottini, & Collignon, 2019; De Paepe, Crombez, & Legrain, 2015; Heed & Azañón, 2014;
29 Röder, Rösler, & Spence, 2004; Sambo et al., 2013; Shore et al., 2002; Vanderclausen,
30 Bourgois, De Volder, & Legrain, 2020; Vanderclausen, Manfron, De Volder, & Legrain,
31 2020; Yamamoto & Kitazawa, 2001). In these tasks, participants judge the temporal
32 order of two successive somatosensory stimuli, one applied to each hand, separated by
33 different temporal delays. Participants' judgements are typically less accurate when
34 their hands are crossed, as compared to an uncrossed posture. Such an effect is
35 accounted for by the fact that the somatotopic representation mismatches the
36 spatiotopic representation (e.g. when crossed, a stimulus applied on the left hand is

37 coming from the right part of space). The fact that TOJ performance depends on the
38 location of the hands in external space suggests that nociception and touch, in addition
39 to the somatotopic coding, are automatically coded according to a spatiotopic reference
40 frame, a process called *somatosensory remapping* (Driver & Spence, 1998).

41 Spatiotopic coding of somatosensory information has also been investigated using
42 other experimental procedures (e.g. Azanon, Camacho, & Soto-Faraco, 2010; Azanon,
43 Longo, Soto-Faraco, & Haggard, 2010; Azañón & Soto-Faraco, 2008; Moayedí et al.,
44 2016; Overvliet, Azañón, & Soto-Faraco, 2011; Smania & Aglioti, 1995; Soto-Faraco &
45 Azañón, 2013; Soto-Faraco, Ronald, & Spence, 2004; Tame, Farne, & Pavani, 2011) such
46 as manipulating the distance between the limbs to which the somatosensory stimuli
47 were applied. The rationale is that, as the somatotopic representations of the two
48 stimulated skin areas do not change between the different postural conditions,
49 potential differences in participants' performance between two conditions can only be
50 attributed to the metric distance between the stimulated limbs in external space.
51 Studies have indeed shown that the discrimination of tactile stimuli applied on one hand
52 was more sensitive to distraction induced by tactile stimuli applied on the opposite hand
53 when the two hands were close together, as compared to when they were further apart
54 (Driver & Grossenbacher, 1996; Evans, Craig, & Rinker, 1992; Lakatos & Shepard, 1997;

55 Soto-Faraco et al., 2004). During tactile TOJ tasks, judgements are more difficult with
56 decreasing the distance between the hands (Shore, Gray, Spry, & Spence, 2005; Roberts,
57 Wing, Durkin, & Humphreys, 2003). Such an effect was also shown when distance
58 manipulation was made through mirror-reflected images of the hands while their
59 physical distance was unchanged (Gallace & Spence, 2005).

60 However, while crossing the hands during tactile and nociceptive TOJ tasks has
61 provided very robust and reliable effects across the different studies, results from the
62 studies having manipulated the distance between the stimulated limbs are very small
63 and less consistent. For instance, Shore et al. (2005) did not replicate the distance effect
64 between arms when different fingers of the hands were stimulated. Similarly, Kuroki,
65 Watanabe, Kawakami, Tachi, and Nishida (2010) showed that participants' judgements
66 were more sensitive to the anatomical distance between two stimulated areas on the
67 skin surface than to the distance in external space between the two body parts. As
68 suggested by the study of Gallace and Spence (2005), the postural effect during tactile
69 TOJ could depend on visual feedback about hand positions. The data of that study
70 indeed illustrate the important role that vision of the body plays in somatosensory
71 perception, sometimes taking priority over proprioceptive cues (see also Botvinick &
72 Cohen, 1998; Gallace & Spence, 2005; Pavani, Spence, & Driver, 2000; Soto-Faraco et

73 al., 2004; Torta, Legrain, & Mouraux, 2015). Accordingly, Cadieux and Shore (2013)
74 showed that preventing vision of the stimulated hands reduced the crossed hands
75 deficit during tactile TOJ (at least when the task procedure minimized the use of
76 spatiotopic coordinates). The aim of the present study was therefore to test the
77 influence of seeing the hands on the modulation of tactile temporal order judgements
78 induced by changing the spatial distance between the two stimulated hands.
79 Participants performed a TOJ task with vibrotactile stimuli delivered to their fingertips
80 with the hands placed according to two postures: close vs. far distance from each other.
81 One group of participants could see their hands during the experiment while another
82 group was blindfolded. It was hypothesized that, because visual information about
83 position of the limbs in external space was prevented, participants would mostly rely on
84 anatomical representations. We therefore expected reduced distance effects in
85 blindfolded participants, as compared to those who could see their hands. In other
86 words, we expected to observe significant differences in TOJ sensitivity between the two
87 hand postures in the group of sighted participants, while such a difference would be
88 reduced in the blindfolded group.

89

90 **2. Methods**

91 *2.1. Participants*

92 Based on the sample size of our previous studies (e.g. Filbrich, Alamia, Blandiaux,
93 Burns, & Legrain, 2017; Filbrich, Alamia, Verfaillie, et al., 2017; Vanderclausen, Filbrich,
94 De Volder, & Legrain, accepted), 30 volunteers participated in the study. Four
95 participants were excluded from the analyses due to unreliable performances during the
96 task (see analyses section). The mean age of the remaining 26 participants (15 women)
97 was 23.88 years old ($SD=3.54$, range=18–36). Inclusion criteria were: normal or
98 corrected-to-normal visual acuity, no prior history of severe neurological, psychiatric, or
99 chronic pain disorder, no traumatic injury of the upper limbs within the last six months,
100 no regular use of psychotropic drugs, no intake of analgesic drugs (e.g. NSAIDs,
101 paracetamol) within the 12 hours preceding the experiment. According to the Flinders
102 Handedness Survey (Flanders) (Nicholls, Thomas, Loetscher, & Grimshaw, 2013), one
103 participant was left-handed, one was ambidextrous, and all the others were right-
104 handed. The local ethic committee in agreement with the sixth revision (2008) of the
105 Declaration of Helsinki approved the experimental procedure. All volunteers signed an
106 informed consent before starting the experiment and received financial compensation
107 for their participation.

108 2.2. *Stimuli and materials*

109 Vibrotactile stimuli were applied on each hand by means of two vibrotactile
110 transducers (TL-002-14R Haptuator, Tactile Labs, Canada) driven by standard audio
111 amplifiers, and lasting 10 ms at 440 Hz (interruption of the last cycle did not affect
112 stimulus perception). Stimuli were remotely controlled using Matlab 2014. Participants
113 held the vibrotactile transducers at ~30 cm from the edge of the table, one in each hand
114 between the thumb and the forefinger. The intensities of the vibrotactile stimuli were
115 matched between the two hands, in order for the stimuli to be perceived as equally
116 intense. If necessary, they were adapted before or during the experiment when this
117 criterion was not met anymore. A small strip of tape pasted on the table along the
118 participant's midsagittal plane at 40 cm from the edge of the table (i.e. at ~10 cm above
119 the hands) was used as a fixation point for the group of participants who could see the
120 stimulated hands (see below).

121 2.3. *Procedure*

122 The experiment consisted of a TOJ task performed on two tactile stimuli, one applied
123 to each hand. More exactly, for each pair of left and right stimuli, participants were
124 asked to discriminate the order of temporal succession between the two stimuli. They
125 responded verbally by saying aloud '*left*' or '*right*', which of the two tactile stimuli they

126 perceived either as having occurred first ('which is first' response condition), or as having
127 occurred second ('which is second' response condition), depending on the experimental
128 blocks (with the aim of minimizing response biases, see Filbrich, Torta, Vanderclausen,
129 Azañón, & Legrain, 2016; D. I. Shore, Spence, & Klein, 2001; Spence & Parise, 2010).
130 Verbal responses were encoded by the experimenter (by pressing one of two keys on
131 the computer, which triggered the next trial 2000 ms later). No instruction regarding the
132 speed of their responses nor any feedback regarding the accuracy of their performance
133 was given to the participants during the task. The participants were pseudo-randomly
134 assigned to one of two groups of equal size. In one group, the participants could see
135 their hands and were asked to maintain their gaze on a fixation point (*vision* group). In
136 the other group, they wore a blindfold to prevent vision of their hands throughout the
137 experiment (*blindfolded* group). The blindfolding was manipulated between
138 participants, instead of within, to avoid extending the duration of the experiment that
139 might have impacted their ability to focus on the task. For each group, the task was
140 performed under two posture conditions, either with the hands close to each other or
141 further apart (see below for more details).

142 The experiment took place in a dimly illuminated testing room. Participants were
143 seated on a chair and rested their arms on a table while holding the transducers in their

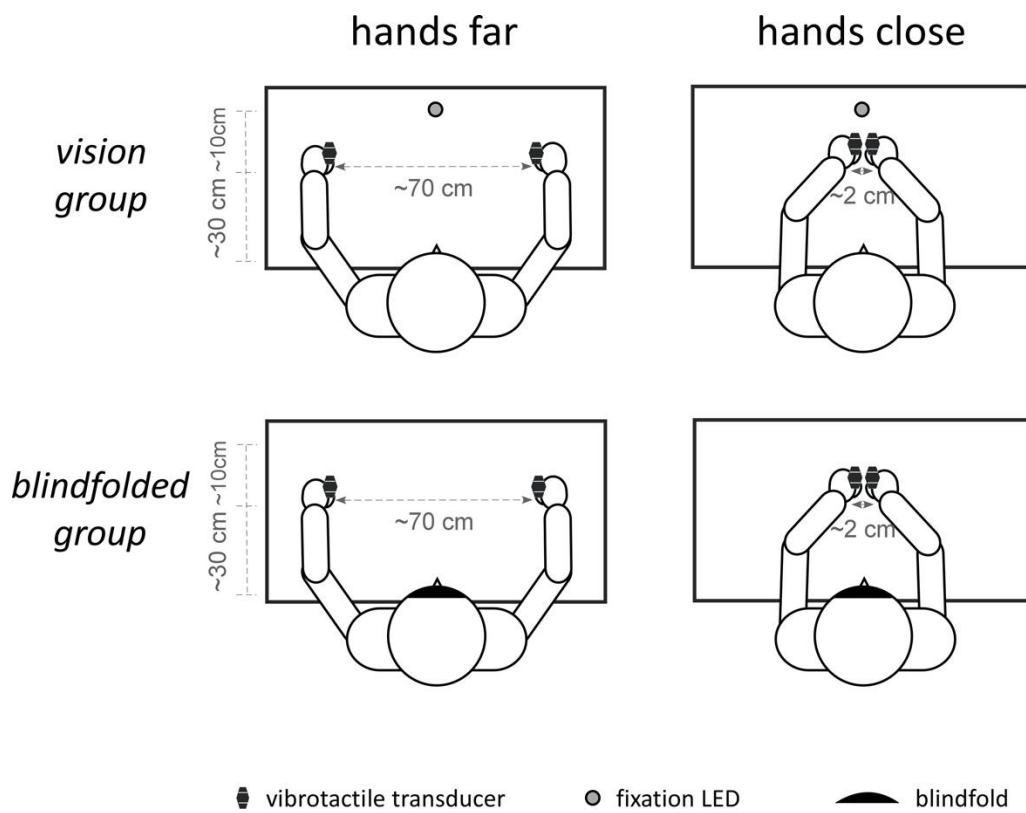
144 hands slightly above the table surface in order to avoid noise from the vibrations of the
145 transducers against it. Their head was stabilized with a chinrest to minimize movement
146 during the experiment. Participants' hands were always equally distant from their
147 midsagittal plane. In the *far* posture, the hands were placed at a distance of 70 cm from
148 each other, as measured between the two vibrotactile transducers, while in the *close*
149 posture the distance was of 2 cm. Before starting the experiment, participants
150 completed a practice session to get familiarized with the vibrotactile stimuli and the
151 experimental set-up. This practice session consisted of 4 blocks of 10 trials each, one
152 block for each combination of posture (*close* vs. *far* hands) and the response conditions
153 (*which is first* vs. *which is second*). During this practice phase, only two SOA were used,
154 i.e. ± 145 , ± 200 . Participants performance was not recorded during practice blocks and
155 no feedback was given to them.

156 During the experiment, each participant was presented with 4 blocks of 40 trials
157 each. During two blocks, the participants' hands were placed according to the *close*
158 posture condition, while they were placed in the *far* posture in two other blocks. Each
159 participant started the experiment with two blocks of the same posture condition, and
160 then continued with the two blocks of the other condition; the order of the posture
161 condition was counterbalanced across participants of the same group. For each block of

162 the same posture condition, one was performed with the '*which is first*' instruction, the
163 other with the '*which is second*' instruction; order of the response conditions was
164 randomized. Noises from experimental devices were covered by means of a white noise
165 played through earphones. Each block lasted approximately 5 minutes and the entire
166 experiment lasted approximately 30 minutes, including instructions and the practice
167 session.

168 For each pair of stimuli, the two vibrotactile stimuli were separated by one out of 22
169 possible time intervals (SOA for stimulus onset asynchronies): ± 5 , ± 10 , ± 15 , ± 30 , ± 45 ,
170 ± 60 , ± 75 , ± 90 , ± 145 , ± 200 , ± 400 ms (negative values indicate that the vibrotactile
171 stimulus on the left hand was applied first, positive values that the right hand stimulus
172 was applied first). At each trial, the presented SOA was selected using the adaptive *psi*
173 method (Kingdom & Prins, 2010) based on the participant's responses in all the previous
174 trials (see Filbrich, Alamia, Verfaillie, et al., 2017; Vanderclausen, Bourgois, et al., 2020;
175 Vanderclausen, Manfron, et al., 2020 for details regarding the use of the *psi* method for
176 TOJ tasks). More specifically, the algorithm adopts a Bayesian framework with the
177 ultimate goal of estimating the posterior probability of the parameters of interest (i.e.
178 the α (PSS) and the β (slope)) without probing extensively all the SOAs. The core idea is
179 to minimize the expected entropy (i.e. uncertainty) of the posterior distribution trial by
180 trial, such as the response of the participant at each trial provides the most information

181 about the distribution of the parameters. In other words, the algorithm, given all the
182 information collected so far in the previous trials, infers which condition (i.e. SOA) is the
183 most informative in the next trial in order to estimate the joint distribution of the
184 parameters.



185

186 **Figure 1. Design of the experiment.** Participants performed a temporal order judgement
187 task on pairs of tactile stimuli applied one to each hand by means of vibrotactile
188 transducers (illustrated by the black diamonds) held between the thumb and the

189 forefinger. Hands were placed so that the vibrotactile transducers were held at a
190 distance of either ~70cm (*hands far*; left) or ~2cm (*hands close*; right) from each other.
191 One group of participants could see their hands during the task (*vision group*; top) while
192 participants of the other group were blindfolded (*blindfolded group*; bottom). The
193 participants of the *vision* group were asked to maintain their gaze on a central point at
194 ~40 cm in front of them (illustrated by the grey circle).

195

196 2.4. *Measures*

197 The TOJ performance, i.e. the probability to perceive one of the two stimuli as
198 occurring first as a function of the SOA, was fitted online for each participant and each
199 condition using the logistic function $f(x)=1/(1+\exp(-\beta(x-\alpha)))$ (Kingdom & Prins, 2010;
200 Kontsevich & Tyler, 1999). Here, the proportion of left first responses was plotted as a
201 function of SOA. Since the adaptive method was used, the α and the β values of the
202 function were estimated at each trial and, at the end of the stimulation block, the last
203 estimates were taken as measures of the participants' performance. The β parameter
204 characterizes the slope of the psychometric function and describes the noisiness of the
205 results (i.e. entropy). Therefore, this parameter reflects the precision of the participants'
206 responses during the experiment, i.e. their performance at the task (Kingdom & Prins,
207 2010; Kontsevich & Tyler, 1999). It constitutes the main parameter of interest in this
208 study, as the slope is often used to derive the just noticeable difference (JND) in typical
209 TOJ experiments (Heed & Azañón, 2014; Spence & Parise, 2010) and was shown to be
210 affected by the distance between the hands during tactile TOJ (Roberts et al., 2003; D.
211 I. Shore et al., 2005). The α parameter is the threshold of the function and refers to the
212 point of subjective simultaneity (PSS). Although the contribution of the α parameter to
213 current data was less relevant, this parameter was also measured in order to assess the
214 presence of possible biases that could affect the estimation of the slope (see Filbrich,

215 Alamia, Blandiaux, et al., 2017; Filbrich, Alamia, Burns, & Legrain, 2017; Vanderclausen,
216 Filbrich, Alamia, & Legrain, 2017). A third non-standard parameter was derived a
217 posteriori to further characterize participants performances. Based on all trials
218 presented for each condition, we computed the mode of the presented SOA to index
219 which of the time interval values was the most often presented to a given participant
220 (see Vanderclausen, Bourgois, et al., 2020; Vanderclausen, Manfron, et al., 2020).

221 Because the adaptive *psi* method is based on a Bayesian framework, priors had to
222 be postulated (Kingdom & Prins, 2010). We used a prior distribution of 0 ± 20 ms to
223 estimate the α parameter, since no bias towards one of the two hands was expected.
224 Based on previous experiments performed with healthy volunteers, 0.06 ± 0.6 was
225 chosen as a prior distribution to estimate the β parameter (Filbrich, Alamia, Verfaillie, et
226 al., 2017; Vanderclausen et al., accepted). Two other parameters, the λ and γ were fixed
227 in advance for all participants and not used for analyses. The λ corresponds to the lapse
228 rate, i.e. the probability of giving an incorrect response independently of stimulation
229 variables, and the γ to the guess rate, i.e. the probability of giving a correct answer
230 whereas the stimulus has not been detected (Prins, 2012). As suggested by Kingdom and
231 Prins (2010), the λ was set at 0.02 and the γ at 0.

232

233 2.5. *Data analyses*

234 Data were excluded from further statistical analyses if the slope of the psychometric
235 function could not be reliably estimated during the 40 trials within one condition (i.e.
236 the parameter estimate did not converge on a stable value on the last trials). Before
237 statistical analyses, data from the two *response* conditions (*'which is first'* and *'which is*
238 *second'*) were averaged together for each group and for each posture condition.

239 One-sample t-tests were used to examine the potential presence of biases towards
240 one of the two hands by comparing the averaged PSS values of each condition to 0. Next,
241 in order to assess the influence of experimental manipulations on participants' TOJ
242 performances, analyses of variance (ANOVA) with *posture* (*far vs. close*) as within-
243 subject variable and *group* (*vision vs. blindfolded*) as between-subject variable were
244 performed separately on the PSS, the slope and the mode values. Effect sizes were
245 measured by means of partial Eta squared for ANOVA and Cohen's d for t-tests.
246 Significance level was set at $p \leq .05$. Finally, classic frequentist statistical analyses were
247 complemented by Bayesian statistics (using Bayesian repeated measures ANOVA with
248 JASP 0.9.2.0, University of Amsterdam, The Netherlands) performed on the PSS, slope
249 and mode values respectively. To this aim, we computed a Bayes factor to quantify the
250 alternative hypothesis (HA) relative to the null hypothesis (H0) (BF_{10} , Cauchy prior =

251 0.707). Interpretations are based on the classification scheme established by Lee and
252 Wagenmakers (2013); Wagenmakers et al. (2017).

253 **3. Results**

254 The psychometric curves fitting TOJ performances are illustrated in Figure 2.
255 Individual data and their means are displayed on Figure 3. Analyses of the slope values
256 did not reveal any significant results neither for the main effect of *posture*
257 ($F(1,24)=0.788$, $p=0.384$, $\eta^2_p=0.032$), nor for that of *group* ($F(1,24)=0.346$, $p=0.562$,
258 $\eta^2_p=0.014$), nor for the interaction between the two variables ($F(1,24)=0.062$, $p=0.805$,
259 $\eta^2_p=0.003$). Regarding Bayesian analyses, anecdotal evidences were shown in favor of
260 H_0 for the *posture* ($BF_{10} = 0.38$, error = 1.636) and *group* factors ($BF_{10} = 0.54$, error =
261 1.556) and for their interaction as well ($BF_{10} = 0.36$, error = 1.202). This suggests that
262 there is no sufficient evidence allowing us to draw conclusions about the effect of the
263 distance between the stimulated hands or the possibility to see them, on TOJ
264 performances.

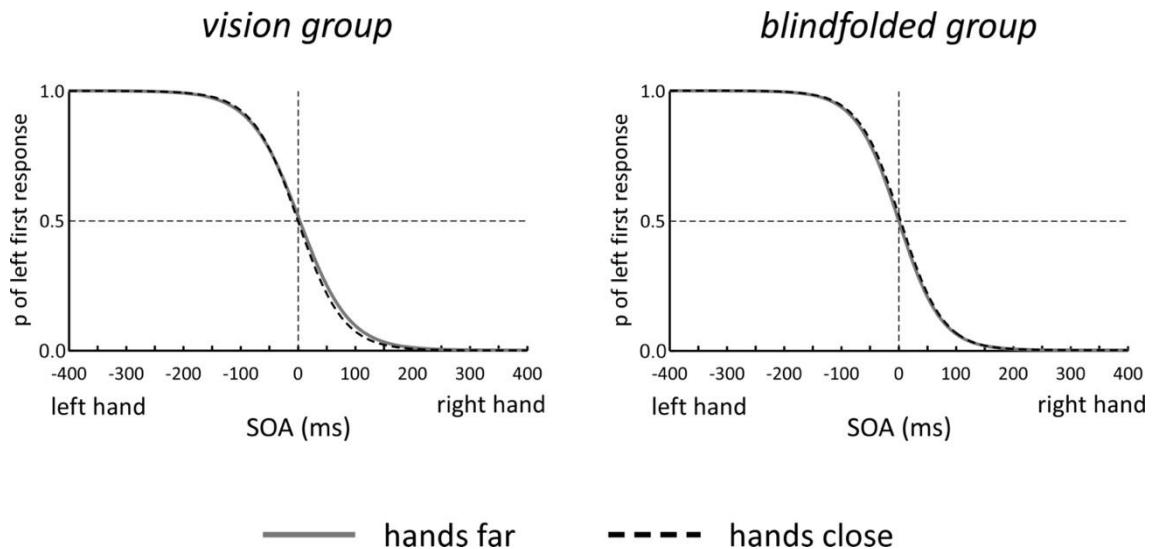
265 The one sample t-tests comparing the PSS values to 0 did not reveal any significant
266 results (all $t(12)\leq 1.648$, all $p\geq 0.125$), suggesting that there was no significant bias
267 affecting the perception of the stimuli applied to one of the two hands in none of the

268 conditions and for either group. The ANOVA performed on the PSS values showed no
269 significant effect either for the *posture* ($F(1,24)=0.072$, $p=0.791$, $\eta^2_p=0.003$) or for the
270 *group* variables ($F(1,24)=0.142$, $p=0.709$, $\eta^2_p=0.060$), or for the interaction between the
271 two variables ($F(1,24)=2.182$, $p=0.153$, $\eta^2_p=0.083$). Bayesian ANOVA analyses revealed
272 moderate evidence in favor of H0 related to the effect of *posture* ($BF_{10} = 0.275$, error =
273 0.819), and anecdotal evidences in favor of H0 for to the main effect of *group* ($BF_{10} =$
274 0.488, error = 1.465) and the interaction between *posture* and *group* as well ($BF_{10} =$
275 0.832, error = 1.126).

276 The ANOVA analyses about the mode of the SOA did not reveal any significant effect
277 of the *posture* ($F(1, 24)=0.477$, $p=0.496$, $\eta^2_p =0.019$), of the *group* ($F(1,24)= 0.916$,
278 $p=0.348$, $\eta^2_p =0.037$), nor significant interaction between the two variables
279 ($F(1,24)=0.477$, $p=0.496$, $\eta^2_p =0.019$) (Figure 2c). Finally, Bayesian analyses revealed
280 moderate evidence in favor of H0 for the main effect of *posture* ($BF_{10} = 0.331$, error =
281 0.950), anecdotal evidences in favor of H0 for the main effect of *group* ($BF_{10} = 0.57$, error
282 = 0.981) and for the interaction between *posture* and *group* as well ($BF_{10} = 0.44$, error =
283 2.493).

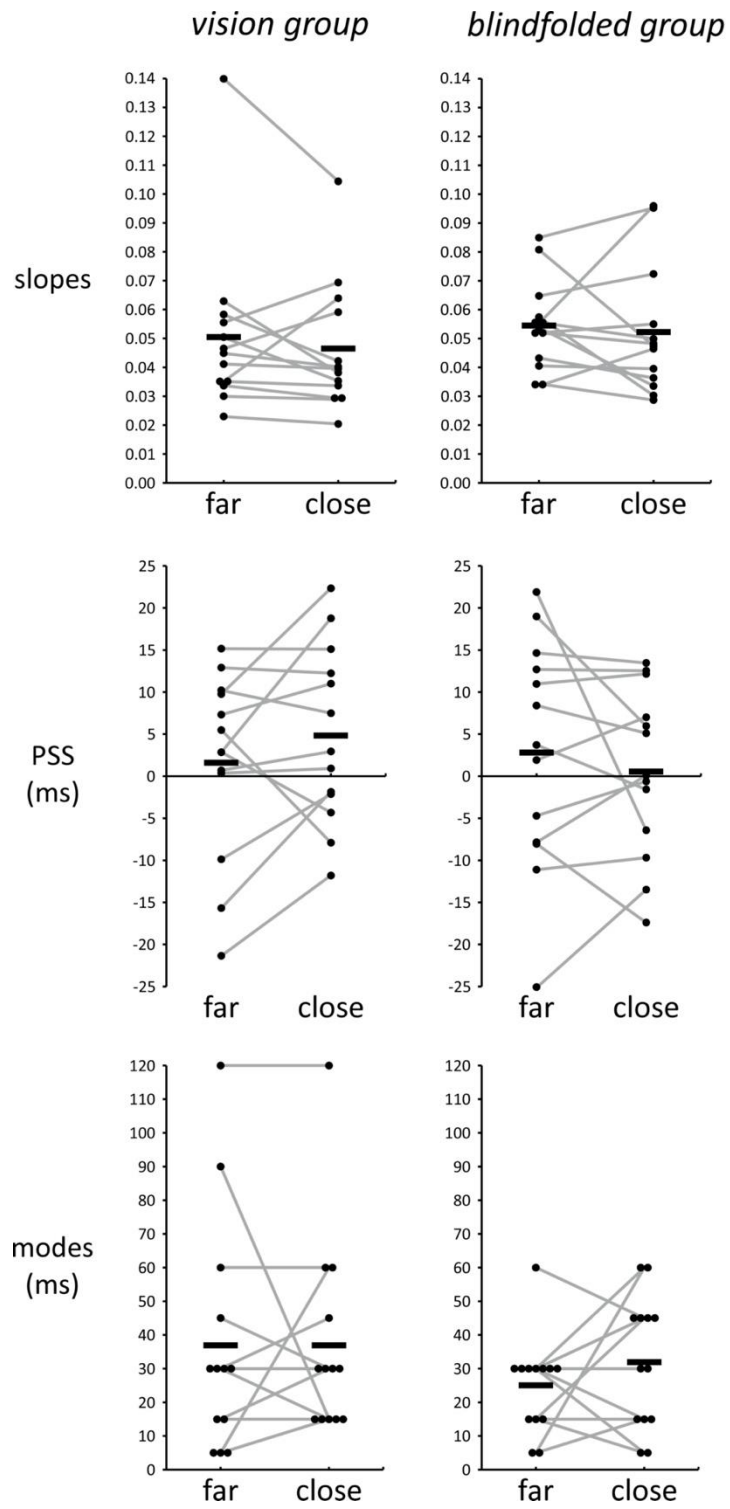
284 Overall, it appears that tactile TOJ performances were not affected by the spatial
285 distance between the stimulated hands. However, results from Bayesian statistics

286 prevent us from concluding on the role of vision on these performances, or on the
287 interaction between *posture* and *group* variables.



289 **Figure 2. TOJ curves.** The figure illustrates the curves of the psychometric function based
290 on group averaged data, from the fitted responses of the *vision* group participants (left)
291 and of the *blindfolded* group participants (right) separately, when performing the task
292 with the hands placed either in a far (solid grey lines) or in a close (dotted black lines)
293 posture. The x-axis corresponds to the different possible stimulus onset asynchronies
294 (i.e. SOA). Negative values indicate that the left hand was stimulated first and positive
295 values that the right hand was stimulated first. The y-axis refers to the proportion of

296 trials in which the tactile stimulus applied on the left hand was reported as being
297 perceived first.



299 **Figure 3. TOJ parameters.** The figure shows scatter plots displaying individual data
300 (black dots) and their means (black strips) respectively for the slopes and PSS values of
301 the TOJ task as well as the modes of the SOA used during the adaptive procedure. The
302 data are plotted according to the group (*vision* group: left; *blindfolded* group: right) and
303 the experimental condition (hands in the *far* posture: left inner-sections; hands in the
304 *close* posture: right inner-sections). Data of the same participant are linked by the grey
305 lines.

306

307 **4. Discussion**

308 The present study aimed to test the influence of the distance in external space
309 between two body limbs on the ability to discriminate the temporal order between two
310 tactile stimuli, one applied to each of those limbs. We also investigated whether such
311 an effect could be modulated by the possibility of seeing or not the limbs on which
312 tactile stimuli were applied. Previous experiments reported decreased performances in
313 judging the order of appearance of two tactile stimuli when the hands are positioned
314 close together as compared to when they are placed farther away, as indexed by higher
315 JND values in the close posture (Gallace & Spence, 2005; Roberts et al., 2003; D. I. Shore
316 et al., 2005). These studies confirm that spatial processing of somatosensory inputs
317 integrates information about the relative posture of the body limbs in external space, in
318 line with the results from the studies having tested tactile TOJ performance with the
319 hands in a crossed posture (e.g. Crollen, Lazzouni, et al., 2017; Crollen et al., 2019; Heed
320 & Azañón, 2014; Röder et al., 2004; Shore et al., 2002; Yamamoto & Kitazawa, 2001). It
321 was also suggested that these effects might be mostly driven by the actual vision of the
322 limbs position (Cadieux & Shore, 2013; Gallace & Spence, 2005). However, in the present
323 study, we did not succeed to provide reliable evidence in favor of the influence of the

324 distance between the stimulated limbs, and its modulation by actual vision of the limbs,
325 on tactile TOJ performances.

326 One of the main differences between the present and previous experiments having
327 tested the influence of hands distance on tactile TOJ performance, relies on the fact that
328 the different time intervals (i.e. SOA) between the two consecutive stimuli were
329 administrated by means of an adaptive procedure in the present experiment while
330 previous studies used methods of constant stimuli (Gallace & Spence, 2005; Roberts et
331 al., 2003; D. I. Shore et al., 2005). In these previous studies, each SOA condition was
332 repeated 8 to 15 times in block of 80 to 90 stimuli, whereas the stimulation blocks of
333 the present experiment only consisted of 40 trials selected among 22 possible SOA
334 conditions. It is therefore possible that our experimental procedure did not succeed to
335 fully sample the psychometric function fitting participants' responses and did not
336 properly measured limb distance effect during somatosensory TOJ tasks. However, this
337 seems unlikely as, on the contrary, one of the main advantages of psychophysics
338 adaptive methods over constant stimuli methods is to allow more reliable estimation of
339 the parameters of the psychometric function even when a limited number of stimuli is
340 used (Filbrich, Alamia, Burns, et al., 2017; Kontsevich & Tyler, 1999). Accordingly, using
341 the same adaptive method as the one used in the present experiment, previous studies

342 succeeded to reliably estimate both the threshold (Filbrich, Alamia, Blandiaux, et al.,
343 2017; Filbrich, Alamia, Burns, et al., 2017; Filbrich, Alamia, Verfaillie, et al., 2017; Filbrich,
344 Halicka, Alamia, & Legrain, 2018; Legrain, Manfron, Garcia, & Filbrich, 2018; Manfron,
345 Legrain, & Filbrich, 2019; Torta, Filbrich, Van Den Broeke, & Legrain, 2018;
346 Vanderclausen et al., 2017) and the slope parameters (Vanderclausen, Bourgois, et al.,
347 2020; Vanderclausen et al., accepted; Vanderclausen, Manfron, et al., 2020) of the TOJ-
348 fitting psychometric function and to significantly measure changes in participants'
349 judgments according to experimental manipulations such as the posture of the
350 stimulated limbs. For instance, Vanderclausen and colleagues (Vanderclausen, Bourgois,
351 et al., 2020; Vanderclausen et al., accepted; Vanderclausen, Manfron, et al., 2020) have
352 shown significant and reliable crossing hands effects during TOJ tasks with
353 somatosensory (vibrotactile or radiant heat) stimuli delivered using the adaptive *psi*
354 procedure.

355 Therefore, one of the most probable reasons why we failed to replicate the limb
356 distance effect during somatosensory TOJ tasks could rely on the fact that such an effect
357 is weaker than that observed when the stimulated limbs are crossed over the body
358 midline. Indeed, while the crossing hands effect has been recurrently and robustly
359 demonstrated during somatosensory TOJ tasks, the limb distance effect seems to be of

360 smaller magnitude (Roberts et al., 2003). For example, in Shore et al. (2005), the
361 averaged differences between the JND of the close and far posture conditions range
362 from 9 to 20 ms. Furthermore, the distance effect varies according to the use of
363 temporal order judgment (Kuroki et al., 2010; D. I. Shore et al., 2005) or simultaneity
364 judgement tasks (Axelrod, Thompson, & Cohen, 1968; Kuroki et al., 2010). Conversely
365 to the manipulation of crossing the hands over the body midline, when the distance
366 between the stimulated limbs is manipulated, each hand remains in its hemispace, and,
367 therefore, the somatotopic and spatiotopic representations remain aligned with each
368 other, even when the hands are placed close together. Indeed, TOJ studies suggest that
369 spatiotopic representation of tactile inputs can be automatically generated and overlaps
370 in times with that of the somatotopic one, at least at the time scale of TOJ experimental
371 designs (e.g. Azanon, Camacho, et al., 2010; Badde & Heed, 2016; Badde, Heed, & Roder,
372 2016). Therefore, their co-activation generates mismatching responses when the limbs
373 are crossed as the left hand is in the right part of space and vice versa. It has been
374 suggested that decreased TOJ performances during the crossed hands posture might
375 actually reflect the effort that the brain has to make in order to inhibit the response
376 from the irrelevant spatial representation and select the relevant one (Crollen et al.,
377 2019; Vanderclausen, Manfron, et al., 2020). By comparison, although decreasing spatial
378 distance between two stimuli might actually induce more attentional competition

379 between the two stimuli (see for instance Mangun & Hillyard, 1987; 1988 for similar
380 effect in the visual domain), such competition might be of lesser magnitude than that
381 induced by crossing the hands. Therefore, it might not be reliably sampled during TOJ
382 tasks manipulating the distance between the stimulated limbs.

383 As a consequence, the possibility to evidence reliable effects of the spatial
384 positions of the stimulated body parts could depend on the cognitive goals manipulated
385 by the task instruction and on the associated attentional requirements. For instance,
386 experiments involving fine discrimination of tactile stimuli did evidence significant effect
387 of the spatiotopic distance between the stimulated body parts (Driver & Grossenbacher,
388 1996; Lakatos & Shepard, 1997; Soto-Faraco et al., 2004). Accordingly, it might be
389 instructive to compare the results of the temporal judgment studies based on whether
390 participants are asked to judge the order between the stimuli or whether they are
391 simultaneous or not. It has been indeed suggested that simultaneity judgments are less
392 demanding in terms of attentional resources than temporal order judgments (Fujisaki,
393 Kitazawa, & Nishida, 2012). However, Kuroki et al. (2010) did not evidence any
394 significant distance effect during neither temporal order nor simultaneity judgment
395 tasks. Further studies will be needed to disclose and describe the conditions under

396 which reliable effect of manipulating the spatial distance between the body parts on
397 which somatosensory stimuli are applied might be observed during perceptual tasks.

398 In conclusion, it seems that changing the spatial distance between the
399 stimulated limbs is less reliable than foreseen in aiming to highlight the complex
400 cognitive processes used to spatially represent somatosensory stimuli. On the contrary,
401 crossing the hands is a more suitable technique to experimentally dissociate the
402 respective contributions of the somatotopic and spatiotopic reference frames
403 underlying the spatial representations of somatic stimuli.

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