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1 Tactile interactions in the path of tactile apparent motion

2

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14

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16 Abstract

17 Perceptual completion is a fundamental perceptual function serving to maintain  
18 robust perception against noise. For example, we can perceive a vivid experience of  
19 motion even for the discrete inputs across time and space (apparent motion: AM). In  
20 vision, stimuli irrelevant to AM perception are suppressed to maintain smooth AM  
21 perception along the AM trajectory where no physical inputs are applied. We  
22 investigated whether such perceptual masking induced by perceptual completion of  
23 dynamic inputs is general across sensory modalities by focusing on touch.  
24 Participants tried to detect a vibro-tactile target stimulus presented along the  
25 trajectory of AM induced by two other tactile stimuli on the forearm. In a control  
26 condition, the inducing stimuli were applied simultaneously, resulting in no motion  
27 percept. Tactile target detection was impaired with tactile AM. Our findings support  
28 the notion that the perceptual masking induced by perceptual completion mechanism  
29 of AM is a general function rather than a sensory specific effect.

30

31 Keywords: apparent motion; perceptual completion; perceptual masking; touch

32           Our sensory systems are continuously exposed to internal and external  
33 noise from a range of sources. Our brain uses perceptual completion mechanisms to  
34 maintain consistent and robust perception against such noise. For example, we can  
35 perceive motion for two or more discrete stimuli alternately appearing and  
36 disappearing in different locations (apparent motion: AM) (Wertheimer, 1912). Under  
37 optimal spatiotemporal conditions, AM is subjectively indistinguishable from real  
38 motion (Korte, 1915), suggesting that perceptual completion occurs along the AM  
39 trajectory where no physical inputs are present.

40           Psychophysical studies have shown impairments in the visual processing of  
41 stimuli irrelevant to AM along the AM trajectory, providing strong evidence for the  
42 perceptual completion of AM (Hidaka, Nagai, Sekuler, Bennett, & Gyoba, 2011;  
43 Yantis & Nakama, 1998). Even simple detection performance is impaired on the AM  
44 trajectory (Hidaka et al., 2011), indicating that perceptual completion of AM affects  
45 early stages of visual processing. This automatic low-level perceptual masking  
46 induced by the perceptual completion mechanism for dynamic inputs can contribute  
47 to maintaining smooth, consistent motion perception in the face of noise. However,  
48 the perceptual masking induced by perceptual completion of AM has been  
49 demonstrated only in vision, although AM can be perceived in other sensory  
50 modalities such as touch, and there exists a shared spatiotemporal rule (Korte's third  
51 law) for AM perception across sensory modalities (Lakatos & Shepard, 1997).

52           Whereas visual information is converted from a single sensory source (i.e.,  
53 light) onto multiple light receptors on retina, tactile information is based on a variety  
54 of mechanical inputs (stretch, pressure, vibration, and so on) through four  
55 qualitatively different types of mechanoreceptor (Lederman & Klatzky, 2009; Saal &  
56 Bensmaia, 2014). Since each distal neuronal mechanism is unique for vision and

57 touch, spatial and temporal properties are naturally different between these sensory  
58 modalities. The temporal resolution of the visual system is known to be relatively low  
59 (10-20 Hz) (Kelly, 1971) compared to touch (250-300 Hz; Gescheider, 1976),  
60 whereas the spatial resolution in vision (1' in visual degree; Campbell & Gubisch,  
61 1966) is superior to touch (less than 5 mm on finger pads; Mancini et al., 2014;  
62 Weinstein, 1968). The perceptual completion mechanism of AM is useful for the  
63 visual system to perceive smooth object motion because this mechanism allows us  
64 to compensate for the lack of information due to the innate low temporal resolution  
65 from perceptually-completed spatial information. It is thus possible that the  
66 perceptual masking induced by perceptual completion of AM is peculiar to the visual  
67 system for maintaining smooth motion perception.

68         On the other hand, the perceptual masking induced by the perceptual  
69 completion mechanism of AM might also exist for touch simply because touch is  
70 frequently exposed to internal (e.g., neural crosstalk) and external (e.g., temperature,  
71 which affects response characteristics of mechanoreceptors) noises (Lederman &  
72 Klatzky, 2009) interrupting the perception of smooth object motion. Intriguingly, visual  
73 and tactile motion processing appear to share perceptual and neural mechanisms:  
74 motion aftereffects transfer bidirectionally between visual and tactile stimuli (Konkle,  
75 Wang, Hayward, & Moore, 2009) and the motion sensitive brain area MT+/V5  
76 responds to both visual (Mather, Pavan, Campana, & Casco, 2008) and tactile  
77 motion (Hagen et al., 2002). These commonalities in the processing of visual and  
78 tactile motion suggest that analogous perceptual masking induced by the perceptual  
79 completion mechanism of AM may also exist in touch. As mentioned above, our  
80 sensory modalities have inherent differences in distal mechanisms and perceptual  
81 properties. Determining whether a common perceptual completion function for

82 dynamic inputs exists can contribute to understanding whether and how our  
83 perceptual systems represent the outer world in coordination with these innate  
84 variabilities of sensory modalities.

85           Here, we investigated this question by testing whether tactile AM impairs  
86 processing of a transient input irrelevant to AM along the AM trajectory. Two vibro-  
87 tactile stimuli were alternatingly presented on the forearm to induce tactile AM.  
88 Participants tried to detect the presence of a tactile stimulus transiently presented at  
89 an intermediate position along the path of AM (**Figure 1**). We compared detection  
90 performance in the presence of AM to a control condition in which the two inducing  
91 touches were presented simultaneously, so that no AM occurred. If the perceptual  
92 completion mechanism of tactile AM can induce low-level perceptual masking along  
93 its trajectory, then detection of the target should be impaired in the AM compared to  
94 the control condition. Our results support the notion that a low-level perceptual  
95 masking occurs in the path of tactile AM.

96

## 97 2. Methods

### 98 2.1. Participants and apparatus

99           Fifteen healthy participants took part in the study after giving informed  
100 consent (7 females; mean age: 30.9 years, SD: 8.5 years, mean handedness score  
101 according to the Edinburgh Inventory (Oldfield, 1971: 82.77, all right-handed, range:  
102 41.2-100). The sample size was determined in reference to previous studies showing  
103 the perceptual interference effects of visual AM (Hidaka et al., 2011; Yantis &  
104 Nakama, 1998). In the study of Yantis and Nakama (1998), the effect of masking of  
105 visual stimuli along the path of AM had an effect size of Cohen's  $d_z = 0.867$   
106 (estimated by the result of a paired sample t-test ( $t(8) = 2.60$ ) in their forth

107 experiment). A power analysis using G\*Power 3.1 software (Faul, Erdfelder, Buchner,  
108 & Lang, 2009) with this effect size, alpha of 0.05, and power of 0.8 indicated that 13  
109 participants were needed. Thus, our sample size is appropriately powered to detect  
110 a comparably sized effect in touch. All participants reported no abnormalities in  
111 sensory perception, and were naïve to the purpose of the study. They were paid or  
112 given course credits for their participation, and gave written informed consent. One  
113 participant was excluded from analyses because she/he was uncomfortable with the  
114 type of stimulation and aborted the experiment, and was replaced by a new  
115 participant. All procedures were approved by the Department of Psychological  
116 Sciences Research Ethics Committee at Birkbeck, University of London (Reference  
117 number: 171887; Title: Building body representations: an investigation of the  
118 formation and maintenance of body representations). The study was conducted in  
119 accordance with the principles of the Declaration of Helsinki.

120 Tactile stimuli were delivered to the forearm using three vibrators (Quaerosys,  
121 Schotten, Germany). The stimulator consisted of ten rods (1 mm in diameter),  
122 protruding from a flat surface of 4 × 8 mm. The rods protruded and retracted at 250  
123 Hz for 50 ms (target) and 200 ms (inducers) with 0.5 ms accuracy, producing clearly  
124 perceivable skin indentations. Wave signal intensity for inducers was always set to  
125 98% of the maximum intensity level available (1.48 mm in indented height). The  
126 intensity of the inducers was calibrated for each participant. Foot pedals (Yamaha  
127 FC5A Sustain Pedal) were used to record participants' responses. Light emission  
128 diodes (LED) were used to present visual cues. The foot pedals and LEDs were  
129 connected with a digital analog converter (NI USB-6341, National Instruments).  
130 These apparatus were connected to a PC (DELL Precision T1700) through a USB  
131 port and controlled by a custom MATLAB (MathWorks, Natick, MA) script with the

132 Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). We used headphones  
133 (Sennheiser HD 439 Audio Headphones) to present white noise bursts in order to  
134 prevent the participants from hearing noises generated by the tactile stimulator.  
135 Fabric athletic arm supporters were used to fix the tactile stimulators on the  
136 participants' left forearm to ensure constant contact force between the skin and the  
137 stimulation devices throughout the experiment. Small cardboard boxes and a sheet  
138 of black cardboard were used to cover the tactile simulators on the participants'  
139 forearm. Participants were asked to keep their eyes open during the experiment and  
140 to fixate a pair of LEDs (i.e., threshold phase) or a black dot positioned on the wall in  
141 front of them.

142

## 143 2.2 Stimuli and procedures

144 Participants were asked to sit on a chair in front of a table, and to place their left  
145 hand and arm on the table with the palm side up in a comfortable position. Three  
146 vibrators were placed into line on the volar skin surface of the participant's left  
147 forearm. One was placed at a position nearby the left elbow (4 cm from the elbow  
148 joint). The other two were set along the proximodistal axis relative to the first one in 5  
149 cm of distance (**Figure 1A**). Participant's left hand and arm were occluded by a black  
150 sheet of cardboard, which rested on four supports. Participants made responses  
151 using two foot pedals. They wore headphones with white noises to prevent audio  
152 cues from the tactile stimulators. No participant reported hearing sounds from the  
153 stimulators. Two LEDs were also placed in front of the participant. First, they  
154 completed a threshold estimation session using a two-interval forced-choice  
155 procedure for determining the target intensity of the subsequent main session. Two  
156 tactile sequences, one with a target presentation and the other without, were



157 sequentially presented with a 1000 ms interval. The target stimulus (i.e., the middle  
158 stimulator) was presented for 50 ms. The onset of the first and second tactile  
159 sequences was cued by the left- and right-side of the LEDs, respectively. For the  
160 target-present sequence, the target occurred 50 ms after the onset of one of the  
161 LEDs. After the observation of two sequences, the participant reported which  
162 sequence they felt with the target, by raising their left (the first sequence) or right (the  
163 second sequence) foot. The intensity of the target was initially set at the above  
164 threshold level (half-maximal intensity available, 0.73 mm in indented height), then  
165 gradually stepped down according to the participant's responses. With this two  
166 interval forced choice task and QUEST method (Watson & Pelli, 1983), we estimated  
167 the 76% detection threshold level of each participant. We run the threshold  
168 estimation session twice, and averaged the last trial of the two thresholds (mean =  
169 0.31 mm, SD = 0.07 mm in indented height).

170           The main experiment session had two conditions. In one condition, two  
171 tactile stimulators placed on the top- and bottom-most positions along proximodistal  
172 axis of the left arm alternately turned on for 200 ms with 100 ms of an inter-  
173 stimulus interval as inducers of AM. Each tactile stimulation was presented 20 times  
174 so that 10 times AM was perceived in each AM sequence in each trial. These  
175 temporal parameters were set by our preliminary observation in order to introduce  
176 the smoothest AM perception in our setup. The target stimulus (50 ms) was  
177 presented once at the middle simulator 25 ms after the presentation of one of the  
178 inducers. The intensity level of the target stimulus was adjusted to the 76% detection  
179 threshold level for each participant based on the results of the threshold estimation  
180 session. We also presented the sequence without the target presentation. As a  
181 control condition, we presented the inducers simultaneously so that no motion was

182 induced. After the experiment, we asked our participants whether the alternate and  
183 simultaneous presentations of the tactile stimulations were perceived as moving or  
184 not. All participants verbally confirmed that they felt AM or no AM in the AM and no-  
185 motion conditions, respectively. Another control condition could be that the target  
186 was presented out of the AM trajectory (“off-path” condition) (Hidaka et al., 2011;  
187 Yantis & Nakama, 1998). Our pilot observations revealed that the sensation of the  
188 tactile stimuli spread out at each stimulation site as covering the whole area along  
189 the mediolateral axis of the arm. Whereas we could introduce a spatial gap between  
190 the inducers and target in 1-3 cm in the mediolateral axis, the above-mentioned  
191 sensory characteristics of tactile vibratory stimulation made it difficult to detect this  
192 spatial gap on the forearm. These observations seemed to be consistent with the  
193 findings that the 75% threshold of spatial gap detection in the mediolateral axis on  
194 forearm is 1 cm even for the single contractor (not vibratory) stimulus with 2 seconds  
195 duration (Gibson & Craig, 2005). We might be able to present the inducers and the  
196 target at different skin surfaces of the forearm (the hairy and glabrous skin surfaces).  
197 However, this idea was discarded because neural (Merzenich, Kaas, Sur, & Lin, 1978)  
198 and perceptual (Le Cornu Knight, Longo, & Bremner, 2014) characteristics are  
199 reported to be different between these skin surfaces. Due to these reasons, we did  
200 not include the “off-path” condition in the current study. The participants were asked  
201 to fixate the visual fixation dot during the stimulus presentations. We also asked  
202 participants to keep their tactile attention (and not visual gaze) on the forearm where  
203 the tactile target was going to be presented during the trial. After the presentation of  
204 these tactile stimulations, the participants reported whether they felt the target or not  
205 during the trial. Half of the participants were asked to raise their left foot to report the  
206 target’s present and their right foot to report its absence, and the other half used the

207 reverse mapping. Our pilot experiment revealed that the detection task was highly  
208 difficult when the AM and no-motion conditions were intermixed in a single block.  
209 Thus, we separated these conditions into different blocks. The AM and control  
210 conditions were counterbalanced in an ABBA order, with the first condition  
211 counterbalanced across participants. Each block consisted of 40 trials, half with the  
212 target present and half with the target absent, making 160 trials in total. The  
213 presentation of the target present and absent trials was randomized across trials.  
214 The target presentation timing (between 2100 to 4200 ms after the initiation (the  
215 presentation of the first inducer(s)) of each trial for both the AM and control  
216 conditions) was also randomized across trials. The starting position of the AM  
217 sequence (from near to hand or to elbow) was also randomized across trials.

218

### 219 2.3 Analysis

220 We calculated hit and false alarm rate for each participant in the AM and no-motion  
221 conditions (**Figure 2A**). The target-present responses in the target-present trials  
222 were regarded as hits and those in the target-absent trials as false alarms. Then, we  
223 computed d-primes as an index of perceptual sensitivity on the basis of the signal  
224 detection theory (Macmillan & Creelman, 1991) by the following formula:  $Z(\text{Hit}) -$   
225  $Z(\text{False alarm})$ . For calculating Z scores from the proportions, we adopted a loglinear  
226 conversion method by adding 0.5 to the numbers of hits and false alarms, and  
227 adding 1 to the number of target-present and target-absent trials (Hautus, 1995). We  
228 also calculated beta values as an index of bias or criterion by the following formula:  $-$   
229  $0.5 \times (Z(\text{Hit}) + Z(\text{False alarm}))$ . The statistical tests were performed by JASP (JASP  
230 Team, 2019). The data have been made publicly available via the Open Science  
231 Framework and can be accessed at <https://osf.io/jfg64/>.

### 232 3. Results

233 We estimated 76% target detection threshold for each participant in the threshold  
234 estimation session and presented the target at that threshold level in the main  
235 session. In the main session, the d-prime for the AM condition ( $M = 0.31$ ,  $SD = 0.69$ )  
236 was significantly smaller than in the no-motion condition ( $M = 0.63$ ,  $SD = 0.64$ ;  $t(14)$   
237  $= -2.52$ ,  $p = .02$ ,  $d_z = 0.65$ ; **Figure 2B**). D-prime was significantly higher than zero  
238 ( $t(14) = 3.82$ ,  $p = .002$ ,  $d_z = 0.97$ ) in the no motion condition, but not in the AM  
239 condition ( $t(14) = 1.75$ ,  $p = .10$ ,  $d_z = 0.45$ ). Finally, the beta values were not  
240 significantly different across conditions (AM:  $M = -0.17$ ,  $SD = 0.98$ ; no motion:  $M = -$   
241  $0.17$ ,  $SD = 0.69$ ;  $t(14) = -0.09$ ,  $p = .93$ ,  $d_z = -0.02$ ) (**Figure 2C**).

242 In order to evaluate the extent to which the obtained results provide positive  
243 support for alternative or null hypotheses, we also performed Bayes factor analyses.  
244 We calculated Bayes factors (default Cauchy prior width  $r = 0.707$ ) and checked the  
245 estimated values were larger than 1. The Bayesian statistical analyses showed that  
246 the observed differences for the d-primers between the AM and no-motion conditions  
247 were more likely to have occurred under the alternative hypothesis than the null  
248 hypothesis. The Bayesian paired sample  $t$ -tests supported the alternative hypothesis  
249 ( $BF_{10} = 2.71$ ). As for the comparison between each d-prime and zero, the Bayesian  
250 one sample  $t$ -tests supported the alternative hypothesis for the no-motion condition  
251 ( $BF_{10} = 22.54$ ) but the null hypothesis for the AM condition ( $BF_{01} = 1.12$ ). The  
252 Bayesian paired sample  $t$ -tests supported the null hypothesis for the difference of the  
253 beta values between the conditions ( $BF_{01} = 3.80$ ).

254 As shown in Figure 2B, some data showed zero or negative d-prime values:  
255 7 of 15 participants' d primes were equal to or below zero (4 showed negative  
256 values) in the AM condition, whereas 2 of 15 participants' d primes showed negative

257 values in the no-motion condition. The zero and negative d-prime values indicate  
258 that the false alarm rates were equal to or higher than the hit rates, respectively.  
259 These results posed the question whether the observed difference in the d-prime  
260 between the AM and no-motion conditions was based on the degradation of  
261 detection performances (i.e., the reduction of the hit rates in the AM condition). To  
262 confirm this, we performed a two-way repeated measure analysis of variance  
263 (ANOVA) with conditions (AM/no-motion) and measurements (hit/false alarm). This  
264 found a significant interaction effect ( $F(1,14) = 7.86, p = .01, \eta_p^2 = 0.36$ ) as well as a  
265 significant effect of measurement ( $F(1,14) = 9.42, p = .01, \eta_p^2 = 0.40$ ), but a non-  
266 significant effect of condition ( $F(1,14) = 0.46, p = .51, \eta_p^2 = 0.03$ ). A simple main  
267 effect showed that the hit rate of the AM condition ( $M = 0.58, SD = 0.25$ ) was  
268 significantly lower than that of the no-motion condition ( $M = 0.67, SD = 0.15$ ) ( $p$   
269  $= .02$ ) (Figure 2A). In contrast, the false alarm rates were comparable between the  
270 conditions (AM:  $M = 0.48, SD = 0.33$ ; no motion:  $M = 0.43, SD = 0.28$ ;  $p = .19$ ).  
271 These results demonstrated that the difference in the d-prime between the AM and  
272 no-motion conditions was mainly explained by the impairment of detection  
273 performances with tactile AM.

274

#### 275 4. Discussion

276 This study demonstrated perceptual masking effects along the trajectory of  
277 tactile AM: sensitivity to the target (d-prime) reduced when targets were presented in  
278 the path of AM. The simultaneous presentation of two tactile stimuli at different skin  
279 locations produces a single illusory focal sensation at the center of the tactile  
280 stimulations where no physical input is presented (Bekesy, 1957; Chen, Friedman, &  
281 Roe, 2003; Sherrick, 1964). This tactile funneling effect can explain the relatively

282 lower d-prime value observed in the no-motion condition: an illusory tactile sensation  
283 could occur at the intermediate, target position between the inducers and this  
284 sensation was hard to be distinguished from the actual target presentation. However,  
285 the perceptual masking effect observed along AM trajectory cannot be solely  
286 explained by the funneling effect, because the presentation of AM (AM condition)  
287 induced lower sensitivity to the target than the no-motion condition.

288           One possibility is that the reduction of the sensitivity to the target with tactile  
289 AM perception could result from attentional distraction from the target position  
290 induced by the alternately presented inducers. Attentional distraction from the  
291 target might simply induce an uncertainty for the status of the target, and this would  
292 result in poor performances both for the target's presence and absence (i.e.,  
293 changes in both hit and false alarm rates) and/or changes in judgment criterion.  
294 However, we observed that only the hit rates were different between the AM and no-  
295 motion conditions and that the beta values were comparable across the conditions.  
296 We also asked our participants to keep their attention to the target position during  
297 the presentations of the inducers in both conditions. Thus, we believe that attentional  
298 distraction cannot fully explain our findings.

299           Our data imply that the perceptual completion more frequently occurred for  
300 the AM condition (7 of 15 participants' d primes were equal to or below zero) relative  
301 to the no-motion condition (2 of 15 participants' d primes showed negative values).  
302 The goal of our perceptual systems is to construct optimal perception with limited  
303 information (Rock, 1983). The current study suggests that similar to vision (Hidaka et  
304 al., 2011; Yantis & Nakama, 1998), the perceptual completion along the tactile AM  
305 trajectory can interfere with the perception of physical inputs irrelevant to AM  
306 perception. The perceptual completion mechanism of AM shared across sensory

307 modalities enables us to maintain smooth motion perception against internal and  
308 external noise. We can assume that the perceptual masking induced by the  
309 perceptual completion mechanism of AM can be a general function rather than a  
310 sensory specific effect in motion perception.

311           Visual AM has been reported to induce the activation of the primary visual  
312 cortex (V1) whose receptive field covers the path of AM (Muckli, Kohler,  
313 Kriegeskorte, & Singer, 2005). It was also suggested that the perceptual completion  
314 along the visual AM trajectory is accomplished by feedback modulation from the  
315 higher-level motion processing area (MT+/V5) to V1 (Sterzer, Haynes, & Rees,  
316 2006). Shared activations in the higher-level motion processing area are reported for  
317 tactile (Hagen et al., 2002) and visual (Mather et al., 2008) motion perception. A  
318 possible underlying mechanism for the perceptual masking of tactile AM may be  
319 feedback modulation from MT+/V5 to primary somatosensory areas (SI and SII), and  
320 the activation of the primary somatosensory areas or low-level 'filling in' would  
321 reduce tactile perceptual sensitivity along the path of AM. It should also be noted that  
322 a neuroimaging study (Alink, Schwiedrzik, Kohler, Singer, & Muckli, 2010) showed  
323 that predictive visual AM stimuli induced inhibition of neural responses in V1 along  
324 the path of AM. In line with this finding, it was reported that that the behavioral data  
325 of the visual AM perceptual masking effect can be explained by the inhibitory neural  
326 activations in V1 assumed by a computational predictive coding model (Van  
327 Humberg, Putzeys, & Wagemans, 2016). Interestingly, involvements of the primary  
328 somatosensory areas including SI (e.g., Whitsel, Roppolo, & Werner, 1972) has  
329 been also reported in response to tactile motion, and the response characteristics of  
330 SI are found to be highly similar to those of MT+/V5 to visual motion (Pei, Hsiao,  
331 Craig, & Bensmaia, 2011). Also, sequential presentations of vibratory stimulations

332 were reported to trigger the perceptual inhibitions between the stimulations on  
333 forearm (Bekesy, 1957). Future studies should investigate the underlying  
334 mechanisms of tactile AM masking effects with neuroimaging and computational  
335 techniques.

336           The current study provided the first demonstration of tactile masking along  
337 the AM trajectory. We demonstrated the tactile AM masking effect with the simple  
338 comparison between AM and no-AM situations, a single spatiotemporal parameter,  
339 and a single body site (i.e., the forearm). These limitations should be addressed in  
340 future research in order to give further understandings of phenomenological aspects  
341 and underlying mechanisms of the effect. Firstly, the relationships between AM  
342 perception and the masking effect should be examined. As in the visual AM masking  
343 effect (Yantis & Nakama, 1998), we would predict that the perceptual quality or  
344 strength of tactile AM is positively correlated with the magnitude of the tactile AM  
345 masking effect. The comparison between the situations where the target presented  
346 along the AM trajectory and where the target appears in a spatial position off the  
347 trajectory of AM (“off-path” situation) (Hidaka et al., 2011; Yantis & Nakama, 1998)  
348 would also clarify the role of AM perception to the AM masking effect. The “off-path”  
349 condition may be introduced if we use a body site (e.g., the belly) whose size is  
350 larger than forearm (see also the methods section). Investigations of commonality  
351 and differences of the tactile AM masking effects across the body sites would also  
352 contribute to understanding whether common perceptual mechanisms exist and how  
353 motion perception is established in the somatosensory system across body parts.  
354 Investigations of spatiotemporal aspects of the tactile AM masking effect, for  
355 example testing the effects of presentation timing of the target relative to that of  
356 inducers along the path of AM (Schwiedrzik, Alink, Kohler, Singer, & Muckli, 2007),



357 would facilitate our understandings of how AM representations are completed along  
358 the tactile AM trajectory. Examinations on how the tactile AM masking effect can  
359 interact with innate spatial (e.g., Longo & Haggard, 2011) and temporal (Hidaka,  
360 Tamè, Zafarana, & Longo, 2020) perceptual distortions of touch can also be of  
361 interest. These future studies can contribute to further understandings of the nature  
362 of perceptual completion mechanisms of tactile AM.

363

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368

#### 369 CRediT statement

370 **Souta Hidaka:** Conceptualization, Methodology, Software, Validation, Formal  
371 analysis, Investigation, Writing - Original Draft, Visualization. **Luigi Tamè:**  
372 Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing -  
373 Review & Editing. **Matthew R. Longo:** Conceptualization, Resources, Writing -  
374 Review & Editing, Funding acquisition.

375

#### 376 Data set

377 Hidaka, S., Tamè, L., & Longo, M. R. Shared\_data of “Tactile interactions in the  
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379 2020. DOI: 10.17605/OSF.IO/DXVTP.

380

381

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489

490 Figure captions

491 Figure 1. (A) A picture and schematic illustration of the experimental setup. Three  
492 tactile vibrators were put on the volar skin surface of the participant's left forearm,  
493 which was covered by a black board. Black circles represent the inducers and purple  
494 (gray) circles the target. Two LEDs were placed in front of the participant. (B) Time  
495 course of stimulus presentations in the apparent motion and no-motion conditions. In  
496 the apparent motion condition, the inducers were alternatively turned on and off so  
497 that the participants felt apparent motion. On the contrary, in the no-motion condition,  
498 tactile vibrators were simultaneously presented from the inducers.

499

500 Figure 2. Results. (A) Proportions of false alarm and hit rates in the apparent motion  
501 and no-motion conditions. (B) D-prime and (C) beta values in the apparent motion  
502 and no-motion conditions. Dot indicates single participant's data (N = 15). Error bars

503 denote standard errors of the means ( $\pm$ SEM). Asterisks indicate significant  
504 differences ( $p < .05$ ).

505