



**HAL**  
open science

## Behavioural synchronization and social referencing of dogs and humans: walking in dyad vs in group

Angélique Lamontagne, Thierry Legou, Birgit Rauchbauer, Marie-Hélène Grosbras, Fannie Fabre, Florence Gaunet

► **To cite this version:**

Angélique Lamontagne, Thierry Legou, Birgit Rauchbauer, Marie-Hélène Grosbras, Fannie Fabre, et al.. Behavioural synchronization and social referencing of dogs and humans: walking in dyad vs in group. *Animal Cognition*, 2023, 26 (3), pp.1021 - 1034. 10.1007/s10071-023-01750-9 . hal-04245082

**HAL Id: hal-04245082**

**<https://hal.science/hal-04245082>**

Submitted on 16 Oct 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Title:** Behavioural synchronization and social referencing of dogs and humans: walking in  
2 dyad vs in group

3  
4 **Authors information:**

5 Angélique Lamontagne<sup>1</sup>, Thierry Legou<sup>2</sup>, Birgit Rauchbauer<sup>2,3</sup>, Marie-Hélène Grosbras<sup>3</sup>,  
6 Fannie Fabre<sup>1</sup>, Florence Gaunet<sup>1</sup>

7 <sup>1</sup>Laboratoire de Psychologie Cognitive (UMR 7290), Aix-Marseille University, CNRS, 3,  
8 place Victor Hugo Marseille Cedex 03, France

9 <sup>2</sup>Laboratoire Parole et Langage (UMR7309), Aix-Marseille University, CNRS, 5 Avenue  
10 Pasteur, 13100 Aix-en-Provence, France

11 <sup>3</sup>Laboratoire de Neurosciences Cognitives, (UMR 7291), Aix-Marseille University, CNRS, 3  
12 Place Victor-Hugo, 13331 Marseille Cedex 3, France

13 Corresponding author: Angélique Lamontagne, email: [angelique.lamontagne@univ-amu.fr](mailto:angelique.lamontagne@univ-amu.fr)

14  
15 **Abstract**

16 Recent studies have demonstrated that dogs synchronize their locomotor behaviour with that  
17 of their owners. The present study aims to improve our understanding of the sensorimotor  
18 processes underlying interspecific behavioural synchronization by testing the influence of the  
19 number of humans on dogs' behavioural synchronization. We used Global Positioning System  
20 (GPS) devices in an outdoor environment to measure dogs' behavioural synchronization to  
21 humans during a locomotor activity involving three speeds (static, slow walking and fast  
22 walking). For half of the dogs, only their owner was walking, while for the other half the  
23 owner walked with two familiar people. We also tested the effect of dog breeds by involving  
24 30 shepherd dogs and 30 molossoids. Our results showed that dogs exhibited the same level  
25 of behavioural synchronization with their owner if alone or if surrounded by two familiar  
26 people. Though the presence of a group of humans did not strengthen the dogs' locomotor  
27 synchronization, it did produce another effect: dogs gazed at their owners more frequently in  
28 the presence of a group compared to their owner alone. This result suggests the same level of  
29 locomotor social entrainment but a difference in social referencing depending on the number  
30 of humans.

31  
32 **Keywords:** dog-human interactions, behaviour, interspecific synchronization, social  
33 referencing, dyads, groups

35 **Statements and Declarations:**

36 • **Competing interests**

37 The authors have no relevant financial or non-financial interests to disclose. No funding was  
38 received for conducting this study.

39

40 • **Ethics approval**

41 This is an observational study. All procedures were in accordance with the ethical standards  
42 of the institutional and national research committee and with the 1964 Helsinki Declaration  
43 and its later amendments or comparable ethical standards.

44

45 • **Author contributions**

46 All authors contributed to the study conception and design. Material preparation and data  
47 collection were performed by Angélique Lamontagne, Fannie Fabre and Thierry Legou.  
48 Statistical analyses were performed by Angélique Lamontagne, Fannie Fabre and Birgit  
49 Rauchbauer. The first draft of the manuscript was written by Angélique Lamontagne and all  
50 authors commented on previous versions of the manuscript. All authors read and approved the  
51 final manuscript. Original idea is from Florence Gaunet.

52

53 • **Data availability statement**

54 The datasets generated and analysed during the current study are available in the on Open  
55 Science Framework repository at the following address:

56 [https://osf.io/bv7ts/?view\\_only=293c79a65c7b466a95cd64bbe8f48339](https://osf.io/bv7ts/?view_only=293c79a65c7b466a95cd64bbe8f48339)

57

58 **Acknowledgments:**

59 The authors are grateful to the company E-Whiz for lending the GPS equipment needed for  
60 the study. The authors also thank the owners and their relatives who volunteered for the study.

61

62

63

64

65

66

67

## 68 **Introduction**

69           Behavioural synchronization and its underlying mechanisms are of increasing  
70 theoretical importance due to their implication in social cognition and communication  
71 (Louwerse et al. 2012; Wheatley et al. 2012). This phenomenon is characterized by three  
72 components: activity synchronization, location synchronization and temporal synchronization  
73 (Duranton and Gaunet 2016). Activity synchronization occurs when individuals perform the  
74 same action at the same time; location synchronization occurs when individuals are spatially  
75 close together; and temporal synchronization occurs when individuals switch actions  
76 simultaneously, whether their actions are identical or different. In general, individuals do not  
77 favour one type of synchronization over another, and behavioural synchronization occurs  
78 when at least one of the three components is observed. In social species, behavioural  
79 synchronization can be observed in a number of everyday situations during dyadic or group  
80 interactions (Cracco and Brass 2018). For example, when two people are sitting next to each  
81 other, they will unconsciously synchronize their leg swings, and when individuals walk side  
82 by side, they will adjust to each other's walking pace. Larger groups also synchronize their  
83 movements, as evidenced by rhythmic clapping during shows (Hove and Risen 2009).

84           Behavioural synchronization is a form of social alignment that involves the immediate  
85 adjustment of behaviours to those of other agents. The temporal aspect is fundamental in  
86 behavioural synchronization. This distinguishes it from social learning, which involves the  
87 reproduction of a behaviour after a temporal delay, subsequent to observation or imitation  
88 (Gaunet 2020). Moreover, unlike social learning, behavioural synchronization does not result  
89 in the acquisition of a new behaviour. Indeed, it involves the initiation of a motor action that  
90 is already part of the interacting agents' behavioural repertoire (Marshall-Pescini and  
91 Kaminski 2014). Nevertheless, behavioural synchronization and social learning rely on the  
92 same sensorimotor mechanisms and can lead to social facilitation, which occurs when the

93 mere presence of an individual increases the likelihood of observers changing their behaviour  
94 (Kubinyi et al 2009). In many social species, behavioural synchronization has adaptive value.  
95 It is very effective in coordinating and synchronizing intraspecific activities, such as searching  
96 for a breeding or hunting area (Gautrais et al. 2007; Sumpter 2006). For example, within a  
97 pack of dogs, individuals behave synchronously by maintaining close contact with each other  
98 to engage in cooperative defence of territory and food resources (Bonanni and Cafazzo 2014;  
99 Duranton and Gaunet 2015). During inter-pack conflicts, dogs take into account their  
100 partners' behaviour by using alternating gazes, and they adjust their movements to those of  
101 their companions when they encircle an isolated opponent, for instance (Bonanni and Cafazzo  
102 2014; Duranton and Gaunet 2015). In prey species, behavioural synchronization increases the  
103 probability of survival. In a school of fish, for example, all of the individuals move at the  
104 same time. This allows them to remain in close proximity, which favours the dilution effect,  
105 as each individual is less likely to be captured by a predator (Duranton and Gaunet 2016). In  
106 addition, synchronization increases the effectiveness of individuals' defences against  
107 predators. The synchronization of vigilance behaviours in birds, for example, facilitates the  
108 early detection of predators, allowing birds to escape quickly in case of danger (Duranton and  
109 Gaunet 2016). For emperor penguins, parental synchronization saves energy and improves  
110 parental collaboration (Ancel et al. 2009).

111         Recently, behavioural synchronization has been studied at the interspecific level  
112 within owner-dog dyads. There is a strong bond between dogs and humans as a result of  
113 domestication over the course of tens of thousands of years. The dog is a highly social species  
114 that shares many characteristics of the complex social systems known in humans. In addition,  
115 dogs live in a human social environment which provides them with extensive experience in  
116 using human social cues (Virányi et al. 2004). Dogs are sensitive to human body positions and  
117 visual attention cues (Palagi et al. 2015). For example, they follow the direction of a human's

118 gaze in object choice or problem-solving situations (Virányi et al. 2004) and adjust their  
119 behaviour according to implicit information obtained from humans (Kubinyi et al. 2009).  
120 Dogs are also capable of social referencing, that is, in the presence of an unfamiliar stimulus  
121 or novel situation, they seek out social information provided by humans and use this  
122 information to adjust their own behaviour (Merola et al. 2012). Indeed, dogs can engage in  
123 communicative behaviours with humans, for example they use gaze alternation between an  
124 object and their owner as a cue for referential communication (Gaunet and Deputte 2011).  
125 This reveals the importance of gazing activity in dog-human communication. A study showed  
126 that when faced with an unfamiliar object, dogs looked at their owner in a referential manner  
127 and adjusted their behaviour based on their owner's behaviour. Indeed, dogs approached the  
128 object more quickly when their owner had a positive attitude than when the owner adopted a  
129 negative attitude towards the object (Merola et al. 2012).

130         Recent studies on dogs' locomotor synchronization with that of humans have shown  
131 that during a walk in a closed space (Duranton et al. 2017a) or an open area (Duranton et al.  
132 2018), dogs synchronize their behaviour with that of their owners: dogs stay close to the  
133 owner and adjust their locomotor activity to their owners' activity. Behavioural  
134 synchronization, shown separately in humans and dogs, also exists in interspecific interactions  
135 and may increase dyadic cohesion and improve the integration of dogs into human society.  
136 This supports the hypothesis that social skills developed in dogs during evolution and  
137 selection to live with humans (Duranton et al. 2019).

138         At the intraspecific and interspecific levels, behavioural synchronization has been  
139 linked to affiliation (Duranton et al.,2017b; Hove and Risen 2009). In humans, behavioural  
140 synchronization enhances cooperation and acts as social glue as it increases social cohesion  
141 and social attachment between individuals (Duranton and Gaunet 2016; Hoehl et al. 2020;  
142 Wiltermuth and Heath 2009). More specifically, behavioural synchronization encourages

143 social ties between individuals (Launay et al. 2016; Tarr et al. 2015). Two people involved in  
144 the same task and acting in synchrony, such as dancing, marching or even moving their  
145 fingers similarly, like each other more than two people who do not act synchronously (Hove  
146 and Risen 2009; Wiltermuth and Heath 2009). Also, the degree of synchronization is  
147 influenced by the pre-existing relationship between the partners in the interaction: the more  
148 closely bonded individuals are, the stronger their synchronization is (Duranton et al. 2017a;  
149 Hoehl et al. 2020). Dogs show higher synchronization between conspecific in dyads or groups  
150 with a high degree of affiliation (Duranton and Gaunet 2015; Palagi and Scopa 2017). At the  
151 interspecific level, in contrast to pet dogs, shelter dogs under similar experimental conditions  
152 do not present behavioural adjustments to shelter caregivers (Duranton et al. 2017b).  
153 Furthermore, dogs show a social preference for people who synchronize with them (Duranton  
154 et al. 2019). This shows that dogs' behavioural synchronization with humans is influenced by  
155 affiliation, since the bond between caregivers and dogs is weaker than the bond between  
156 owners and dogs (Duranton et al. 2017b).

157         To our knowledge, interspecific behavioural synchronization has only been studied at  
158 the level of a dyad. Yet, in many everyday situations, dogs are surrounded by groups of  
159 people. In the present study, we investigated dog behavioural synchronization to humans at  
160 the dyad level and at the group level. In humans, research in cognitive psychology and  
161 neurophysiology has shown that the degree of behavioural synchronization depends on the  
162 number of agents observed (Cracco and Brass 2018; Cracco et al. 2015, 2016). Indeed, the  
163 observed actions are represented in the motor system in each of the interacting subjects,  
164 whether they are performing or observing the action. This simultaneous activation of the  
165 motor representations in interacting subjects is called motor resonance (Rizzolatti et al. 2004).  
166 A subject who observes an action is then likely to reproduce this action by motor resonance.  
167 As the number of agents increases, the activation of the motor system increases, resulting in

168 stronger behavioural synchronization (Cracco and Brass 2018). Motor resonance is thus the  
169 sensorimotor basis of behavioural synchronization. For example, in a study, participants were  
170 asked to perform a finger abduction task while they observed between one and four hands  
171 showing the same or different movements. The results showed that as the number of observed  
172 hands increased, behavioural synchronization improved (Cracco and Brass 2018).  
173 Behavioural synchronization is therefore stronger as group size increases. Moreover,  
174 individuals are more likely to synchronize with other group members compared to those  
175 outside the group (Palagi and Scopa 2017), and the more harmony there is within a group, the  
176 less likely the group is to split apart (Duranton and Gaunet 2016). This phenomenon is  
177 adaptive because it increases the sense of familiarity and understanding of others, which  
178 promotes prosocial behaviour (Palagi and Scopa 2017).

179         The aim of this study was to investigate properties of interspecific behavioural  
180 synchronization, establishing whether it has the same sensorimotor basis as intraspecific  
181 behavioural synchronization in humans. Previous studies on dogs' locomotor synchronization  
182 to humans were based only on video data analysis (Duranton et al. 2017a,b, 2018). In the  
183 present study, we investigated the three components of locomotor synchronization using  
184 cameras and GPS devices with a Real Time Kinematic (RTK) base station. Using these  
185 reliable, accurate and objective devices, we sought to compare the synchronization and gazing  
186 activity of dogs to humans at the dyad and group levels. Given that synchronization is  
187 dependent on group size in humans and that dogs' synchronization to human behaviour has  
188 already been demonstrated, we tested whether the presence of a group of humans composed  
189 of the owner and two people familiar with the dog would increase the degree of the dog's  
190 locomotor synchronization and visual attention towards the owner. We therefore compared  
191 dog-owner dyads and dog-familiar groups walking in an open space with the dogs off-leash  
192 under three successive speed conditions: static, slow walking and fast walking. We



193 hypothesized that dogs with their owner and two familiar people would show a higher degree  
194 of location, activity and temporal synchronization and gazing activity than dogs with their  
195 owner alone. More precisely, we expected that (hyp 1) dogs with their owner and two familiar  
196 people would be closer to their owner and spend more time close to their owner compared to  
197 dogs with their owner alone (location synchronization). We also expected that (hyp 2) the  
198 difference between the dog's speed and the owner's speed would be smaller for dogs with  
199 their owner and two familiar people compared to dogs with the owner alone, consequently the  
200 dog's speed would differ between dogs with their owner alone and dogs with their owner and  
201 two familiar people (activity synchronization). Given the three speed conditions, humans  
202 changed their walking pace twice during the test and the type of change in locomotor activity  
203 depended on the order of the three speed conditions. There were thus three types of changes in  
204 human locomotor activity: switching from still to motion (static to slow-walk or fast-walk),  
205 from motion to still (slow-walk or fast-walk to static), and variation in walking pace (slow-  
206 walk to fast-walk or *vice versa*). We expected that (hyp 3) dogs with their owner surrounded  
207 by two familiar people would adapt their speed faster than dogs with their owner alone  
208 (temporal synchronization). Finally, visual attention increases with group size in humans, so  
209 we expected that (hyp 4) dogs with their owner and two familiar people would gaze at their  
210 owner for longer than dogs with their owner alone.

211         Also, we expected (hyp 5) an effect of speed condition on the dog's speed, as dogs  
212 would change their speed according to the speed condition, and no effect of speed condition  
213 on (hyp 6) the difference between the dog's speed and the owner's speed, (hyp 7) on location  
214 synchronization and (hyp 8) on gazing activity. During the change of speed condition, we  
215 expected that (hyp 9) dogs would adapt their speed faster during changes from still to motion  
216 or motion to still than during variations in walking pace, as changes from still to motion or  
217 motion to still would be more easily noticeable than variations in walking pace.

218 Our research also took into account the fact that certain breeds of dogs were selected  
219 during domestication for their human-like social skills. Working dogs, for example, are better  
220 at using human communication cues than other breeds (Wobber et al. 2009). Therefore, we  
221 also investigated the potential effects of two types of working dog breeds, shepherd dogs and  
222 molossoids, on the three components of behavioural synchronization. Working dogs share a  
223 common pool of skills, with some nuances: shepherd dogs were selected to be attentive and  
224 responsive to human cues, while molossoids were selected to monitor their shared  
225 environment with humans. Duranton et al. (2017a, 2018) revealed tenuous and specific breed  
226 effects. The authors did not detect a breed effect on location synchronization, but they found  
227 that shepherd dogs had a faster walking pace than molossoids and changed their activity faster  
228 when their owner changed their own activity compared to molossoids, which are by their  
229 morphology slower and heavier. They also found that shepherd dogs gazed for longer at their  
230 owner than molossoids. We thus expected comparable results, that is, a breed effect (hyp 10)  
231 on activity synchronization, (hyp 11) temporal synchronization and (hyp 12) gazing activity,  
232 but (hyp 13) no breed effect on location synchronization.

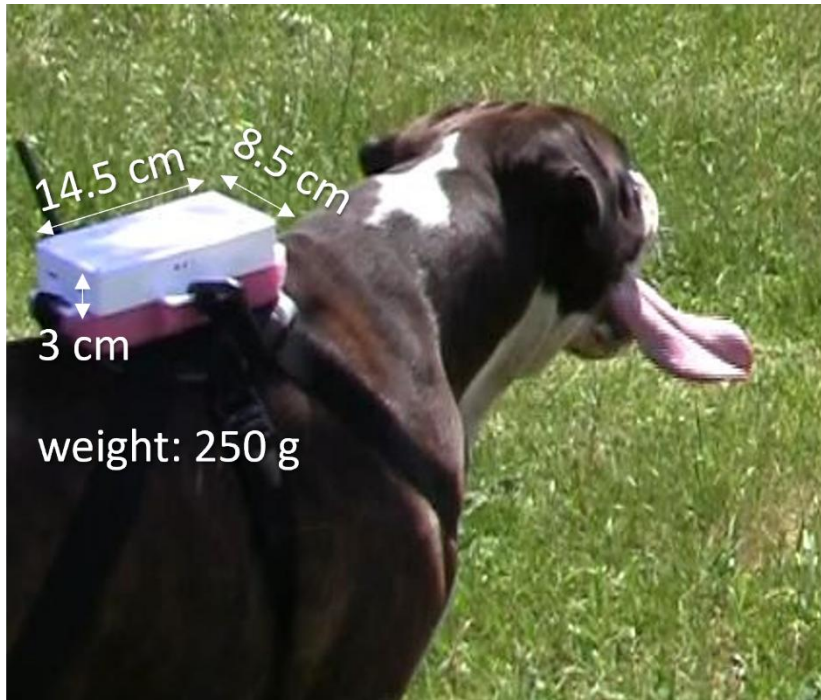
233

## 234 **Material and Method**

### 235 *Ethics*

236 This experimental study was conducted in accordance with the Declaration of Helsinki  
237 and its latest revision in 2013. All participants signed a consent form for their participation.  
238 All the dogs were healthy, and none showed signs of disease or behavioural problems, based  
239 on information from the owners and observations by the experimenters. They were all  
240 familiar with humans and comfortable wearing harnesses and going on leash-free walks in  
241 open outdoor areas. The dogs were not caused any physical strain, and no biological samples  
242 were taken. During the experiment, the dogs were carrying a gopro® harness with a GPS

243 device attached on it (size and weight are shown in Fig. 1). The dogs had an adaptation time  
244 to get used to the test area and the equipment. Based on the video recordings, none of the dogs  
245 showed any discomfort or stress signals during the experiment. After the experiment, all of  
246 the dogs returned home with their owners.



247

248 **Fig. 1** Weight and size of the GPS device carried by the dog

249 *Participants*

250 We included a total of 60 dogs in the study: 30 molossoids and 30 shepherd dogs. The  
251 breed division was based on the International Canine Federation nomenclature. The list of  
252 breeds in each group is shown in Table 1 in Supplemental file. Half of the shepherd dogs and  
253 half of the molossoids were assigned to an experimental group with only their owners; the  
254 other halves were assigned to an experimental group with their owners and two other people  
255 who were familiar with the dog. Familiar people were relatives of the owner who had shared  
256 an activity with the dog or spent time with the dog at the owner's home at least 3 times. The  
257 dogs were between 1 and 9 years old (mean  $\pm$  SEM = 3.74  $\pm$  0.25 years old; shepherd dogs =  
258 3.90  $\pm$  0.37 years and molossoids = 3.59  $\pm$  0.32 years old). There were 38 females and 22

259 males. The owners were between 20 and 69 years old (42 women and 18 men; mean  $\pm$  SEM =  
260  $37.58 \pm 1.65$  years old; shepherd dog owners =  $37.30 \pm 2.44$  years and molossoid owners =  
261  $37.87 \pm 2.27$  years old). The two people familiar with the dog (65% women) were between 18  
262 and 52 years old (mean  $\pm$  SEM =  $28.05 \pm 1.15$  years old).

263 All of the dogs were used to obeying basic commands, such as sitting, lying down, and  
264 walking on a leash. However, some of the dogs had more training: 17 dogs (13 shepherd dogs  
265 and 4 molossoids) had a higher level of training (they occasionally attended training courses),  
266 and 12 dogs (8 shepherd dogs and 5 molossoids) had a very high level of training (they  
267 attended daily training courses and participated in obedience or agility competitions  
268 regularly). The dogs also had different levels of familiarity with the testing area: 21 of them  
269 (14 shepherd dogs and 7 molossoids) out of 60 had previously been on a walk at the test site.  
270 The potential effect of these two factors was statistically tested.

#### 271 *RTK technology*

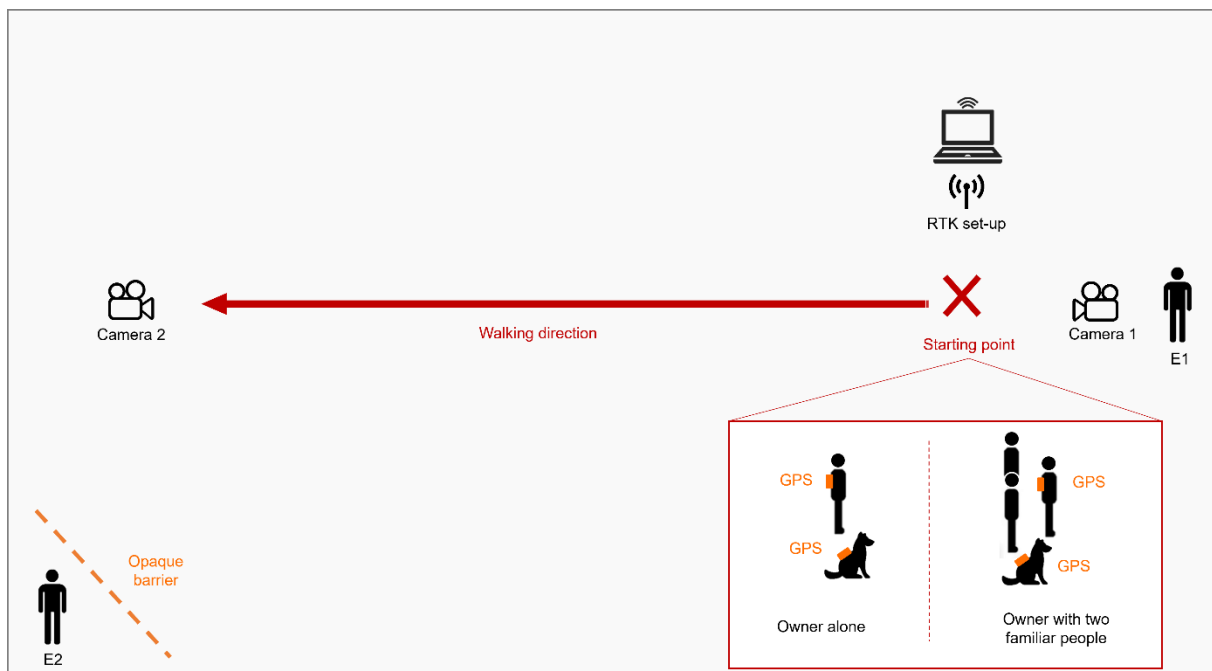
272 To collect data, we used the Real Time Kinematic (RTK) technology. It is based on  
273 the use of a fixed station that sends real-time corrections to (Global Positioning System) GPS  
274 devices to achieve centimetric precision. More precisely, the fixed station extracts the phase  
275 of the carrier waves from the GPS. The use of the phase information permits to strongly  
276 enhance the accuracy of the mobile positioning. We used two GPS, one for the dog and one  
277 for the owner. The GPS were Z-F9P by U-Blow. The accuracy of the system was tested on a 2  
278 m long (model train track). For each position recorded, the distance from the track was less  
279 than 2 cm. Each device recorded every 0.25s to an SD card the received GPS frames  
280 including the time, location, and the quality of the RTK correction. The processing of these  
281 GPS frames received (4 per second) provided positional data in XY coordinates for the dog  
282 and positional data in XY coordinates for the owner.

283

284 *Procedure*

285 Two experimenters were present during the test (E1 and E2). The dogs were tested  
286 individually, off-leash, in an open area of 80m long and 70m wide, that is 5 600m<sup>2</sup>, in  
287 Toulouse, France. The dogs and their owners were each equipped with a GPS device. The dog  
288 was then given 10 minutes to get used to the testing area while wearing a harness and roaming  
289 freely. During this time, E1 explained the experimental procedure to the human participants  
290 (the owner alone or the owner and two familiar people). Two cameras mounted on a tripod  
291 were used to record the dogs' behaviours during the tests (Fig. 2). E1 placed Camera 1 five  
292 metres behind the starting point of the test; E2 placed Camera 2 at the endpoint, 50 metres  
293 away from the starting point; then E2 waited until the dog was not attentive to her and then  
294 went to hide behind an opaque obstacle 50 metres away from Camera 2 (Fig. 2). While E2  
295 was going to hide, the owner called the dog to prevent him/her from looking back at where E2  
296 was going. The human participants were instructed to walk from the starting point to the  
297 endpoint. The human participants performed the three speed conditions (static, slow-walk,  
298 fast-walk) in a randomly assigned order for 15 seconds each without breaks. A web  
299 application (available at <https://intense-coast-72496.herokuapp.com/>) was created specifically  
300 for the experiment and was used as a timer for the human participants. The application  
301 prompted the human participants to change speed using an audible signal transmitted over  
302 headphones so as not to distract the dogs during the test. The application started with a 10-  
303 second countdown. During this preparation phase, the human participants stood facing the  
304 opposite direction from the test area and could communicate with the dogs. They were  
305 instructed to turn 180° when they heard the first beep at the end of the preparation phase to  
306 begin the first speed condition. Following this, a beep was produced every 15 seconds,  
307 indicating the start of the next speed condition. A final beep indicated the end of the trial  
308 which lasted a total of 45 seconds. Following the first beep and throughout the trial, the

309 human participants were instructed not to show any emotional reactions and not to talk to the  
 310 dogs, look at them or interact with them. In the *stay-still condition*, the human participants  
 311 stayed still for 15 seconds. In the *slow-walk condition*, the participants walked slowly for 15  
 312 seconds. In the *fast-walk condition*, they walked quickly for 15 seconds. The human  
 313 participants chose their own step frequency; their only instruction was to walk faster in the  
 314 fast-walk condition than in the slow-walk condition. For dogs tested with their owners and  
 315 two familiar people, the three people started the application at the same time in order to hear  
 316 the signals simultaneously. They were instructed to synchronize their walking pace. The  
 317 owner was in the middle of the group (Fig. 3), and we instructed the owner to stay 2 metres  
 318 behind the two other people and maintain this distance throughout the test, because when  
 319 humans walk in groups of 3 people, the person in the middle tends to stand behind the other  
 320 two individuals (Moussaïd et al., 2010).



321  
 322 **Fig. 2** Experimental set-up. During the preparation phase, the human participants were facing  
 323 Camera 1. For dogs with their owner and two familiar people, the owner was then in front of  
 324 the two familiar people. At the end of the preparation phase, the human participants turned  
 325 180° and started the first speed condition. The owner was then behind the two familiar people



326

327 **Fig. 3** Number of people and their position: owner alone on the left, owner with two familiar  
 328 people on the right. The three people were instructed to maintain this configuration  
 329 throughout the test. The owner and the dog each wore a GPS (white boxes on their backs)

330

331 *Data analysis*

332 Definitions of the dependent variables and independent variables are in Table 1.

333

	<b>Dependent variable</b>	<b>Definition</b>	<b>Independent variables</b>
Location synchronization	Distance between the dog and the owner	Distance in metres between the dog and the owner, calculated every 0.25 seconds from GPS data.	Number of people (hyp 1) Speed condition (hyp 7) Breed (hyp 13)
	Time spent close to the owner	Time in seconds that the dog spent less than one metre away from the owner, three values per dog calculated from GPS data.	Number of people (hyp 1) Speed condition (hyp 7) Breed (hyp 13)

Activity synchronization	Dog's speed	Dog's raw speed in metres per second, calculated every 0.25 seconds from GPS data.	Number of people (hyp 2) Speed condition (hyp 5) Breed (hyp 10)
	Difference between the dog's speed and the owner's speed	Difference in metres per second between the dog's raw speed in metres per second and the owner's raw speed in metres per second, calculated every 0.25 seconds from GPS data.	Number of people (hyp 2) Speed condition (hyp 6) Breed (hyp 10)
Temporal synchronization	Latency	Time delay in seconds for the dog to change his/her speed after the owner changed speed, calculated from GPS data and video recordings.	Number of people (hyp 3) Type of change in human locomotor activity (hyp 9) Breed (hyp 11)
Gazing activity	Time spent gazing at the owner	Time the dog spent with his/her head or nose oriented toward the owner, three values per dog calculated from video recordings.	Number of people (hyp 4) Speed condition (hyp 8) Breed (hyp 12)
	Number of short gaze bouts	The number of times the dog looked at the owner for less than two seconds, three values per dog calculated	Number of people (hyp 4) Speed condition (hyp 8) Breed (hyp 12)



		from video recordings.	
--	--	------------------------	--

334 **Table 1** Description of the dependant and independent variables. The number next to each  
335 independent variable corresponds to the associated hypothesis formulated in the introduction.

336 To investigate location synchronization, we computed the following variables: the  
337 distance between the dog and the owner, and the time spent close to the owner. Activity  
338 synchronization was studied using the dog's speed and the difference between the dog's speed  
339 and the owner's speed as variables. We analyzed the effect of number of people, speed  
340 condition and breed on location synchronization and activity synchronization. In addition, to  
341 better characterize the dog's locomotor activity in relation to their owner's locomotor activity,  
342 we conducted an exploratory analysis using a Student t test to compare the total distance  
343 covered by the dog and that covered by the owner. To explore temporal synchronization, we  
344 computed the latency and we considered that this variable could be defined when the  
345 following criteria were met: the presence of a slope on the speed graph obtained from the GPS  
346 data and a change of gait based on a qualitative analysis of the camera recordings. Three gaits  
347 were studied: walking, trotting and galloping. There was no latency value for dogs that did not  
348 exhibit a change in speed during the change of speed condition. For statistical analysis, we  
349 only included dogs whose data met these criteria. We examined the effect of breed, type of  
350 change in locomotor activity and number of people on the temporal synchronization variable.

351 To better characterize the dog's social referencing behaviour and relate it to  
352 behavioural synchronization, we further defined two additional variables: the time the dog  
353 spent gazing at the owner and the number of short gaze bouts (see social referencing in  
354 Duranton et al. 2016). We also examined the effect of breed, number of people and speed  
355 condition on these variables.

356 Both experimenters independently coded 100% of the gazes and temporal  
357 synchronization variables by visual inspection using Media Player Classic Home Cinema  
358 software (version 1.7.13, <https://mpc-hc.org/>). The inter-rater reliability was assessed by  
359 Pearson's (latency and time the dog spent gazing the owner) and Spearman's (number of short  
360 gaze bouts) correlations. For all the variables, Pearson and Spearman coefficients lead to  $P_s <$   
361 0.001 (time spent gazing at the owner:  $r = 0.838$ ,  $p < 0.001$ ; number of short gaze bouts:  $r =$   
362 0.797,  $p < 0.001$ ; latency:  $r = 0.860$ ,  $p < 0.001$ ). These results indicate a good level of  
363 agreement between raters.

364 We verified that the human participants followed the speed instructions using a linear  
365 mixed effects models (LMM) in R (version 4.0.2, <http://www.r-project.org>, RStudio Team,  
366 2020) with the *lme4* package (Bates et al. 2015). We modelled the owner's speed as a  
367 function of the speed condition, number of people and the interaction between these factors as  
368 fixed effects. We included dog participants as random effects. As the position data were  
369 computed every 0.25 seconds, each data was very dependent on the previous one, so we  
370 included an autocorrelation structure of order 1 (AR1).

371 We analyzed each dependent variable data using LMM. We included dog participants  
372 as random effects. As the position data were computed every 0.25 seconds, each data was  
373 very dependent on the previous one, so we included an autocorrelation structure of order 1  
374 (AR1). Independent variables (Table 1) were used as fixed effects. We also included the  
375 interactions between these variables in the models as an exploratory analysis. We did not have  
376 specific predictions regarding these interactions, we added this exploratory analysis to expand  
377 our understanding of the relationships among the variables in the models. We included the  
378 dog's age, sex, level of training and familiarity with the testing area as control predictors in  
379 the models (results of the effects accounted for by these predictors are reported in  
380 Supplemental file). The normality of the distribution of residuals was graphically checked. As

381 the number of short gaze bouts were discrete data, we used a generalized linear mixed model  
382 using Poisson distribution and gaussian error structure. For each model, we created a null  
383 model lacking the predictors of interest but keeping the same random structure and control  
384 predictors. We compared the full model and the null model using a likelihood ratio test. We  
385 stopped here when the comparison was not significant. When it was significant, we calculated  
386 on the full model test statistics (from Wald chi-square tests) using the *car* package (Fox and  
387 Weisberg 2019) with orthogonal sum contrasts and Type 3 sums of squares. To resolve  
388 significant interactions, we performed pairwise post hoc comparisons using the *emmeans*  
389 package (Searle et al. 1980) with the Kenward-Roger approximation and Tukey corrections  
390 for multiple testing.

391

## 392 **Results**

### 393 *Human participants' following of instructions*

394 Human participants followed the speed instructions since the owner's speed  
395 significantly differed between the speed conditions (null-full model comparison:  $L$  ratio =  
396 291.27,  $df = 5$ ,  $p < 0.001$ ; LMM:  $\chi^2 = 357.49$ ,  $df = 2$ ,  $p < 0.001$ ; mean speed  $\pm$  SEM in the  
397 static condition:  $0.07 \pm 0.003$  m/s; mean speed  $\pm$  SEM in the slow-walk condition:  $0.97 \pm$   
398  $0.004$  m/s; mean speed  $\pm$  SEM in the fast-walk condition:  $1.59 \pm 0.004$  m/s). There was no  
399 effect of number of people (LMM:  $\chi^2 = 0.42$ ,  $df = 1$ ,  $p = 0.517$ ), and no significant interaction  
400 between speed condition and number of people (LMM:  $\chi^2 = 1.70$ ,  $df = 2$ ,  $p = 0.427$ ) on the  
401 owner's speed.

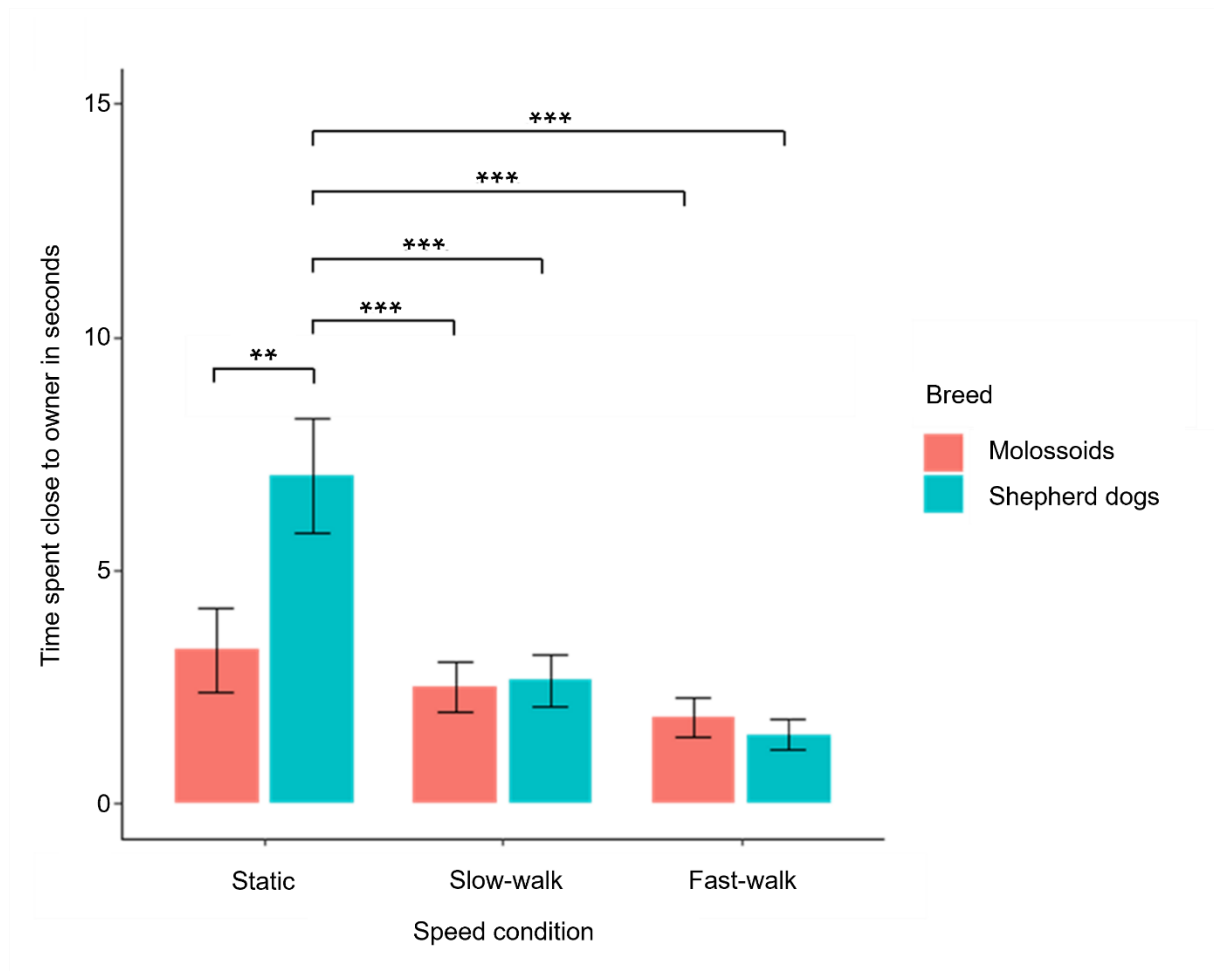
402

### 403 *Location synchronization*

404 Regarding the distance between the dog and the owner, the null-full model comparison  
405 was not significant ( $L$  ratio = 4.72,  $df = 11$ ,  $p = 0.944$ ). Thus, there was no effect of number of

406 people (hyp 1), speed condition (hyp 7) and breed (hyp 13) on the distance between the dog  
407 and the owner. The mean distance over the course of the test between the dog and the owner  
408 was  $4.83 \pm 0.05$  metres.

409       Regarding the time dogs spent close to their owners, the null-full model comparison  
410 was significant ( $L$  ratio = 41.14,  $df = 11$ ,  $p < 0.001$ ). The time dogs spent close to their owners  
411 was not affected by number of people (hyp 1) ( $\chi^2 = 1.87$ ,  $df = 1$ ,  $p = 0.172$ ). Exploratory  
412 analysis of interactions between variables showed that there was a significant interaction  
413 between speed condition and breed (hyp 7) and (hyp 13) ( $\chi^2 = 10.54$ ,  $df = 2$ ,  $p = 0.005$ ). Other  
414 interactions were not significant (see Table 3a in Supplemental file). Fig. 4 shows that  
415 shepherd dogs spent significantly more time close to their owners in the static condition  
416 compared to the slow-walk and fast-walk conditions, and compared to molossoids in the  
417 static, slow-walk and fast-walk conditions (all  $P$ s  $< 0.05$ , pairwise post-hoc comparisons are in  
418 Table 3b in Supplemental file).



419

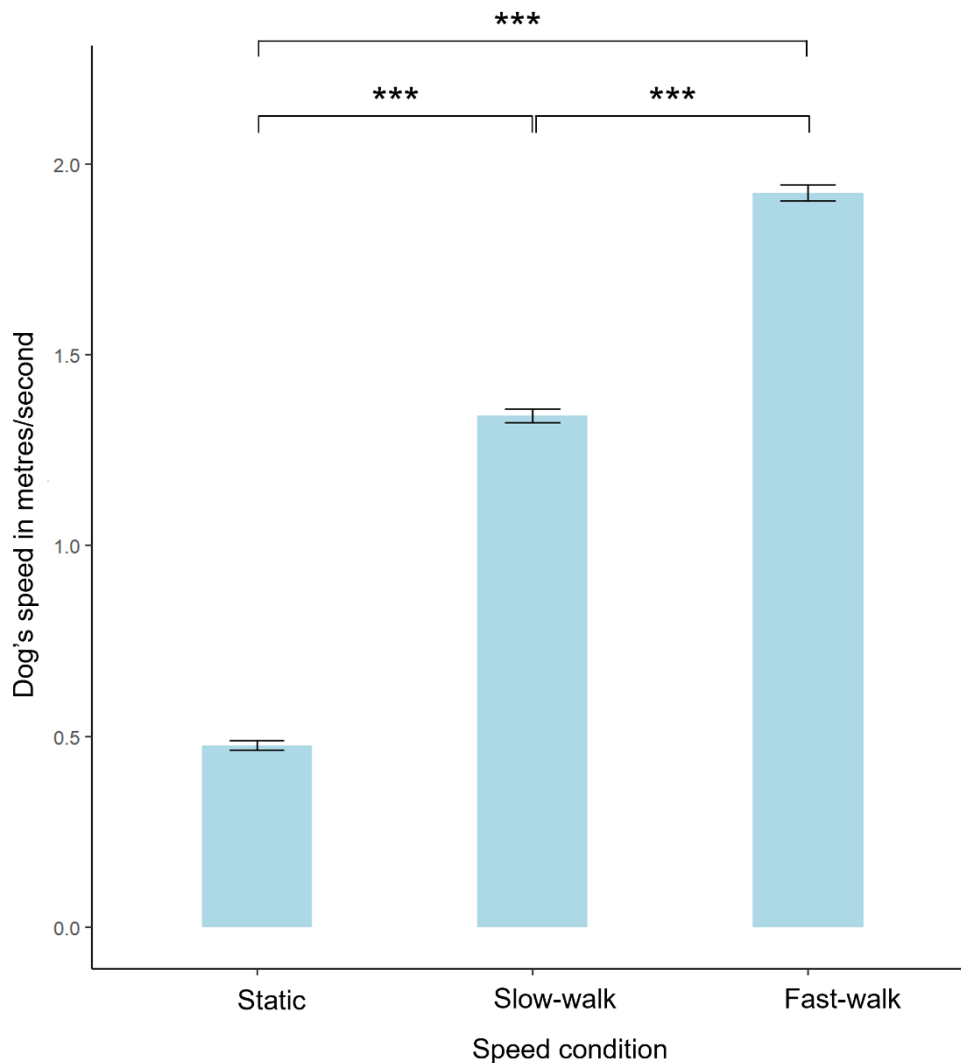
420 **Fig. 4** Time spent close to the owner as a function of the speed condition, for both breeds.  
 421 Data are presented as mean  $\pm$  SEM. \*\*  $0.001 < p < 0.01$ ; \*\*\*  $p < 0.001$

422

423 *Activity synchronization*

424 The null-full model comparison for dog's speed was significant ( $L$  ratio = 15.69,  $df$  =  
 425 11,  $p$  =0.015). There was no effect of number of people (hyp 2) (LMM:  $\chi^2$  = 0.43,  $df$  = 1,  $p$   
 426 =0.512) on the dog's speed. There was an effect of speed condition on the dog's speed (hyp 5)  
 427 (LMM:  $\chi^2$  = 7.69,  $df$  = 2,  $p$  < 0.001). Dogs were faster in the fast walk condition compared to  
 428 the other two speed conditions and were faster in the slow walk condition compared to the  
 429 static condition (Fig. 5). The pairwise post hoc comparison tests yielded the following results:  
 430 fast-walk - slow-walk: *estimate* = 0.59, *SE* = 0.02,  $df$  = 112,  $t$  = -26.94,  $p$  <0.001; fast-walk -  
 431 static: *estimate* = 1.45, *SE* = 0.02,  $df$  = 112,  $t$  = 66.78,  $p$  < 0.001; slow-walk - static: *estimate* =  
 432 0.87, *SE* = 0.02,  $df$  = 112,  $t$  = 40.15,  $p$  < 0.001. There was no effect of breed (hyp 10) (LMM:

433  $\chi^2 = 0.00$ ,  $df = 1$ ,  $p = 0.969$ ) on the dog's speed. The exploratory analysis of interactions  
434 between variables did not reveal significant interaction (all  $P_s > 0.05$ , Table 4 in Supplemental  
435 file).



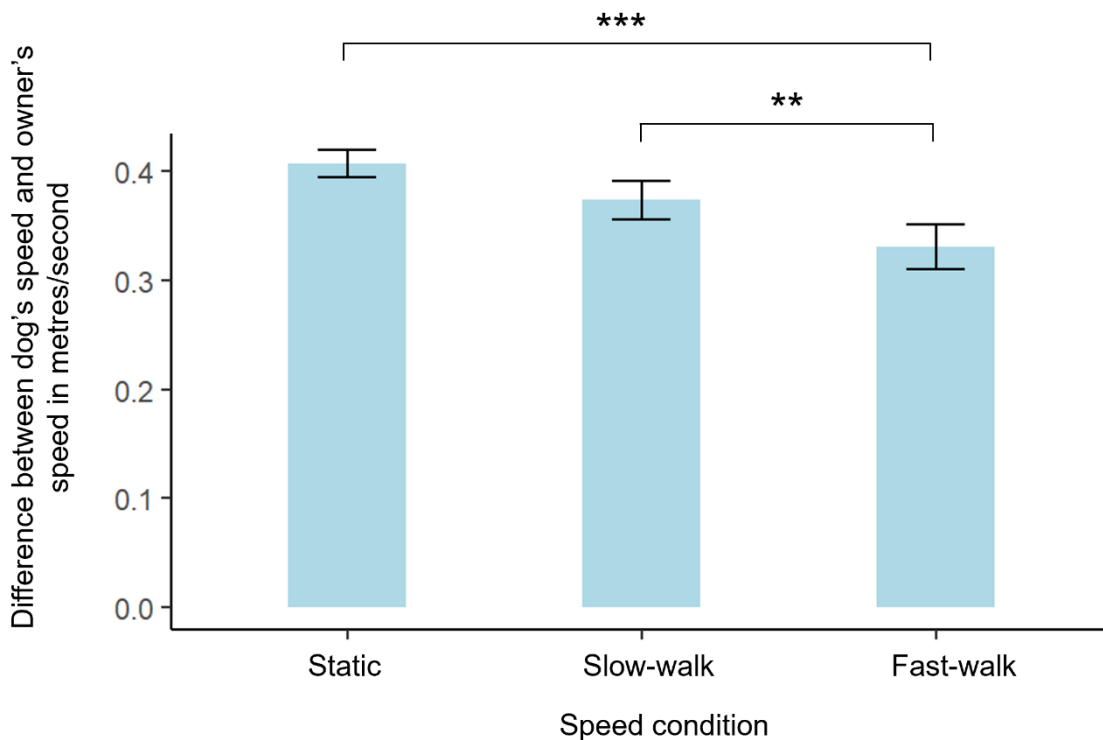
436

437 **Fig. 5** Dog's speed as a function of the speed condition. Data are presented as mean ± SEM.

438 \*\*  $0.001 < p < 0.01$ ; \*\*\*  $p < 0.001$

439 The analysis of the difference between the dog's speed and the owner's speed showed  
440 that dogs were always faster than owners, as the difference was always positive. This is in line  
441 with a supplemental observation: in total the dogs covered a greater distance (mean ± SEM =  
442  $55.65 \pm 2.78$  m) than the owners (mean ± SEM =  $39.15 \pm 0.63$  m,  $t(64.96) = 5.79$ ,  $p < 0.01$ ).  
443 The visual inspection of the GPS trajectories showed that the dogs did not follow a straight

444 line but went back and forth around the owner, coming back to the owner after having moved  
445 a few meters away. The null-full model comparison for the difference between the dog's  
446 speed and the owner's speed was significant ( $L\ ratio = 43.77, df = 11, p < 0.001$ ). The  
447 difference between the dog's speed and the owner's speed did not vary by number of people  
448 (hyp 2) (LMM:  $\chi^2 = 1.14, df = 1, p = 0.285$ ). However, there was an effect of speed condition  
449 (hyp 6) (LMM:  $\chi^2 = 31.54, df = 2, p < 0.001$ ): the difference was smaller in the fast-walk  
450 condition than in the other two speed conditions, and for the slow-walk compared to the static  
451 condition (Fig. 6). The pairwise post hoc comparison tests yielded the following results: fast-  
452 walk - slow-walk:  $estimate = -0.17, SE = 0.04, df = 112, t = -3.85, p = 0.004$ ; fast-walk -  
453 static:  $estimate = -0.24, SE = 0.04, df = 112, t = -5.48, p < 0.001$ ; slow-walk - static:  $estimate =$   
454  $-0.07, SE = 0.04, df = 112, t = -1.66, p = 0.222$ . There was no effect of breed (hyp 10) (LMM:  
455  $\chi^2 = 0.01, df = 1, p = 0.936$ ) on the difference between the dog's speed and the owner's speed.  
456 The exploratory analysis of interactions between variables did not reveal significant  
457 interaction (all  $P_s > 0.05$ , Table 5 in Supplemental file).



458

459 **Fig. 6** Difference between the dog's speed and the owner's speed as a function of the speed  
460 condition. Data are presented as mean  $\pm$  SEM. \*\*  $0.001 < p < 0.01$ ; \*\*\*  $p < 0.001$

461 *Temporal synchronization*

462 Forty-eight dogs changed their speed when the humans changed their speed, so 80% of  
463 the dogs exhibited temporal adjustment during the change of speed condition. The change in  
464 dog's speed was always in accordance with the owner's change of speed: dogs changed to a  
465 faster gait for accelerating changes of speed (static to slow walk, static to fast walk, slow walk  
466 to fast walk), changed to a slower gait for slowing changes of speed (fast walk to static, fast  
467 walk to slow walk, slow walk to static). The null-full model comparison for dogs' latency to  
468 change their speed was not significant ( $L$  ratio = 4.69,  $df = 11$ ,  $p = 0.945$ ). Dogs who  
469 exhibited a latency changed their speed  $2.26 \pm 0.19$  seconds after the owners changed speed,  
470 with no influence of number of people (hyp 3), type of change in human locomotor activity  
471 (hyp 9) and breed (hyp 11).

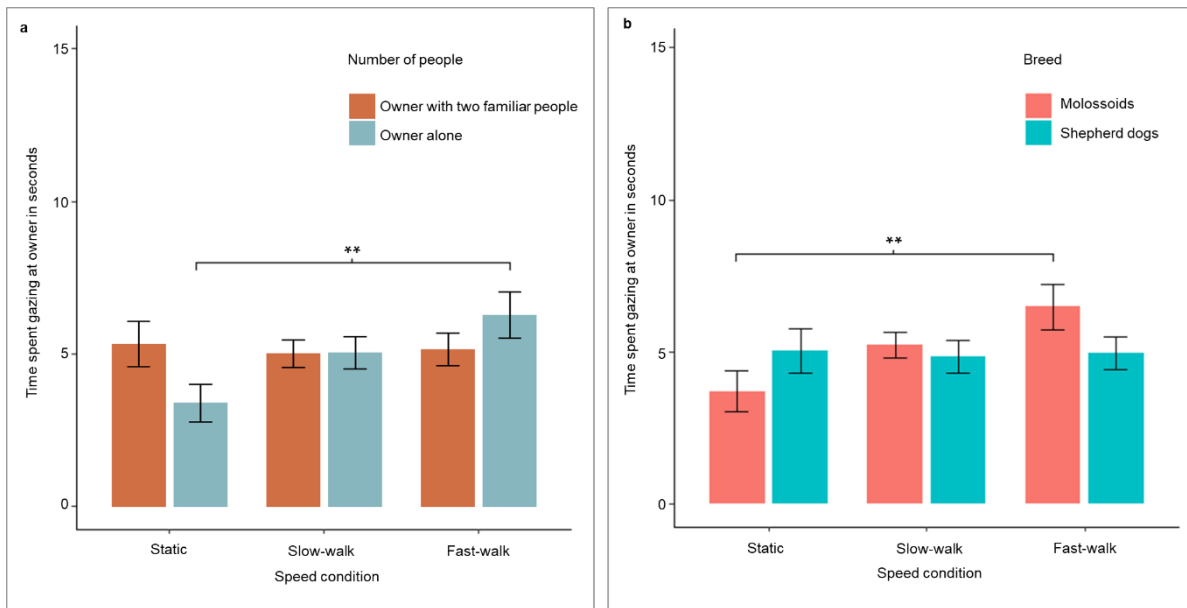
472

473 *Gazing activity*

474 The null-full model comparison for the time spent gazing at the owner was significant  
475 ( $L$  ratio = 26.07,  $df = 11$ ,  $p = 0.006$ ). The exploratory analysis revealed a significant  
476 interaction between number of people (hyp 4) and speed condition (hyp 8) (LMM:  $\chi^2 = 8.21$ ,  
477  $df = 2$ ,  $p = 0.017$ ) and a significant interaction between breed (hyp 12) and speed condition  
478 (hyp 8) (LMM:  $\chi^2 = 6.98$ ,  $df = 2$ ,  $p = 0.031$ ). The interaction between number of people and  
479 breed was not significant (Table 7a in Supplemental file). Fig. 7a showed that dogs with their  
480 owners alone spent significantly less time looking at the owner when the latter was in the  
481 static condition compared to the fast-walk condition. Fig. 7b showed that molossoids spent  
482 more time looking at their owners, whether alone or with the two familiar people, in the fast-



483 walk condition compared to the static condition. Results of post-hoc comparison tests are in  
484 Table 7b in Supplemental file.



485

486 **Fig. 7** Time spent gazing at the owner as a function of the speed condition, for both number of  
487 people (a) and for both breeds (b). Data are presented as mean  $\pm$  SEM. \*\*  $0.001 < p < 0.01$

488

489 The null-full model comparison for the number of short gaze bouts was significant ( $L$   
490  $ratio = 19.43$ ,  $df = 11$ ,  $p = 0.045$ ). The number of short gaze bouts was affected by number of  
491 people (hyp 4) (LMM:  $\chi^2 = 3.86$ ,  $df = 1$ ,  $p = 0.049$ ). Dogs with their owner and two familiar  
492 people produced more short gaze bouts compared to dogs with their owner alone (Table 2a).  
493 In addition, there was an effect of speed condition (hyp 8) on the number of short gaze bouts  
494 (Table 2b, LMM:  $\chi^2 = 7.32$ ,  $df = 2$ ,  $p = 0.026$ ). Dogs produced fewer short gaze bouts toward  
495 their owners in the static condition compared to the slow-walk and fast-walk conditions. Post-  
496 hoc comparison tests showed the following results: fast-walk – slow-walk:  $estimate = -0.01$ ,  
497  $SE = 0.14$ ,  $z = -0.07$ ,  $p = 0.997$ ; fast-walk - static:  $estimate = 0.36$ ,  $SE = 0.15$ ,  $z = 2.38$ ,  $p =$   
498  $0.046$ ; slow-walk - static:  $estimate = 0.37$ ,  $SE = 0.15$ ,  $z = 2.45$ ,  $p = 0.038$ . There was no effect  
499 of breed (hyp 12) on the number of short gaze bouts (LMM:  $\chi^2 = 0.10$ ,  $df = 1$ ,  $p = 0.750$ ). The

500 exploratory analysis of interactions between variables did not reveal significant interactions  
 501 (all  $P_s > 0.05$ , Table 8 in Supplemental file).

502

503

a	Owner alone	Owner and two familiar people
Number of short gaze bouts	$n = 30$ $1.39 \pm 0.12$	$n = 30$ $1.84 \pm 0.13$

504

b	Static	Slow-walk	Fast-walk
Number of short gaze bouts	$n = 60$ $1.23 \pm 0.13$	$n = 60$ $1.82 \pm 0.17$	$n = 60$ $1.80 \pm 0.16$

505 **Table 2** Number of short gaze bouts, for each number of people (a) and for each speed  
 506 condition (b). Data are presented as mean  $\pm$  SEM

507

## 508 Discussion

509 Recent studies have shown that dogs synchronize their locomotion with that of their  
 510 owners. In this study, we wanted to investigate new properties of interspecific behavioural  
 511 synchronization. We hypothesized that the presence of a familiar group would affect the dog's  
 512 localization synchronization (hyp 1), activity (hyp 2) and temporal synchronization (hyp 3)  
 513 compared to the owner alone. We showed the same level of locomotor synchronization  
 514 between dogs with their owner alone and dogs with their owner and two familiar people.  
 515 Behavioural synchronization may already be at its highest degree with the owner alone and  
 516 cannot be increased with additional individuals. We found that dogs adapted their speed to the  
 517 people's in just over 2 seconds; it is possible that the delay between perception and action  
 518 could not be shortened any further. Another explanation could involve the size of the familiar  
 519 group. In humans, behavioural synchronization is strengthened as the number of individuals  
 520 increases (Cracco and Brass 2018). It is thus possible that the size of the groups in our study

521 was insufficient to observe differences based on the number of walkers present during the test.  
522 Replicating this protocol by including and comparing greater group sizes could help  
523 characterize the possible effect of group size on interspecific behavioural synchronization,  
524 which could contribute to the hypothesis that mirror neurons are involved, as reported in  
525 human studies (Cracco and Brass 2018; Cracco et al. 2015, 2016, 2019). Another possible  
526 explanation for the lack of an effect of the number of people could involve the relationship  
527 between the dog and the familiar people. In our study, the familiar people involved were  
528 individuals with whom the dog had already interacted on several occasions; they were not  
529 necessarily people living in the same household as the dog. However, dog-human interactions  
530 are affected by affiliation and not simply social familiarity. In a recent study, dogs observed a  
531 person performing specific actions using an object: looking at the object, handling it and  
532 moving it (Horn et al. 2013). This person was either unknown to the dog or familiar to the  
533 dog, with a more or less close relationship. Dogs paid more attention to people with whom  
534 they had a close relationship, characterized as having many shared activities, while they paid  
535 equally little attention to both familiar people with whom they had spent less active time and  
536 unfamiliar people (Horn et al. 2013). Overall, at both the intraspecific and interspecific levels,  
537 dogs closely affiliated with each other or with humans show stronger behavioural synchrony  
538 (Duranton and Gaunet 2015; Duranton 2020). Therefore, it is possible that in our study, the  
539 dogs and the familiar people did not have a close enough relationship to increase their degree  
540 of synchronization at the group level.

541 We also expected that dogs with their owner and two familiar people would gaze at  
542 their owner for longer than dogs with their owner alone (hyp 4). In our study, we cannot rule  
543 out the possibility that when three humans were present, the dog was looking at the whole  
544 group and not just their owner; however, we found that dogs in the presence of the owner and  
545 two familiar people produced more short gaze bouts towards their owner than dogs with their

546 owner alone. This shows that the dog's processing of visual information differs as a function  
547 of the number of people present, without changing their behavioural response. Humans use  
548 eye contact to initiate and maintain communicative interactions (Gaunet and El Massioui  
549 2014; Hare 2002; Virányi et al. 2006). On an interspecific scale, dogs make eye contact with  
550 humans in many contexts, and gazes are considered to reflect attentional state (Gaunet and El  
551 Massioui 2014; Miklósi et al. 2003; Virányi et al. 2004) and probably social referencing  
552 (Duranton et al. 2016). Dogs seek out social information provided by humans, and eye contact  
553 is an ostensive signal that provides the dog with information about the human's willingness to  
554 communicate (Savalli et al. 2016). When eye contact is established, dogs engage in social  
555 referencing and adjust their behaviour to that of humans (Duranton et al. 2016; Merola et al.  
556 2012). One could argue that dogs looked more at their owner in the group because it made  
557 them more uncertain. However, walks with the owner and other people are not an unusual  
558 situation for dogs. In addition, the dogs in this study were used to being walked off-leash and  
559 were familiar with the people accompanying the owner. It seems more likely that dogs looked  
560 more at their owner in the group because of an increase in perceived sensory input, as is the  
561 case in humans (Gallup et al. 2012). However, unlike humans (Cracco and Brass 2018),  
562 increased sensory input in dogs does not seem to result in increased motor activation.

563         The straight-line walk performed by the human participants involved three speed  
564 conditions. We expected an effect of speed condition (hyp 5) on the dog's speed and no effect  
565 of speed condition on the difference between the dog's speed and the owner's speed (hyp 6),  
566 location synchronization (hyp 7) and gazing activity (hyp 8). Results showed that location and  
567 activity synchronization and gazing activity were affected by speed conditions. Indeed, dog's  
568 speed was different as a function of the speed condition, and dogs were always faster than the  
569 humans. Thus, dogs did not adjust their speed to people's in an absolute manner; rather, they  
570 adjusted their speed relatively. Humans, being bipedal, and dogs, being quadrupedal, have

571 different locomotor sequences, which may explain why dogs always moved faster than  
572 humans in our study. The dogs stayed within about 5m away of their owners; they constantly  
573 moved back and forth, towards and away from them. Owners are social attractors; dogs return  
574 to them when the distance between them becomes too great, like a rubber band that returns to  
575 its initial position after being stretched out. This explains why the distance between the dog  
576 and the owner remained constant and is confirmed by the fact that the total distance covered  
577 by the dogs was greater than that covered by the people. These results are in line with those of  
578 previous studies (Ákos et al. 2014; Foltin 2020), which found that during off-leash walks,  
579 dogs always travelled longer distances than their owners, and demonstrated that the dog's  
580 speed was 1.5 to 3.7 times higher than the owner's. Furthermore, our results showed that the  
581 faster the people walked, the more the dogs gazed at them and the better they adjusted their  
582 speed. The dogs thus became more attentive and exhibited stronger activity synchronization  
583 as people walked faster. The present study suggests that seeing human motor activity (speed  
584 or change in speed) may be a signal that triggers dogs' behavioural synchronization.

585         As humans performed three speed conditions, they changed their speed twice during  
586 the test. We expected that (hyp 9) dogs would adapt their speed faster during changes from  
587 still to motion or motion to still than during variations in walking pace. This hypothesis has  
588 not been validated, so apparently the dog's perception of the human's change of speed does  
589 not differ according to the type of change in human locomotor activity.

590         Finally, we compared dog's locomotor synchronization to humans for two types of  
591 breeds: shepherd dogs and molossoids. We expected a breed effect on activity  
592 synchronization (hyp 10), temporal synchronization (hyp 11) and gazing activity (hyp 12),  
593 and no breed effect on location synchronization (hyp 13). We did not validate our predictions  
594 on breed effect. Instead, we found that molossoids spent more time looking at their owner in  
595 the fast-walk condition compared to the static condition. We also noted that shepherd dogs

596 spent more time in close proximity to their owner in the static condition compared to the other  
597 two conditions. Dogs behave according to the task they were selected for (Mehrkam et al.  
598 2014), and shepherd dogs were selected for herding and the ability to follow their owner's  
599 directions (Passalacqua et al. 2011). This would suggest that when the owners were static in  
600 our study, the shepherd dogs were likely to join them to wait for their next action and copy it.  
601 Molossoids were selected for protection and detection of unknown individuals and unusual  
602 situations (Passalacqua et al. 2011). According to our results, the faster the people walked, the  
603 more time molossoids spent watching them. This could be interpreted as the dogs' way of  
604 monitoring the people and their close environment in order to react in case of abnormal  
605 changes. Finally, we found tenuous differences between the two breed groups. It is not  
606 surprising that such a basic mechanism is present in many breeds; future studies should thus  
607 focus on all breeds.

608         Our experimental protocol was taken from Duranton et al. (2017a, 2018). The set-up  
609 had previously been replicated by Wanser et al. (2021), who focused on dogs' locomotor  
610 synchronization with child family members. Duranton et al. (2017a, 2018) and Wanser et al.  
611 (2021) studied dog locomotor synchronization using video coding. They concluded that dogs  
612 synchronize their behaviour with that of their owner and that behavioural synchronization acts  
613 as a social glue, keeping individuals close to each other and ensuring cohesion within the  
614 group, even at the interspecific level. It contributes to the social functioning of dyads and  
615 groups, facilitating the exchange of information between individuals (Wheatley et al. 2012).  
616 Furthermore, by synchronizing to a model's movements, motor learning is facilitated  
617 (Fuhrmann et al. 2015). Behavioural synchronization can therefore be a tool for humans, to  
618 reinforce a behaviour produced by a dog for example. In the present study, we used an  
619 innovative, automatic and accurate measuring system: GPS devices with an RTK base station.  
620 This system made it possible to obtain the positions of dogs and owners in real time with

621 centimetric precision. Thus, we measured the distance between the dogs and their owner and  
622 the dogs' speed relative to their owner' speed, which had not been done before. We have thus  
623 shown that dogs spontaneously stayed within a few meters of their owner despite all the space  
624 available and that they adapted their speed according to their owner's speed. In previous  
625 studies, the authors coded the amount of time the dogs spent within one metre of their owner  
626 based on video recordings. In our study, based on GPS data, we found that dogs spent on  
627 average 20.96% of the test time within one metre of their owner. This figure is lower than the  
628 results obtained by Duranton et al. (2017a, 2018) (79.47% of the time within one metre of the  
629 owner in the 2017a study, 72.90% in the 2018 study) but closer to the result obtained by  
630 Wanser et al. (2021) (27.1% of the test time). Regarding temporal synchronization, the dog's  
631 latency to change speed relative to the owner's change in speed was lower in our study ( $2.26$   
632  $\pm 0.21$  seconds) compared to Duranton et al. (2017a) ( $3.40 \pm 0.52$  seconds). The data  
633 collection and analyses (visual screening on computers vs GPS data) differed between studies.  
634 The measurement of behavioural synchronization using video recordings involves coding by  
635 the human eye. Data collection using GPS is objective and allows to obtain a centimetric  
636 precision on the data. This difference in accuracy likely explains the difference between our  
637 results and those of previous studies.

638 This was the first study to examine the effect of the presence of a group of people on  
639 dog behavioural synchronization with humans. Understanding the properties of interspecific  
640 behavioural synchronization provides a new perspective on human-dog interactions. Knowing  
641 that dogs relatively adjust their behaviour to the people around them allows for improved  
642 understanding of interspecific interactions. Indeed, in many daily situations, dogs are in the  
643 presence of several people. For example, during a veterinary consultation, dogs are often  
644 stressed. If the people around them, i.e. owner, veterinarian and veterinary assistant, act in a  
645 synchronized and calm manner, dogs will probably adjust their behaviour accordingly. This

646 provides a more relaxed and secure context for the consultation. Also, during walks, dogs  
647 often meet unfamiliar people. During these encounters, dogs refer to owners' attitude. If  
648 owners adopt a relaxed posture, dogs will adjust their behaviour. In this way, it is possible to  
649 manage dogs in new situations without stress or physical constraint. Behavioural  
650 synchronization can therefore be a tool to guide the reaction of the dog in many contexts and  
651 it contributes to dog well-being, improving the quality of dog-human relationship.

652

### 653 **Conclusion**

654 This study was the first to examine the effect of a group of people on interspecific  
655 behavioural synchronization. Using a new, GPS-based tool to collect objective and  
656 quantitative data, we highlighted new properties of the three components of interspecific  
657 behavioural synchronization of dogs to humans in open, outdoor environments. We showed  
658 that dogs engage in the same level of locomotor synchronization with their owner alone or  
659 with two additional familiar people. We also showed that the faster people walk, the more  
660 dogs are visually attentive to them and synchronize their locomotor behaviour with them. The  
661 higher number of gazes produced by dogs with their owner and the two familiar people may  
662 reflect a specific type of processing of the number of stimuli that deserves additional  
663 investigation. More research is also needed to further explore whether dogs experience an  
664 increase in synchronization in the presence of more individuals, as humans do (Cracco et al.,  
665 2015, 2016, 2019; Milgram et al., 1969).

666 Characterizing the properties of dogs' behavioural synchronization with humans is of  
667 practical interest. Our findings can be applied during walks, for instance: speeding up the  
668 walk or moving in groups can increase the dog's state of attention and thus social referencing,  
669 improving interspecific interactions in daily life.

670

### 671 **References**



672 Ákos Z, Beck R, Nagy M, Vicsek T, Kubinyi E (2014) Leadership and path characteristics  
673 during walks are linked to dominance order and individual traits in dogs. *PLoS*  
674 *Comput Biol* 10 (1):e1003446. <https://doi.org/10.1371/journal.pcbi.1003446>

675 Ancel A, Beaulieu M, Le Maho Y, Gilbert C (2009) Emperor penguin mates: keeping  
676 together in the crowd. *Proc R Soc B Biol Sci* 276:2163–2169.  
677 <https://doi.org/10.1098/rspb.2009.0140>

678 Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using  
679 lme4. *J Stat Softw* 67(1): 1–48. <https://doi.org/10.18637/jss.v067.i01>

680 Bonanni R, Cafazzo S (2014) The social organisation of a population of free-ranging dogs in  
681 a suburban area of Rome: a reassessment of the effects of domestication on dogs’  
682 behaviour. In: Kaminski J, Marshall-Pescini S (eds) *The social dog: behaviour and*  
683 *cognition*. Academic Press, London, pp. 65-104

684 Cracco E, Brass M (2018) The role of sensorimotor processes in social group contagion. *Cogn*  
685 *Psychol* 103:23-41. <https://doi.org/10.1016/j.cogpsych.2018.02.001>

686 Cracco E, De Coster L, Andres M, Brass M (2015) Motor simulation beyond the dyad:  
687 automatic imitation of multiple actors. *J Exp Psychol Hum Percept Perform*  
688 41(6):1488-1501. <https://doi.org/10.1037/a0039737>

689 Cracco E, De Coster L, Andres M, Brass M (2016) Mirroring multiple agents: motor  
690 resonance during action observation is modulated by the number of agents. *Soc Cogn*  
691 *Affect Neurosci* 11( 9):1422-1427. <https://doi.org/10.1093/scan/nsw059>

692 Cracco E, Keysers C, Clauwaert A, Brass M (2019) Representing multiple observed actions in  
693 the motor system. *Cerebr Cortex* 29(8):3631–3641.  
694 <https://doi.org/10.1093/cercor/bhy237>

695 Duranton C (2020) Local synchronization as a tool to estimate affiliation in dogs. *J Vet Behav*  
696 *Clin Appl Res* 36:48-53. <https://doi.org/10.1016/j.jveb.2019.10.007>

697

698 Duranton C, Bedossa T, Gaunet F (2016) When facing an unfamiliar person, pet dogs present  
699 social referencing based on their owners' direction of movement alone. *Anim Behav*  
700 113:147-156. <https://doi.org/10.1016/j.anbehav.2016.01.004>

701 Duranton C, Bedossa T, Gaunet F (2017a) Interspecific behavioural synchronization: dogs  
702 exhibit locomotor synchronization with humans. *Sci Rep* 7(1):1-9.  
703 <https://doi.org/10.1038/s41598-017-12577-z>

704 Duranton C, Bedossa T, Gaunet F (2017b) Do shelter dogs engage in social referencing with  
705 their caregiver in an approach paradigm? An exploratory study. *Appl Anim Behav Sci*  
706 189:57-65. <https://doi.org/10.1016/j.applanim.2017.01.009>

707 Duranton C, Bedossa T, Gaunet F (2018). Pet dogs synchronize their walking pace with that  
708 of their owners in open outdoor areas. *Anim Cogn* 21(2):219-226.  
709 <https://doi.org/10.1007/s10071-017-1155-x>

710 Duranton C, Bedossa T, Gaunet F (2019). Pet dogs exhibit social preference for people who  
711 synchronize with them: what does it tell us about the evolution of behavioural  
712 synchronization? *Anim Cogn* 22(2):243-250. [https://doi.org/10.1007/s10071-019-](https://doi.org/10.1007/s10071-019-01241-w)  
713 [01241-w](https://doi.org/10.1007/s10071-019-01241-w)

714 Duranton C, Gaunet F (2015) *Canis sensitivus*: affiliation and dogs' sensitivity to others'  
715 behaviour as the basis for synchronization with humans? *J Vet Behav Clin Appl Res*  
716 10(6):513-524. <https://doi.org/10.1016/j.jveb.2015.08.008>

717 Duranton C, Gaunet F (2016) Behavioural synchronization from an ethological perspective:  
718 overview of its adaptive value. *Adapt Behav* 24(3):181-191.  
719 <https://doi.org/10.1177/1059712316644966>

720 Foltin S (2021) Spatial orientation and exploration behavior of free-ranging domestic dogs.  
721 Dissertation, Universität Duisburg-Essen

- 722 Fox J, Weisberg S (2019) An R companion to applied regression, 3rd edn. Sage, Thousand  
723 Oaks CA
- 724 Fuhrmann D, Ravnani A, Marshall-Pescini S, Whiten A (2014) Synchrony and motor  
725 mimicking in chimpanzee observational learning. *Sci Rep* 4:5283.  
726 <https://doi.org/10.1038/srep05283>
- 727 Gallup AC, Hale JJ, Sumpter DJ, Garnier S, Kacelnik A, Krebs JR, Couzin ID (2012) Visual  
728 attention and the acquisition of information in human crowds. *Proc Natl Acad Sci*  
729 109(19):7245-7250. <https://doi.org/10.1073/pnas.1116141109>
- 730 Gaunet F, El Massioui F (2014) Marked referential communicative behaviours, but no  
731 differentiation of the "knowledge state" of humans in untrained pet dogs versus 1-  
732 year-old infants. *Anim Cogn* 17(5):1137-47. [https://doi.org/10.1007/s10071-014-](https://doi.org/10.1007/s10071-014-0746-z)  
733 [0746-z](https://doi.org/10.1007/s10071-014-0746-z)
- 734 Gaunet F, Deputte BL (2011) Functionally referential and intentional communication in the  
735 domestic dog: effects of spatial and social contexts. *Anim Cogn* 14(6):849-860.  
736 <https://doi.org/10.1007/s10071-011-0418-1>
- 737 Gautrais J, Michelena P, Sibbald A, Bon R, Deneubourg JL (2007) Allelomimetic  
738 synchronization in Merino sheep. *Anim Behav* 74(5):1443-1454.  
739 <http://dx.doi.org/10.1016/j.anbehav.2007.02.020>
- 740 Hare B (2002) The domestication of social cognition in dogs. *Sci* 298(5598):1634- 1636.  
741 <https://doi.org/10.1126/science.1072702>
- 742 Horn L, Range F, Huber L (2013) Dogs' attention towards humans depends on their  
743 relationship, not only on social familiarity. *Anim Cogn* 16(3):435-443.  
744 <https://doi.org/10.1007/s10071-012-0584-9>

745 Hoehl S, Fairhurst M, Schirmer A (2020) Interactional synchronization: signals, mechanisms  
746 and benefits. *Soc Cogn Affect Neurosci* 16(1-2):5-18.  
747 <https://doi.org/10.1093/scan/nsaa024>

748 Hove MJ, Risen JL (2009) It's all in the timing: interpersonal synchronization increases  
749 affiliation. *Soc Cogn* 27(6):949-960. <https://doi.org/10.1521/soco.2009.27.6.949>

750 Kubinyi E, Pongrácz P, Miklósi A (2009) Dog as a model for studying conspecific and  
751 heterospecific social learning. *J Vet Behav Clin Appl Res* 4:31-41.  
752 <https://doi.org/10.1016/j.jveb.2008.08.009>

753 Launay J, Tarr B, Dunbar RI (2016) Synchrony as an adaptive mechanism for large- scale  
754 human social bonding. *Ethol* 122(10):779-789. <https://doi.org/10.1111/eth.12528>

755 Louwerse MM, Dale R, Bard EG, Jeuniaux P (2012) Behaviour matching in multimodal  
756 communication is synchronized. *Cogn Sci* 36(8):1404-1426.  
757 <https://doi.org/10.1111/j.1551-6709.2012.01269.x>

758 Mehrkam LR, Wynne CD (2014) Behavioral differences among breeds of domestic dogs  
759 (*Canis lupus familiaris*): current status of the science. *Appl Anim Behav Sci* 155:12-  
760 27. <https://doi.org/10.1016/j.applanim.2014.03.005>

761 Merola I, Prato-Previde E, Marshall-Pescini S (2012) Dogs' social referencing towards  
762 owners and strangers. *PLoS One* 7(10): e47653.  
763 <https://doi.org/10.1371/journal.pone.0047653>

764 Miklósi Á, Kubinyi E, Topál J, Gácsi M, Virányi Z, Csányi V (2003) A simple reason for a  
765 big difference: wolves do not look back at humans, but dogs do. *Curr Biol* 13(9):763-  
766 766. [https://doi.org/10.1016/s0960-9822\(03\)00263-x](https://doi.org/10.1016/s0960-9822(03)00263-x)

767 Milgram S, Bickman L, Berkowitz L (1969) Note on the drawing power of crowds of  
768 different size. *J Pers Soc Psychol* 13(2):79-82.  
769 <https://psycnet.apa.org/doi/10.1037/h0028070>

770 Moussaïd M, Perozo N, Garnier S, Helbing D, Theraulaz G (2010) The Walking Behaviour of  
771 Pedestrian Social Groups and Its Impact on Crowd Dynamics. PLOS ONE 5(4):  
772 e10047. <https://doi.org/10.1371/journal.pone.0010047>

773 Palagi E, Nicotra V, Cordoni G (2015) Rapid mimicry and emotional contagion in domestic  
774 dogs. R Soc Open Sci 2(12):150505. <https://doi.org/10.1098/rsos.150505>

775 Palagi E, Scopa C (2017) Integrating Tinbergen's inquiries: mimicry and play in humans and  
776 other social mammals. Learn Behav 45(4):378-389. [https://doi.org/10.3758/s13420-  
777 017-0278-x](https://doi.org/10.3758/s13420-017-0278-x)

778 Passalacqua C, Marshall-Pescini S, Barnard S, Lakatos G, Valsecchi P, Previde EP (2011)  
779 Human-directed gazing behaviour in puppies and adult dogs, *Canis lupus familiaris*.  
780 Anim Behav 82(5):1043-1050. <https://doi.org/10.1016/j.anbehav.2011.07.039>

781 Rizzolatti G, Craighero L (2004) The mirror-neuron system. Annu Rev Neurosci 27:169-92.  
782 [https://doi.org:10.1146/annurev.neuro.27.070203.144230](https://doi.org/10.1146/annurev.neuro.27.070203.144230)

783 Tarr B, Launay J, Cohen E, Dunbar R (2015) Synchrony and exertion during dance  
784 independently raise pain threshold and encourage social bonding. Biol Lett  
785 11(10):20150767. <https://doi.org/10.1098/rsbl.2015.0767>

786 Savalli C, Resende B, Gaunet F (2016) Eye contact is crucial for referential communication in  
787 pet dogs. PLoS One 11(9):e0162161. <https://doi.org/10.1371/journal.pone.0162161>

788 Searle SR, Speed FM, Milliken GA (1980) Population marginal means in the linear model: an  
789 alternative to least squares means. The American Statistician 34(4):216–221.  
790 <https://doi.org/10.2307/2684063>

791 Sumpter DJ (2006) The principles of collective animal behaviour. Phil Trans R Soc  
792 361(1465):5-22. <https://doi.org/10.1098/rstb.2005.1733>

793 Van Baaren R, Janssen L, Chartrand TL, Dijksterhuis A (2009) Where is the love? The social  
794 aspects of mimicry. *Phil Trans R Soc* 364(1528):2381-2389.  
795 <https://doi.org/10.1098/rstb.2009.0057>

796 Virányi Z, Topál J, Gácsi M, Miklósi Á, Csányi V (2004) Dogs respond appropriately to cues  
797 of humans' attentional focus. *Behavioural Process* 66(2):161-172.  
798 <https://doi.org/10.1016/j.beproc.2004.01.012>

799 Virányi Z, Topál J, Miklósi Á, Csányi V (2006) A nonverbal test of knowledge attribution: a  
800 comparative study on dogs and children. *Anim Cogn* 9(1):13- 26.  
801 <https://doi.org/10.1007/s10071-005-0257-z>

802 Wanser SH, MacDonald M, Udell MA (2021) Dog-human behavioral synchronization: family  
803 dogs synchronize their behavior with child family members. *Anim Cogn* 24:747-752.  
804 <https://doi.org/10.1007/s10071-020-01454-4>

805 Wheatley T, Kang O, Parkinson C, Looser CE (2012) From mind perception to mental  
806 connection: synchrony as a mechanism for social understanding. *Soc Personal Psychol*  
807 *Compass* 6(8):589-606. <https://doi.org/10.1111/j.1751-9004.2012.00450.x>

808 Wiltermuth SS, Heath C (2009) Synchronization and cooperation. *Psychol Sci* 20(1) :1-5.  
809 <https://doi.org/10.1111/j.1467-9280.2008.02253.x>

810 Wobber V, Hare B, Koler-Matznick J, Wrangham R, Tomasello M (2009). Breed differences  
811 in domestic dogs' (*Canis familiaris*) comprehension of human communicative signals.  
812 *Interact Stud* 10(2):206-224. <https://psycnet.apa.org/doi/10.1075/is.10.2.06wob>