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

3
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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

57

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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.

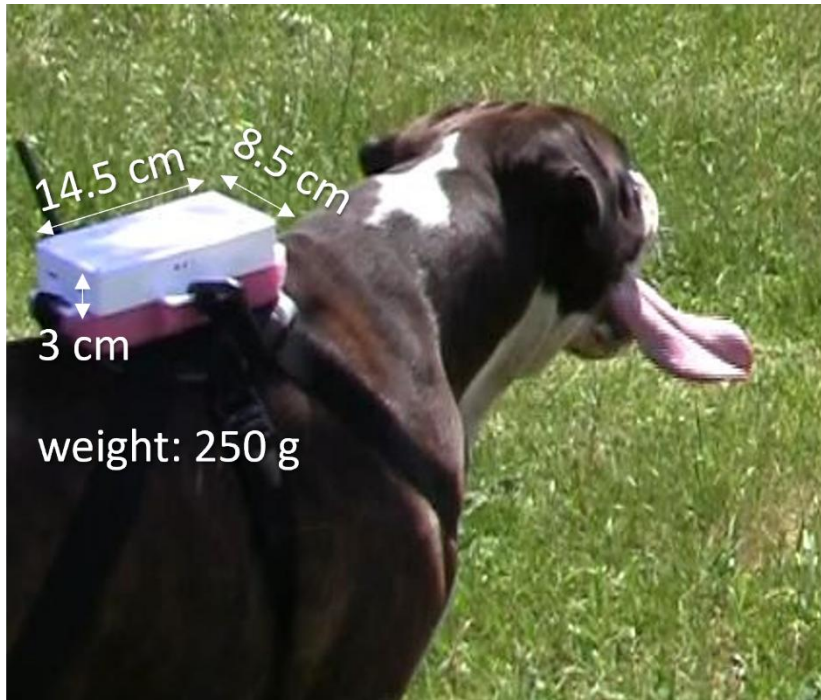
233

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 ± 1.65 years old; shepherd dog owners = 37.30 ± 2.44 years and molossoid owners =
261 37.87 ± 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 ± 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*

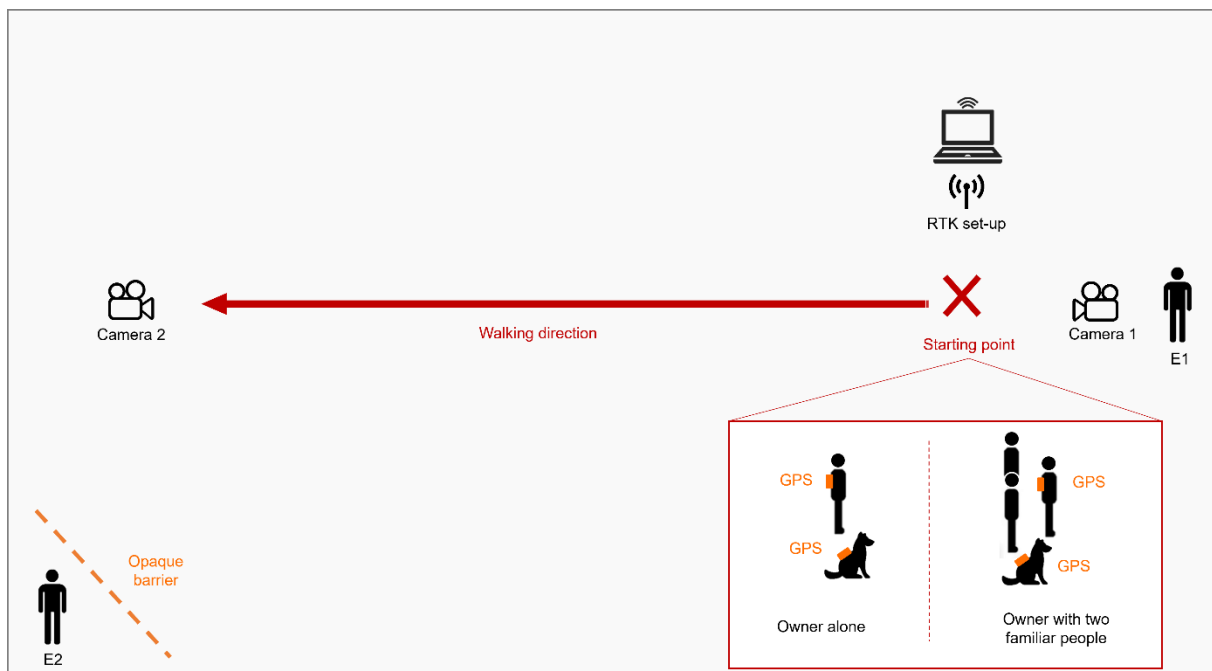
272 To collect data, we used the Real Time Kinematic (RTK) technology. It is based on
273 the use of a fixed station that sends real-time corrections to (Global Positioning System) GPS
274 devices to achieve centimetric precision. More precisely, the fixed station extracts the phase
275 of the carrier 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 600m², 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

	Dependent variable	Definition	Independent variables
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.	
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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 ± 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 ± 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.

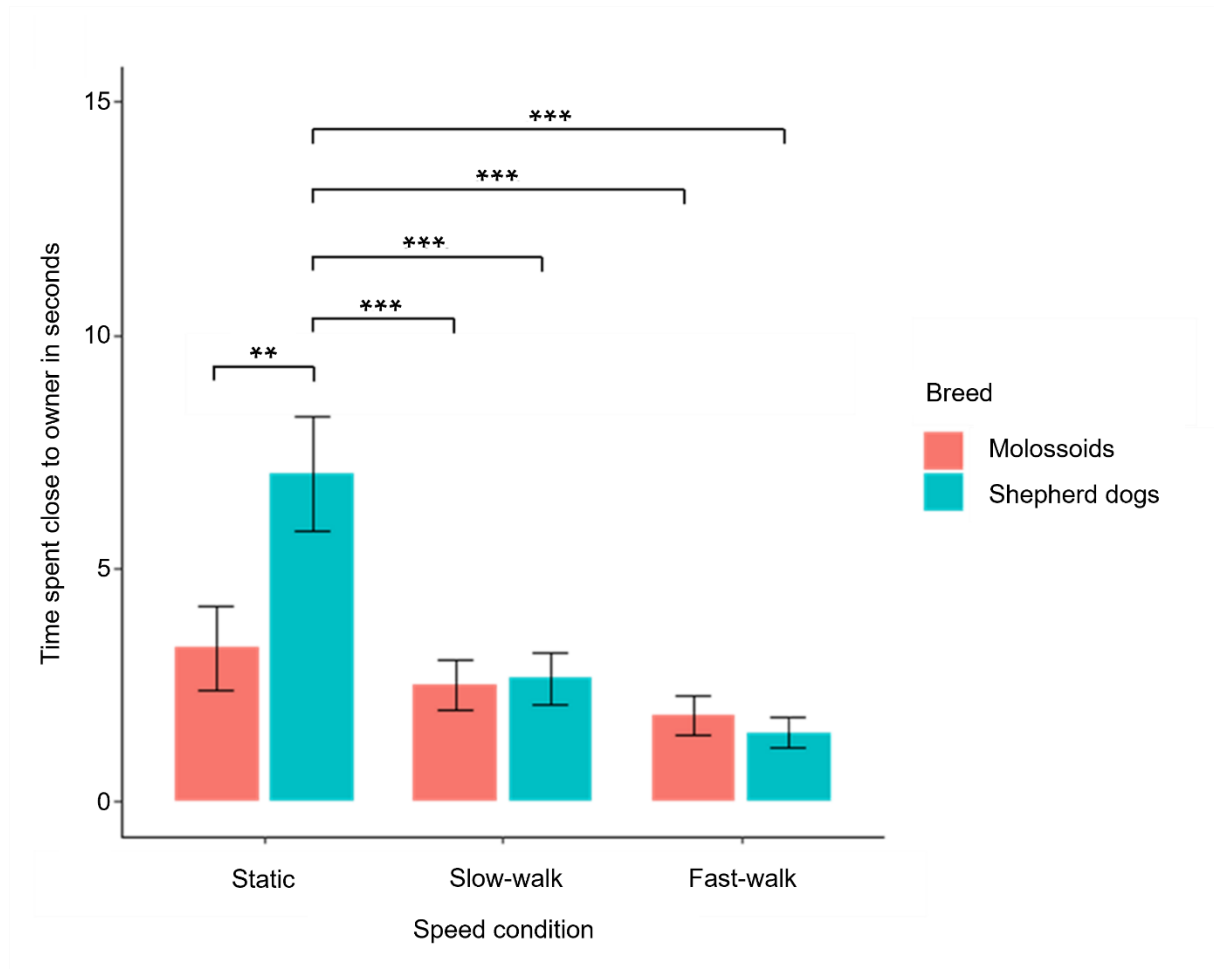
402

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 ± 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

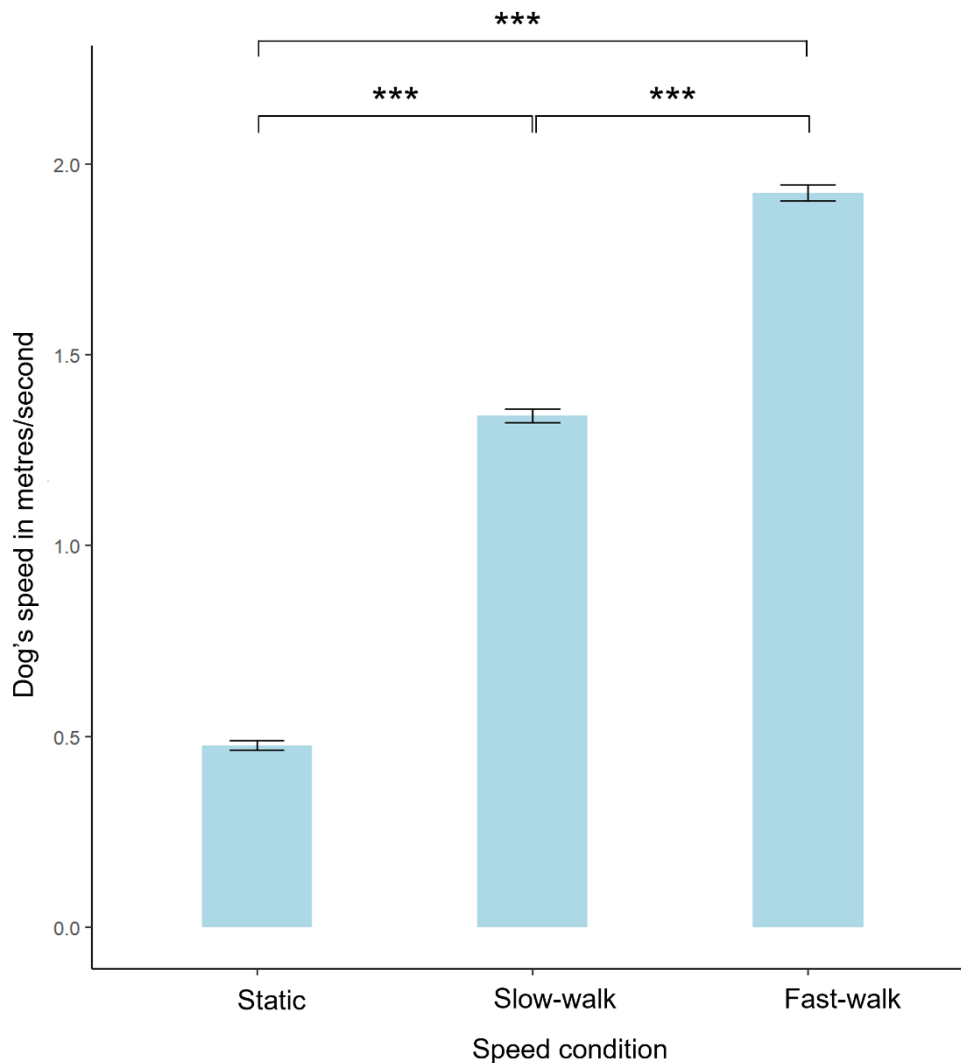
420 **Fig. 4** Time spent close to the owner as a function of the speed condition, for both breeds.
 421 Data are presented as mean \pm SEM. ** $0.001 < p < 0.01$; *** $p < 0.001$

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).



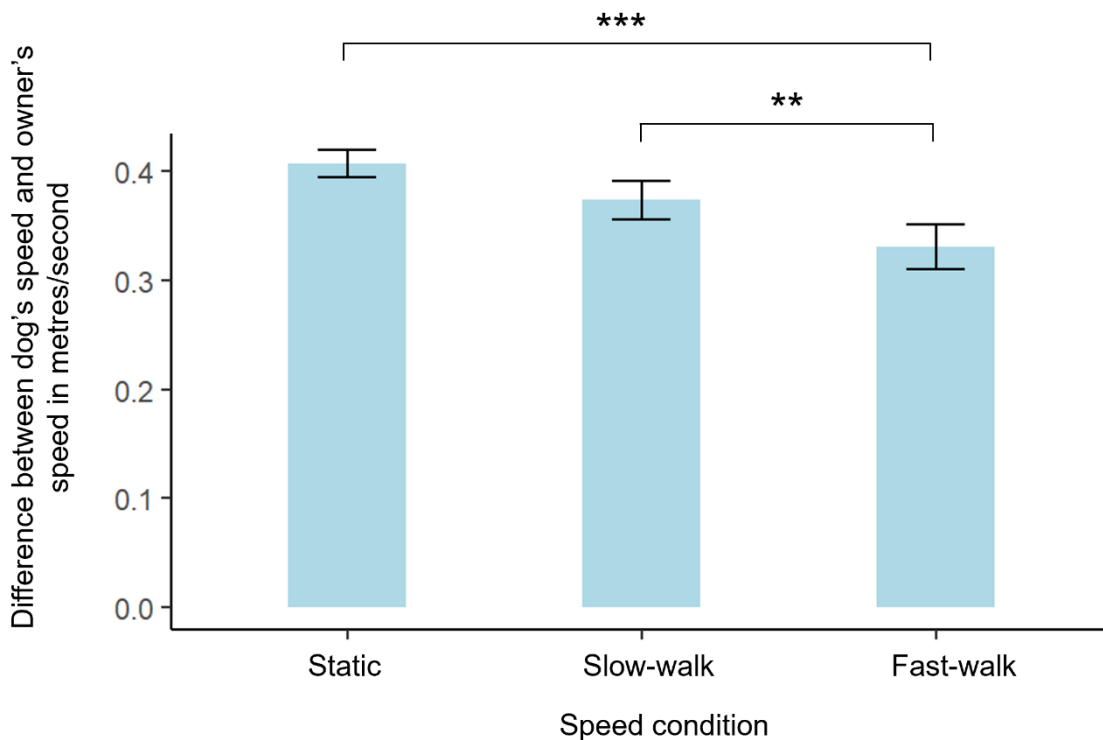
436

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 ± 2.78 m) than the owners (mean ± SEM = 39.15 ± 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*

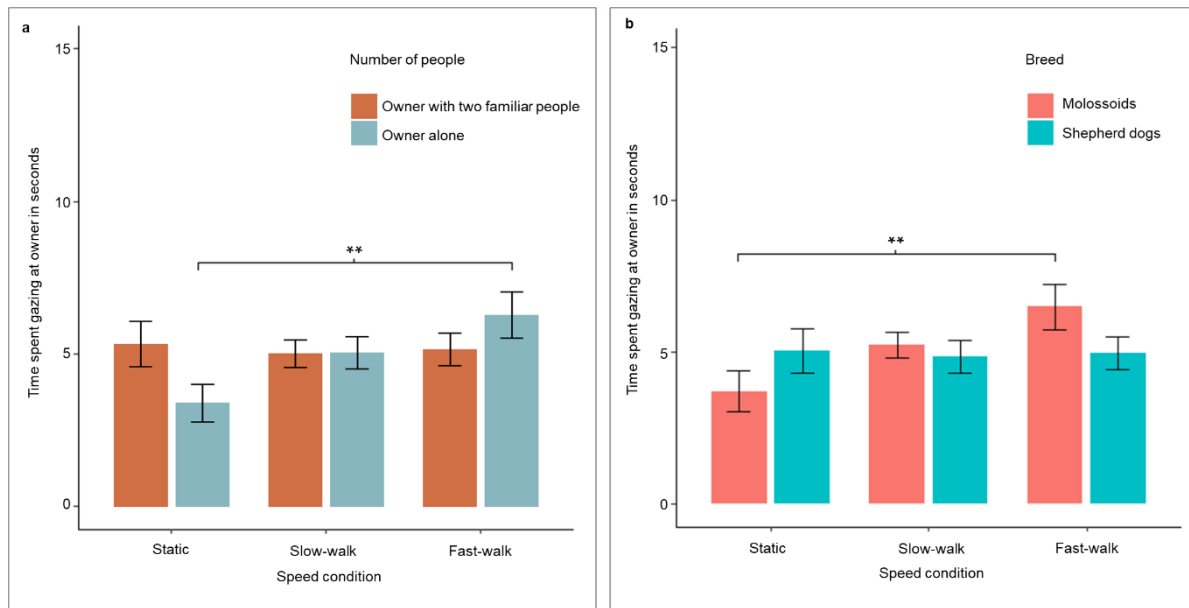
462 Forty-eight dogs changed their speed when the humans changed their speed, so 80% of
463 the dogs exhibited temporal adjustment during the change of speed condition. The change in
464 dog's speed was always in accordance with the owner's change of speed: dogs changed to a
465 faster gait for accelerating 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 ± 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 ± 0.12	$n = 30$ 1.84 ± 0.13

504

b	Static	Slow-walk	Fast-walk
Number of short gaze bouts	$n = 60$ 1.23 ± 0.13	$n = 60$ 1.82 ± 0.17	$n = 60$ 1.80 ± 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 hypothesize 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 ± 0.21 seconds) compared to Duranton et al. (2017a) (3.40 ± 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

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