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

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Abstract

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

Keywords: dog-human interactions, behaviour, interspecific synchronization, social referencing, dyads, groups

Statements and Declarations:

- **Competing interests**

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

- **Ethics approval**

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

- **Author contributions**

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

- **Data availability statement**

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

https://osf.io/bv7ts/?view_only=293c79a65c7b466a95cd64bbe8f48339

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Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Material and Method

Ethics

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

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

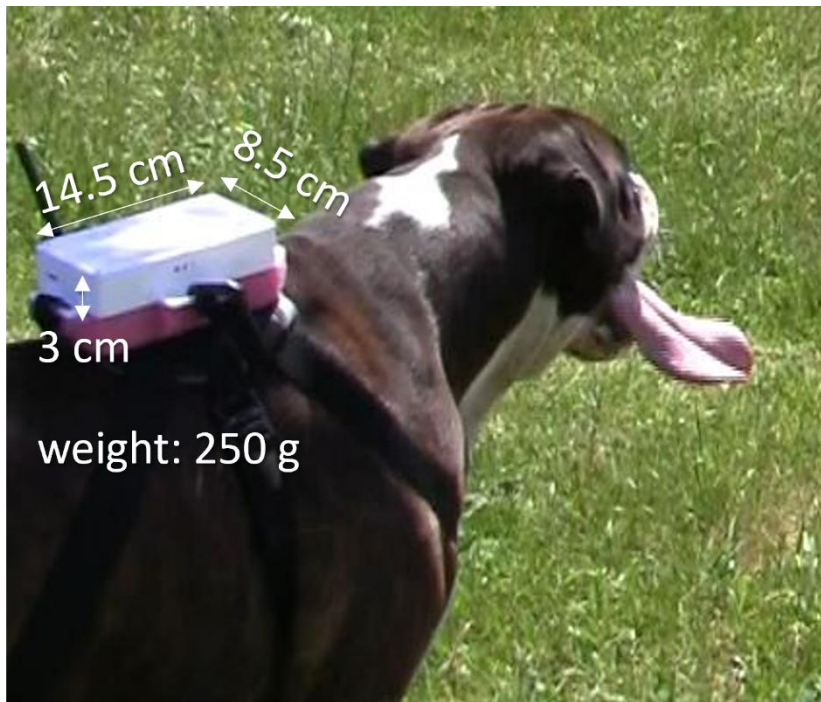


Fig. 1 Weight and size of the GPS device carried by the dog

Participants

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

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

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

RTK technology

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

Procedure

Two experimenters were present during the test (E1 and E2). The dogs were tested individually, off-leash, in an open area of 80m long and 70m wide, that is 5 600m², in Toulouse, France. The dogs and their owners were each equipped with a GPS device. The dog was then given 10 minutes to get used to the testing area while wearing a harness and roaming freely. During this time, E1 explained the experimental procedure to the human participants (the owner alone or the owner and two familiar people). Two cameras mounted on a tripod were used to record the dogs' behaviours during the tests (Fig. 2). E1 placed Camera 1 five metres behind the starting point of the test; E2 placed Camera 2 at the endpoint, 50 metres away from the starting point; then E2 waited until the dog was not attentive to her and then went to hide behind an opaque obstacle 50 metres away from Camera 2 (Fig. 2). While E2 was going to hide, the owner called the dog to prevent him/her from looking back at where E2 was going. The human participants were instructed to walk from the starting point to the endpoint. The human participants performed the three speed conditions (static, slow-walk, fast-walk) in a randomly assigned order for 15 seconds each without breaks. A web application (available at <https://intense-coast-72496.herokuapp.com/>) was created specifically for the experiment and was used as a timer for the human participants. The application prompted the human participants to change speed using an audible signal transmitted over headphones so as not to distract the dogs during the test. The application started with a 10-second countdown. During this preparation phase, the human participants stood facing the opposite direction from the test area and could communicate with the dogs. They were instructed to turn 180° when they heard the first beep at the end of the preparation phase to begin the first speed condition. Following this, a beep was produced every 15 seconds, indicating the start of the next speed condition. A final beep indicated the end of the trial which lasted a total of 45 seconds. Following the first beep and throughout the trial, the

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

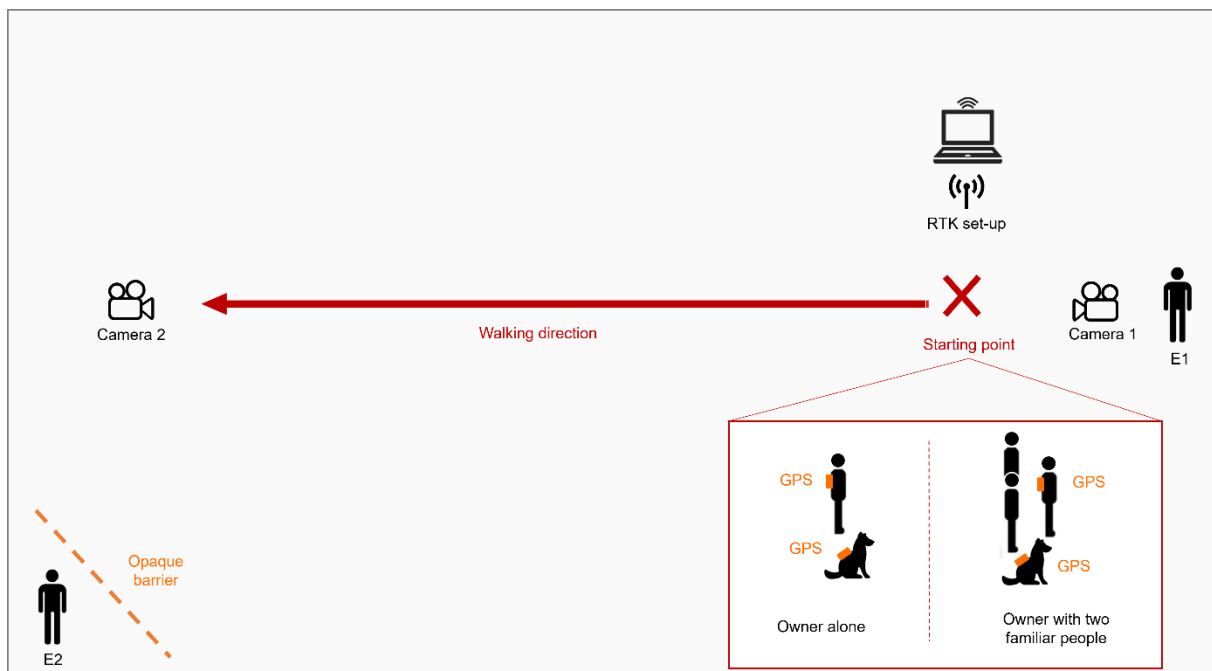


Fig. 2 Experimental set-up. During the preparation phase, the human participants were facing Camera 1. For dogs with their owner and two familiar people, the owner was then in front of the two familiar people. At the end of the preparation phase, the human participants turned 180° and started the first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



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

Data analysis

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

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

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

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

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

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

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

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

Results

Human participants' following of instructions

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

Location synchronization

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

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

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

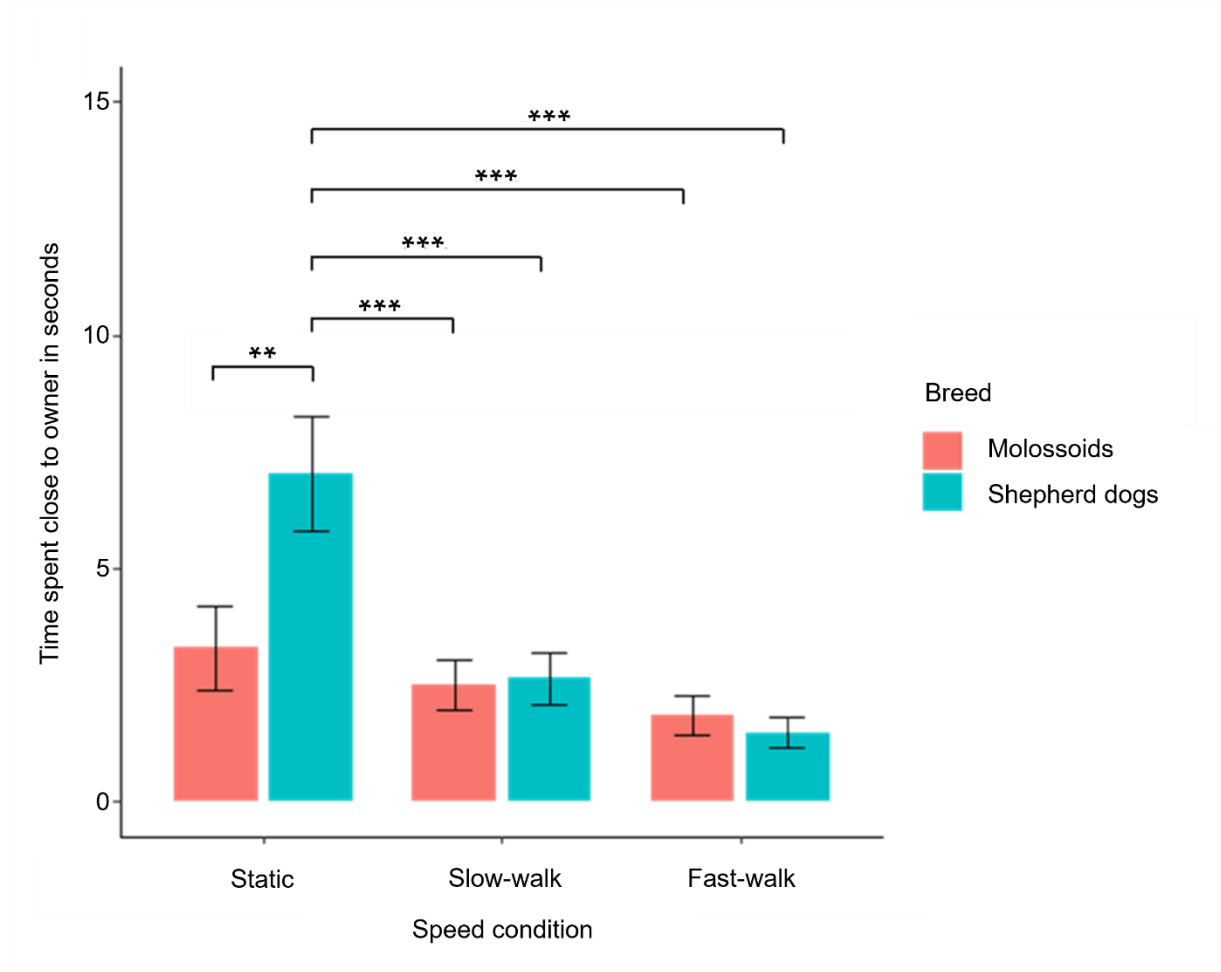


Fig. 4 Time spent close to the owner as a function of the speed condition, for both breeds. Data are presented as mean \pm SEM. ** $0.001 < p < 0.01$; *** $p < 0.001$

Activity synchronization

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

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

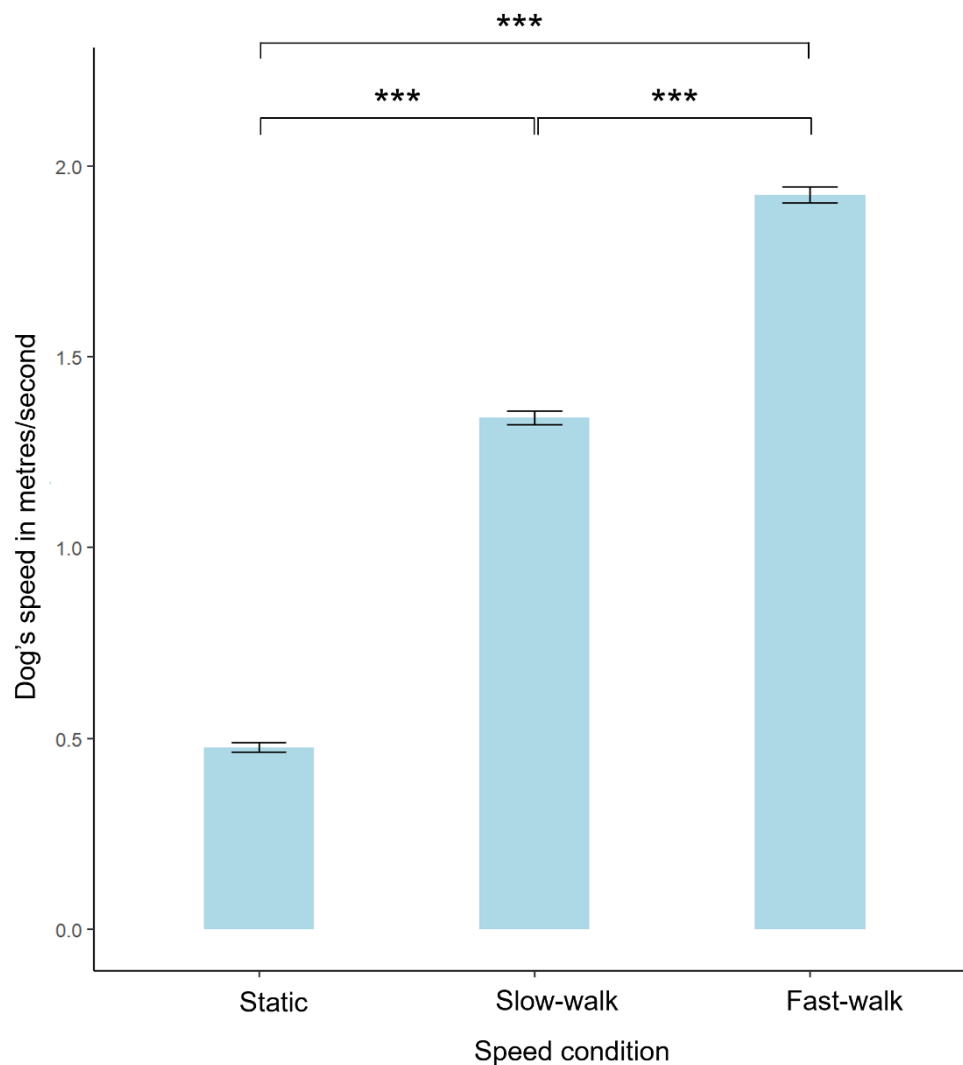


Fig. 5 Dog's speed as a function of the speed condition. Data are presented as mean ± SEM.

** $0.001 < p < 0.01$; *** $p < 0.001$

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

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

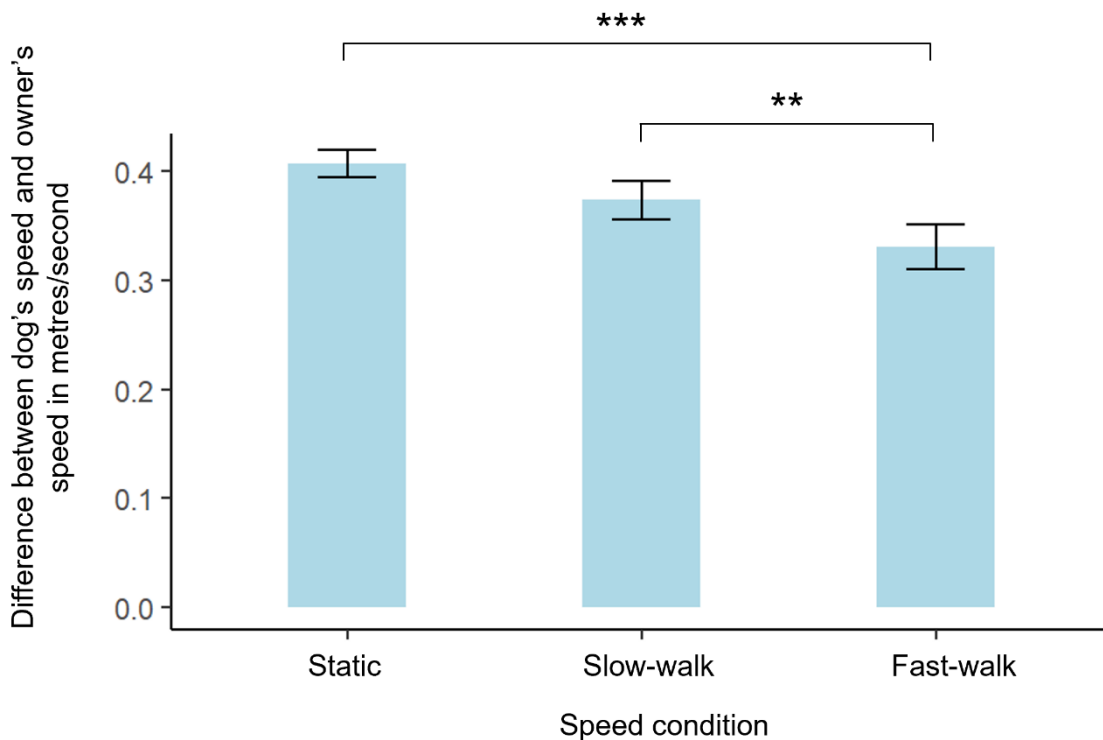


Fig. 6 Difference between the dog's speed and the owner's speed as a function of the speed condition. Data are presented as mean \pm SEM. ** $0.001 < p < 0.01$; *** $p < 0.001$

Temporal synchronization

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

Gazing activity

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

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

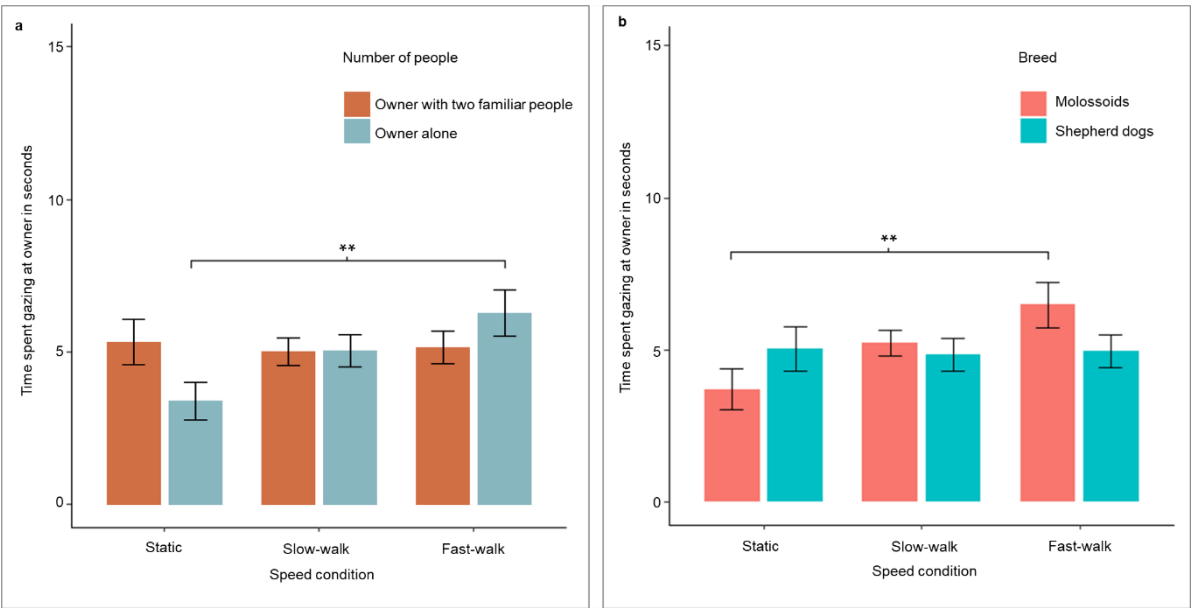


Fig. 7 Time spent gazing at the owner as a function of the speed condition, for both number of people (a) and for both breeds (b). Data are presented as mean \pm SEM. ** $0.001 < p < 0.01$

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

Conclusion

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

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

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, Ravignani 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-](https://doi.org/10.3758/s13420-017-0278-x)
 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>
 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>