A preliminary comparison between proximity and interaction-based methods to construct equine (*Equus caballus*) social networks

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Highlights

- Social networks based on proximity were similar to affiliative interaction networks
- Global Positioning System units enabled equine proximity networks to be constructed
- Utilising wearable technology proved a more cost-effective means of data collection
- It is unclear if considering activity level is useful for building social networks

Abstract

Evidence suggests that keeping horses in groups may be beneficial, as increased opportunities for social interaction have been linked to improved welfare and trainability. Considering social structure within these groups is also recommended, so attempts may be made to minimise inter-horse aggression and subsequent injury risk, thus encouraging more owners to adopt this management practice. Manual observation of dyadic interactions is often considered the most reliable way to determine group structure. However, alternative methods, such as the use of inter-individual proximity, may be more practical but first requires validation in the species of interest to ensure reliability.

Four interaction-based methods, which considered (1) ‘All observed’, (2) ‘Affiliative’, (3) ‘Allogrooming’ and (4) ‘Agonistic’ equine interactions, were used to construct social networks for three small domestic horse groups following 20hrs of observation. Horses also wore Global Positioning System (GPS) units, so distance between group members could be calculated every 10-minute, with this information used to create proximity networks for each group. Mantel tests were run in Socprog2.9 to determine if networks based on observed interactions are structurally similar to those based on inter-individual proximity. Accelerometers were also used to monitor horse activity, to investigate the effect that filtering proximity data by activity level has on its agreement with interaction-based methods.

Mantel tests identified that proximity networks were similar to networks based on affiliative interactions between horses, with positive but non-significant agreement seen in all three groups (‘Group A’: Z=0.85438, *n*=4, P=0.05; ‘Group B’: Z=0.61582, *n*=3, P=0.475; ‘Group C’: Z=0.88925, *n*=4, P=0.05) Proximity was not seen to be significantly associated with any other methods.

These findings suggest that GPS-derived proximity may be a viable alternative to manually collected data when affiliative interactions are of interest. Although, more work is warranted to establish how generalisable these results are in larger groups, and how variables, such as field size, group composition and resource provision, influence method agreement. Ultimately, this study has assessed agreement between existing social network techniques, whilst also considering the costs associated with each, the results of which are of use to inform both equine management and future studies.

Keywords: Accelerometery; Equine; Global Positioning Systems; Social network analysis

Introduction

Horses (*Equus caballus*) are highly gregarious, with social behaviours playing an important role within herds. Despite this, modern equine management limits opportunities for social contact due to the extensive use of single box housing (Ruet et al., 2019), regardless of the fact that this management style has been linked to increased stress (Visser, et al., 2008; Yarnell, et al., 2015) reactivity (Lesimple, et al., 2011) and increased stereotypies in horses (Normando, et al., 2011). This is largely due to concerns that group housing increases aggressive encounters and injury risk (Hartmann et al., 2015). Consequently, work to improve understanding of social structure within domestic horse groups may help to overcome this by enabling more informed companion selection and the identification of factors that increase the frequency of aggressive encounters. Monitoring group structure may also provide a novel method to assess both welfare (Boissy et al., 2007; Koene and Ipema, 2013), stress (Proudfoot & Habing, 2015), and better understand the influence of social status on parameters such as foraging efficacy and weight maintenance (Giles, et al., 2020).

Social network analysis (SNA) is a widely used technique to summarise social structure within a group (Davis, et al., 2018;). It typically involves either the manual observation and recording of all dyadic interactions that occur within the group (‘interaction-based’ approach) or monitoring spatial association between individuals within the group (‘proximity-based’ approach) (Croft, et al., 2008). Whilst interaction-based methods are widely considered to be the most reliable representation of true social structure (Whitehead, 2008), the practical application of this method is limited by the need to manually monitor the group, which may not be possible outside of daylight hours or for wide roaming species (Marchant-Forde, 2015). Consequently, proximity-based methods may be more readily applied to equid groups, particularly as data may be collected remotely, causing minimal disruption to the animals, with the addition of devices such as proximity collars (Boyland et al., 2013) or global positioning system (GPS) units (Hampson et al., 2010; Sato et al., 2017). As this method may be considered more convenient and is potentially less sensitive to observer influence and subjectivity, some may consider it a more practical substitute for interaction-based techniques. Whether or not these two methods can be used interchangeably continues to be a contentious topic amongst animal researchers (Castles et al., 2014; Davis et al., 2018; Farine et al., 2016). It appears that, whilst there may be potential for proximity to act as a valid proxy for social interactions, research is needed to assess under what conditions, and with which species, this is a reliable alternative (Farine, 2015b). Proximity may be a good predictor of interaction context in the horse as affiliative social equine behaviours, such as mutual grooming or resting together, require individuals to be close to one another for a prolonged period of time (Wolter, et al., 2018). In feral horse groups, some agreement between the frequency of mutual grooming and spatial proximity was reported (Wolter et al., 2018), suggesting that social networks constructed using these different methods may be comparable. However, it is unclear if the same would be seen within domestic groups, particularly as differences in the social behaviour and group spacing has been observed between horses kept under naturalistic and domestic conditions (Christensen, et al., 2002).

The identification of affiliative relationships within equine proximity networks may be enhanced if activity levels during dyadic interactions are considered (Farine, 2015; Muller, et al., 2018). This could be achieved with the application of wearable accelerometers (Bailey et al., 2018; Burla et al., 2014) and may help to determine if close proximity is due to a chance passing or a high intensity agonistic interaction, rather than a decision to remain stationary near another individual for an extended period of time (Farine, 2015).

The work of Castles et al. (2014) and Farine (2015) clearly highlights that work to compare different methods of social networks construction is warranted, particularly when these networks are focussed on domestically housed horse groups. Therefore, we addressed the following questions: (1) Are equine social networks based on inter-individual proximity comparable with those based on context-specific interactions? (2) Does filtering proximity data by activity level improve agreement with interaction-based networks? We also consider the reliability and associated cost of each method to fully realise their potential for real-life application.

Methodology

Animals and Housing

During May, June and July 2019, three independent groups of mature horses, referred to as ‘Group A’ (*n*=4; mean age 20±4.55[SD] years), ‘Group B’ (*n*=3; mean age17.67±7.09[SD] years) and ‘Group C’ (*n*=4; mean age 16±7.17[SD] years) were studied *(table 1).* All groups were considered stable, having been together for a minimum of three years, and at the time of the study were living out in their respective fields at either ‘Location 1’ (50°48'48"N, 0°57'35"W; Field size: 2325.66m^2) (‘Group A’ (during May/ early June) and ‘Group C’ (late June/ July)) or ‘Location 2’ (50°49'07"N, 0°58'59"W; Field size: 3108.25m^2) (‘Group B’ during May 2019) for 24 hrs per day, seven days per week. These fields were considered to contain adequate grass for all individuals without need for additional forage, with all horses receiving only one small concentrate feed in the evening around 19:00h. Some shelter was provided by a row of mixed-species trees that bordered the fields on the East and West side in ‘Location 1’ and the North side in ‘Location 2’. No additional resources were provided other than a water trough, which was a permanent fixture in each field.

Table 1 - Overview of sample population

Study I.D.	Group	Height (cm)	Breed	Age (yrs)	Sex
1	A	149.86	New Forest	25	M
2	A	137.16	New Forest X	14	G
3	A	139.70	Welsh Sec C X	20	M
4	A	157.48	TB X	21	M
5	B	139.70	New Forest	10	G
6	B	162.56	TB X	19	M
7	B	132.08	New Forest	24	G
8	C	142.24	New Forest	20	M
9	C	139.70	Appaloosa X	9	G

10	C	132.08	Connemara	24	M
11	C	144.78	Cob X	11	M

Observation protocol

On randomly assigned days during this time period, groups were observed for 2 hr periods, during which time all dyadic interactions, the time at which they occurred, and the individuals involved were recorded using a continuous behaviour sampling method, supported by a study specific ethogram (table 2). All observations were completed by one observer, who was familiar with equine behaviour and positioned a minimum of 2m outside of the field fence line. Prior to the study onset, this observer was tested for reliability against another also familiar with equine behaviour.

Horse observations (2hrs) took place in either the morning (between 9:00 and 13:00) or the afternoon (between 13:00 and 17:00) until a total of 20h had been collected for each group. Times were randomised to prevent any effects of diurnal rhythm. Horses were not ridden or removed from the field at any point on observation days.

Table 2 - Ethogram of equine interactions, adapted from Cozzi, et al. (2010); Jørgensen, et al. (2009); Jørgensen, Liestøl, and Bøe (2011); McDonnell and Poulin (2002) and Pierard et al. (2019).

	Interaction	Description
Affiliative Interactions	Allogrooming	Seen between two individuals, positioned with bodies laterally parallel to one another (usually head-to-shoulder or head-to-tail) to enable gentle nipping, nuzzling or rubbing each other's neck, mane, rump or tail. This action will be maintained for ≥10s
	Play	Play directed at one or multiple other individuals, which may or may not be reciprocated. Includes movements such as rapid biting, grasping and pulling at the others body, mane, tail or limbs, where body position is maintained for ≥10s. May also include a 'play fight' involving movements such as rearing, circling, kneeling and chasing. Play will be distinguished from true fighting by the fact that during play, individuals appear to alternate offensive and defensive roles, and stop short of injury.
	Head rest	One horse rests it's chin or entire head on the neck, body or rump of another individual. Maintained for longer than 10s.
	Groom-attempt	Two individuals position their bodies laterally parallel to one another (as described above, see '*Allogrooming*') and may also begin gentle nipping, nuzzling or rubbing each other's neck, mane, rump or tail, although this is not maintained for ≥10s.
	Follow	Moving immediately behind another horse (within three body-lengths) that had just initiated locomotion, for at least 10s without initiating physical contact.
	Approach	Moving towards another individual to be within two body-lengths of another horse that does not immediately move away and remaining there for at least 10 s without initiating physical contact.

	Touch	Contact made by one individual with any area on the body of another, does not provoke an observable response from the receiver. If an aggressive response from either individual is observed immediately following this action, 'touch' will instead be replaced by this agonistic interaction.
Agonistic Interactions	Bite	Opening and rapid closing of the jaws to make contact at any location on the body, head or limbs of another individual.
	Kick	One or both hind legs lift off the ground and rapidly extend backwards toward another horse, with apparent intent to make contact (which may or may not occur).
	Strike	With ears laid back, and one forelimb is moved outward to make contact, or in an apparent attempt to make contact, with the body or limbs of the other individual. Often accompanied by high pitched vocalisation.
	Push	Pressing of the head, neck, shoulder, chest or body against another horse, causing it to move, or reposition one or more limbs to retain balance.
	Threat to bite	Bite intention movement with ears back and neck extended, jaws are open but do not make physical contact with other individual.
	Threat to kick	Individual behaves as if they may kick, by swinging rump or backing up, and by raising or stamping a hind leg toward another individual, but they will stop short without extending a limb backwards.
	Chase	One horse pursuing another at a fast pace. The chaser typically pins the ears, lowers the head, exposes the teeth and bites at the rump and tail of the pursued horse.
	Displacement	Approach of one individual causes another/ multiple other individuals to move away so that inter-individual distance is maintained or increased, without physical contact being made (facial expression may convey aggression).
	Drive	Initially appears to be a displacement, but the initiator will continue to pursue the receiver at a fast-walk pace, often with head lowered towards the ground and ears back.
Neutral Interactions	Mutual Nasal Sniff	Two or more individuals engaged in simultaneous olfactory investigation of one another positioned with noses in close proximity.
	Body Sniff	One individual will perform an olfactory investigation of another individual, which may or may not be reciprocated. Using their nose to investigate any part of the body, limbs or head.

Monitoring Equipment

Prior to every observation period, a 'field safe' headcollar (Nylon headcollar with Velcro®, Rhinegold, UK) to horses with a Holux GPS unit (Holux RCV-3000, measuring: 6.3 x 4.1 x 1.8 cm, weight: 49.9 g) contained within a small 'Ziplock' bag attached with electrical tape to the ventral side (Sato et al., 2017) (*fig. 1*). GPS loggers were set to log and store position, in degrees of latitude and longitude, every 10 minutes. This sampling interval was used to ensure the independence of samples when calculating spatial proximity, as results from Wells and Feh (unpublished, quoted by Feh (1988)) found that horses show a mean latency of changing spatial distribution of group members every 8 min.

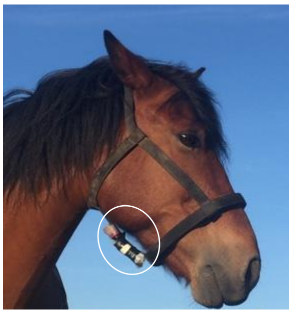

Figure 1- Global Positioning System (GPS) device contained within 'Ziplock' bag and attached to field-safe headcollar (Author's own, 2019)

For half the observation time (10/20hrs) horses wore fly rugs (Zebra Print Fly Combo Rug, Rhinegold, UK) with the neck removed to attach a non-commercial version of the Orscana sensor (Arioneo, Paris, France) measuring: 5.0x1.5cm, weight: 17g, housed within a 7 x 7cm nylon mesh pocket, located at the hollow area below the left hip *(fig. 2)* (Arioneo, 2019) containing an internal accelerometer and gyroscope set to log movement data every minute. To determine if wearing rugs containing an accelerometer influenced the frequency or type of interactions recorded, the total number of interactions initiated was calculated for each horse in both the 'Rug' and 'No Rug' condition and Wilcoxon Signed Rank tests were run to identify significant differences between them.

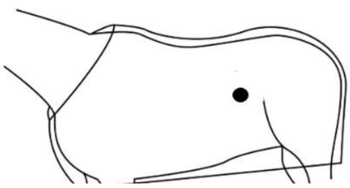

Figure 2 - Location of the Orscana sensor under horse rug (Arioneo, 2017).

All internal clocks were synchronised prior to data collection. Prior to each data collection period, 20 minutes habituation time for observer and equipment was allowed. At the end of each data collection period data were downloaded for subsequent analysis.

Equipment Tests

GPS device

Two Holux RCV-3000 GPS units were placed on the ground at a distance of 2m. The inter-device distance was increased at ten-minute intervals so that 2m, 5m, 10m and 15m were captured. Inter-device distances were calculated from the given degrees of latitude and longitude using a variation of Haversine's distance formula, where 'x' and 'y' represents longitude and latitude respectively for both 'device 1' and '2':

$$1.2742 \times 10^{7} ASin \sqrt{\sin\left(\frac{\left(y_2 \frac{\pi}{180}\right) - \left(y_1 \frac{\pi}{180}\right)}{2}\right)^2 + \left(\cos\left(y_2 \frac{\pi}{180}\right) \cos\left(y_1 \frac{\pi}{180}\right) \sin\left(\frac{x_2 \frac{\pi}{180} - x_1 \frac{\pi}{180}}{2}\right)\right)^2}$$

Average deviation from the true distance (reference measure) was 0.081± 0.783[SD]m, thus the devices were considered suitable for use as this is well within the range reported for models used in similar studies (Sato et al., 2017). This conclusion was further supported with the construction of a Bland-Altman plot where 78/80 data points (97.5%) fall within the calculated limits of agreement.

Accelerometer

To determine if the accelerometers differentiated between varying activity levels, and to identify values that constitute 'high activity' for use in later analysis, two horses were fitted with a sensor, and spent 10 minutes in each of the following conditions:

- **'Standing'**- horses stood tied up outside of their usual stables.
- **'Grazing'**- horses were loose in their usual field and observed so that ten minutes involving no interactions with conspecifics or extended periods of locomotion
- **'Walking'** – horses were led in hand on a grass surface in walk
- **'Trotting'**- horses were led in hand on a grass surface in trot

Differences in median accelerometry output between each condition were tested for statistical significance using Friedman Tests. This test identified significant differences (χ^2=30.00; DF=3; P<0.001) in the accelerometry output values between four activity conditions (Standing; Grazing; Walking; Trotting). Post-hoc Wilcoxon tests found that all four conditions were significantly different (W=0.00; DF=1; P=0.006), even when a Bonferroni correction factor was applied, reducing the critical P-value to 0.008, therefore the accelerometer could reliably differentiate between these activity levels.

Social Network Construction

Six social networks, four based on observation of specific interactions and two based on GPS-derived proximity, were created for each group, using the methods outlined in *table 3*. In methods 1-4 the strength of connection between dyads was calculated as a proportion of the total number of interactions observed for the whole group (Castles et al., 2014), as was the frequency of close proximity in methods 5 and 6, which was given as a percentage of the total number of GPS fixes.This allowed for the underlying structure of each network to be compared, even if the total number of associations sampled initially differed between methods.

Table 3- Methods of network construction

Method	Name	Type	Description & Edge Definition
1	All interactions	Observation of Interactions	Network will be constructed based on all dyadic interactions manually observed between individuals. ***Edge Definition:*** *frequency of interaction between individuals, given as a percentage of the total number of all interactions observed within the group.*
2	Affiliative interactions only	Observation of Interactions	Network will be constructed based on all affiliative (as defined in study ethogram) dyadic interactions manually observed between individuals. ***Edge Definition:*** *frequency of affiliative interaction between individuals, given as a percentage of the total number of all interactions observed within the group.*
3	Allogrooming Frequency	Observation of Interactions	Network will be constructed based on the number of dyadic allogrooming interactions (as defined in study ethogram) manually observed between individuals. *Edge Definition: frequency of allogrooming observed between individuals, given as a percentage of the total number of all allogrooming interactions observed within the group.*
4	Agonistic interactions only	Observation of Interactions	Network will be constructed based on all agonistic (as defined in study ethogram) dyadic interactions manually observed between individuals. ***Edge definition:*** *frequency of agonistic interaction between individuals, given as a percentage of the total number of all interactions observed within the group.*
5	5m proximity	GPS-derived Proximity	Based on GPS data sampling location every 10 minutes, with inter-individual distance calculated using Haversine's distance formula. All individuals positioned within 5m of each other at the time of each sample will be recorded. ***Edge Definition:*** *frequency that individuals are ≤5m from each other, given as a percentage of the total number of GPS samples logged.*
6	Low activity proximity	GPS-derived Proximity	As above (method 5) but only individuals that are positioned within 5m of each other and performing low levels of activity (accelerometery values ≤1000) at the time of interaction will be defined as associating. All incidence of close proximity that occur at higher activity levels will not be recorded or used to construct this network. ***Edge Definition:*** *frequency that individuals are ≤5m from each other whilst showing low levels of activity, given as a percentage of the total number of GPS samples logged.*

Statistical Analysis

Network Comparison

Mantel Z-tests were run with 1000 permutations in Socprog2.9 (compiled version) to compare association matrices derived using the different methods, providing a two-sided p-value and matrix correlation coefficient (Z) based on the correlation between non-diagonal elements of the test matrices (Whitehead, 2008). Proximity networks were first tested against 'all interaction' networks, before interactions was further categorised *(table 4)* to reflect either affiliative, agonistic or allogrooming interaction, and again tested against the original proximity network. The alpha value for this study was set at $P \leq 0.05$.

Table 4 - Classification of interactions by type

Affiliative	Play; Head rest; Groom attempt; Follow; Approach; Touch
Agonistic	Bite; Kick; Strike; Push; Threat to bite; Threat to kick; Chase; Displacement; Drive
Neutral	Mutual Nasal Sniff; Body Sniff
Allogrooming	Allogrooming

Incorporating Accelerometery

Once these results had been obtained, further work was undertaken to determine if filtering proximity data, so that only associations which occurred whilst horses were showing low levels of activity (defined as accelerometery values ≥1000) were used to construct a new proximity network, improved agreement with interaction-based methods. The equipment tests conducted to assess accelerometer suitability formed the basis for the choice of activity threshold (see S1). An output value of ≥1000 was considered to be a reasonable cut off point, as this was seen to remove all activities where accelerometery output equated to walking or higher-level activities. This would enable the GPS data to be filtered so that only incidence of close proximity that occur whilst both individuals are stationary would remain. As accelerometers and rugs were only worn for 10 hours (50% of total observation time), new networks were created, utilising the same methods described previously *(table 3)*, based only on days where this equipment was present. The proximity-based networks developed were tested against 'All Interaction', 'Affiliative Interaction', and 'Agonistic Interaction', again with Mantel tests in Socprog2.9.

Cost-benefit Analysis of Social Network Construction Methods

The initial cost *(£)* of all specialist equipment required to undertake the different methods of social network construction, and the time *(hrs)* required to achieve this, was calculated. This was based on the requirements of a single observer to collect and analyse 10hrs of data for a group of four horses in a 2325.66m^2 field.

Ethical Statement

The study and all procedures were approved by the Sparsholt Research Ethics and Standards Group prior to data collection.

Results

In total, 999 interactions were observed across the three horse groups (‘Group A’= 220; ‘Group B’=339; ‘Group C’=440), 497 of which were categorised as ‘affiliative’ (‘Group A’=116; ‘Group B’=173; ‘Group C’=208), 453 as ‘agonistic’ (‘Group A’=90; ‘Group B’=142; ‘Group C’=221), and 28 as an ‘allogrooming’ interaction (‘Group A’=11; ‘Group B’=6; ‘Group C’=11). Inter-observer reliability was tested using Fleiss Kappa and considered ‘Very good’, (κ=0.82888, Z=6.0165, P<0.001). Mantel tests compared proximity-based networks against networks constructed using ‘all interactions’ showing a positive relationship in each of the three groups (Group A: Z=0.88478, P=0.121; Group B: Z=0.72875, P=0.533; Group C: Z=0.69174, P=0.233) although all lacked significance. When the same proximity network was tested against only affiliative interactions, positive but non-significant associations were seen in ‘Group A’ (Z=0.85438, P=0.05), ‘Group B’ (Z=0.61582, P=0.475) and ‘Group C’ (Z=0.88925, P=0.05). Agreement between proximity and allogrooming networks was seen to differ between the groups, with positive but non-significant agreement seen in ‘Group B’ (Z=0.92447, P=0.324) and ‘Group C’ (Z=0.52606, P=0.573), and a non-significant negative association in ‘Group A’ (Z=-0.61721, P=0.216). Agonistic networks were positively associated with proximity in ‘Group A’ (Z=0.51863, P=0.466), ‘Group B’ (Z=0.33103, P=0.845) and had a negative relationship in ‘Group C’ (Z=-0.26442, P=0.612) although none of these reached significance.

Considering Activity Level

As only 50% of the data collected were used to create new activity networks, the relationship between proximity and the interaction-based methods differed from that previously reported. Allogrooming networks were not included as the low number of allogrooming events observed meant that there were insufficient data for network construction when half of the original data were excluded. When an 'activity filter' was applied to remove all associations that occurred when accelerometer values were ≥1000, only 3, 6 and 2 of the original associations were removed for 'Group A', 'Group B' and 'Group C' respectively, and consequently there was no changes in the agreement seen between proximity and any of the methods *(Table 5).*

Table 5 - Mantel test results when 'All interactions', 'Affiliative' and 'Agonistic' networks were compared with proximity both before and after an activity filter is applied.

		Original Proximity	**Proximity with 'activity filter' applied**
Group A (*n*=4)	All Interactions	0.08544 (P=0.680)	0.08544 (P=0.706)
	Affiliative Interactions	0.30935 (P=0.504)	0.30935 (P=0.423)
	Agonistic Interactions	-0.32640 (P=0.602)	-0.32640 (P=0.673)
Group B (*n*=3)	All Interactions	-0.18898 (P=0.793)	-0.18898 (P=0.808)
	Affiliative Interactions	-0.43637 (P=0.838)	-0.43637 (P=0.836)
	Agonistic Interactions	0.99795 (P=0.166)	0.99795 (P=0.168)
Group C (*n*=4)	All Interactions	0.66621 (P=0.227)	0.66621 (P=0.236)
	Affiliative Interactions	0.82125 (P=0.146)	0.82125 (P=0.119)
	Agonistic Interactions	-0.09611 (P=0.833)	-0.09611 (P=0.862)

Wilcoxon signed rank tests identified a significant difference in the occurrence of 'All interactions' (W=65.00; *n*=11; DF=1; P=0.005) and 'Agonistic Interactions' (W=50.00; *n*=11; DF=1; P=0.025) between 'No Rug' and 'Rug' conditions (see S2).

Cost-benefit Analysis of Methods

The financial and time costs associated with three different methods of data collection were recorded and displayed *(fig. 3 & 4)* to enable comparison between the three techniques. Researcher time (referred to as staffing costs in *fig. 4*) was priced at £10 per hour in accordance with other work of this nature.

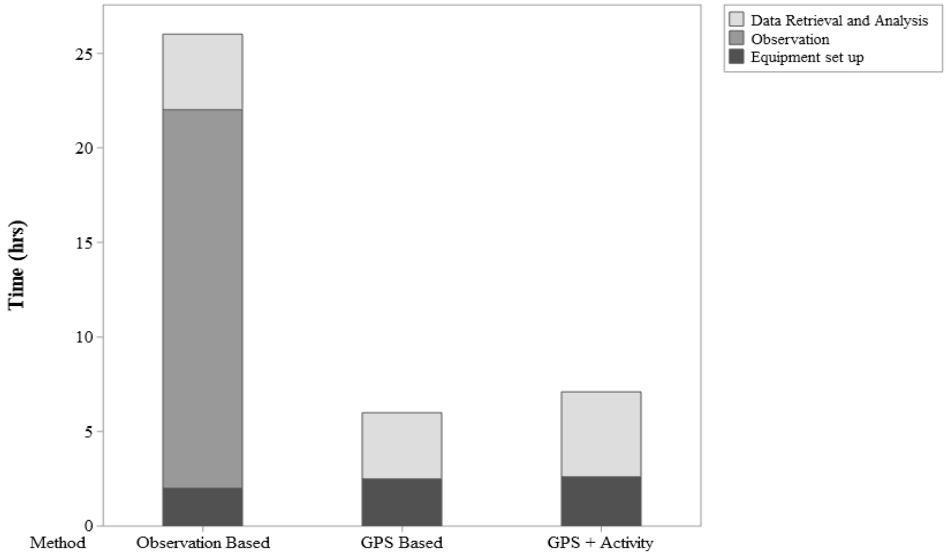

Figure 3 - Time required to collect 10hrs of data for a group of four horses using three different methods.

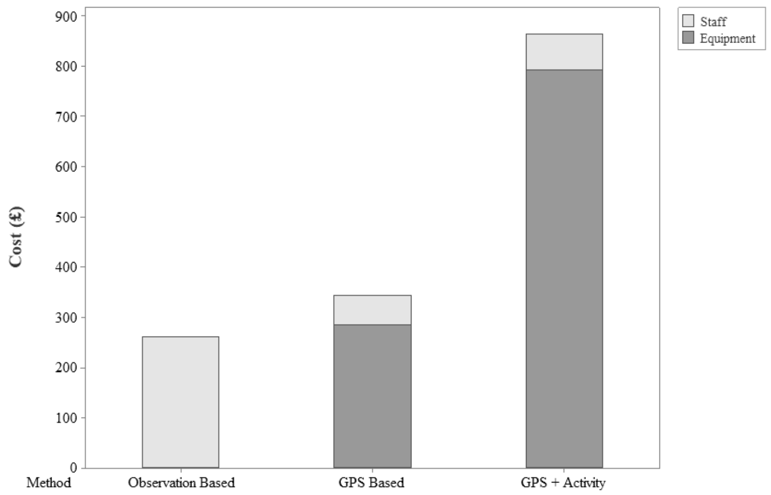

Figure 4 - Equipment and staffing costs (paid at a rate of £10/hour) required to collect and analyse 10hrs of data for a group of four horses in a 2325.66m^2 field, compared across three methods.

Table 6 - cost of equipment, shown for each specific item, required to collect 10hrs of data for a group of four horses using three different methods.

Method	Equipment	Cost (£)		
		Single unit	4x units	Total

Observation Based	No specialised equipment required	0	0	0
GPS Based	Headcollars (Rhinegold Field-safe headcollar)	6.95	27.8	283.8
	GPS Device (Holux RCV-3000)	64	256	
GPS + Activity	Fly Rugs (Rhinegold Zebra-print Combo)	35.95	143.8	791.6
	Headcollars (Rhinegold Field-safe headcollar)	6.95	27.8	
	GPS Device (Holux RCV-3000)	64	256	
	Accelerometer (Orscana sensor*)	91	364	

*note that the Orscana sensor used is not currently available to purchase, so this price has been estimated based on the cost of a commercially available earlier version.

Discussion

Agreement with Proximity Networks

This study assessed the viability of proximity as a proxy for interactions in small horse groups through Mantel test comparison of their resulting social networks.

All interactions

Agreement between ‘proximity’ and ‘all interaction’ networks was consistent across the three groups, with all demonstrating a positive, although not significant, relationship. This trend for positive agreement may be considered logical, as fundamentally individuals must be in close proximity for an interaction to occur (Croft et al., 2016). Although, this information alone does not give any indication of the relationship shared by these individuals, and could just as likely be the result of frequent agonistic interactions, as the existence of a positive social bond. The causal nature of these association is also unclear, as without further investigation it is not possible to determine if individuals are actively choosing to spend time near conspecifics whom they prefer interacting with, or if they are interacting more frequently simply because they are nearby. Whilst no artificial resources were provided, it was not possible to remove what may be referred to as ‘natural resources’ (shade, distribution of grass species, etc.) which may have somewhat biased space usage and, consequently, dyadic interaction frequency.

Overall, the relationship between proximity and ‘all interactions’ lacked significance, although it is worth noting that the small sample size may have reduced the likelihood of mantel tests returning significant results, particularly in ‘Group B’ where only three subjects were present, highlighting a need for more work to determine the extent to which this is likely to have an effect. However, the use of small groups in this study was intentional, as this was believed to most closely reflect how most modern domestic horses are housed.

Affiliative Interactions

Proximity was seen to agree most closely with affiliative networks. This would suggest that horses do exhibit a preference to spend time near individuals with whom they share more positive exchanges, thereby aligning with the results of Wolter et al. (2018), who suggest that this may evidence the existence of positive social bond between individuals. This supports the use of GPS derived data, not only in studies to map physical contact, but also in those that consider the nature of relationships within a group. Although, this conclusion was only reached based on results from two of the three groups in this study, so caution must be exercised when these methods are used interchangeably in groups of less than four horses, and that further work is conducted to determine the effect of group size and composition.

Allogrooming Interactions

A decision was made to construct separate allogrooming networks, rather than only considering these interactions within the affiliative network, as allogrooming is frequently used as a measure for social network construction in Equidae (Stanley et al., 2018), and there is some evidence to suggest that this may be particularly relevant for the analysis of social bonds alongside interindividual proximity in horses (Wolter et al., 2018). Networks based on close proximity were not seen to be significantly associated with networks based on allogrooming frequency. These findings are in contrast to those of Wolter et al. (2018) and Koene and Ipema (2013), although, this may be attributed to the fact that mare/ foal relationships existed in the latter study, or because both of these examples used ‘nearest neighbour’ as a measure of proximity measure, rather than the frequency that individuals were within a set distance as was used here. It is worth considering that Stanley et al. (2018) reported that incidence of mutual grooming was too infrequently observed in horses to allow reliable networks to be built at all times of the year. As allogrooming frequency is known to fluctuate between seasons, and altered by factors such as parasite load and coat growth (Wolter et al., 2018) this could in itself be considered an unreliable method for long term network construction. This, in addition to the fact that only low levels of allogrooming were observed in this study, could explain the differences seen between allogrooming and proximity network. Additionally, allogrooming relationships within the groups were observed to be asymmetric, with the same individuals always initiating allogrooming bouts. This was noted in a previous study of cattle, where allogrooming behaviour was not completely reciprocal (Val-Laillet, et al., 2009). These authors argue that the asymmetric nature of allogrooming relationships raises the question of whether affiliative bonds can be inferred from on undirected networks, whilst Dunbar and Shultz (2010) also theorise that allogrooming and spatial proximity might represent different aspects of bonding.

Agonistic Interactions

Agonistic interactions were found to be inconsistent in their relationship with proximity across the groups with none reaching significance. Additionally, there was no agreement between the affiliative and agonistic networks, thereby indicating that the two social behaviours followed different patterns within the groups. This aligns with previous studies in cattle (Foris et al., 2019; Val-Laillet et al., 2009) and horses (Pierard et al., 2019) where authors suggest that that separate analyses of the two interaction types may not provide a complete picture of group social structure.

Filtering by Activity Level

No change in method agreement with proximity was seen when this activity filter was applied. This result was largely attributed to the fact that horses in this sample rarely performed activity at levels above the pre-designated threshold, highlighting the difficulties in selecting a threshold that is appropriate for the sample group whilst also being sufficiently high to meet research aims. A limitation of the present study was that equipment tests only investigated the accelerometers ability to differentiate between simple equine gaits, but failed to account for other movements and social interactions that are of primary interest in this study. Consequently, it is recommended that further work investigates the inclusion of accelerometery in social network construction and interpretation, but is preceded by a more comprehensive study to first assess accelerometer ability to quantify equine activity. However, the use of an accelerometer at all in SNA may be questionable as setting a threshold would rule out all high activity interactions, included those that are ‘play based’, which may have wider implications for welfare in domestic individuals (Hausberger, et al., 2012). Furthermore, comparison between the 'rug' and 'no rug' conditions suggested that the presence of the accelerometer and fly rugs may have had some impact on group interactions. The Orscana device was chosen for use as it has been specifically designed and marketed for use in the target species, and thus its ability to withstand impact from the horses (e.g. whilst rolling) had been verified to some extent. Other devices that do not require a rug to be worn do exist, and may be preferable for use when social interactions are of interest, although further work to investigate their reliability and robustness when used on horses in the field, and determine their ideal placement for use in social network studies, would be beneficial (Thompson et al., 2017).

Cost/ benefit Analysis

Whilst a researcher's primary concern should ultimately be producing reliable results, it is inevitable that financial and time costs associated with different techniques are going to influence their choice of methodology. The ideal method would be quick, cheap and easy to use without limiting their ability to provide results that alight with the study aims (Holt and Elliott, 2002). The GPS units were straightforward to use and greatly reduced the time needed to collect data, whilst also appearing well tolerated by the sample horses. This technique has the added advantage of enabling data to be obtained remotely following device attachment, facilitating the collection of data outside of daylight hours, even when horses are out of sight, or where group behaviour may be altered by human presence. More data may also be collected over a longer time period, which is likely to increase confidence in the resulting network (Feczko et al., 2015; Henzi et al., 2009). Although, caution must be taken to ensure that this does not lead to networks becoming too dense, as several researchers report this may mean closer dyadic interactions are missed, thus making the network less representative in species, like horses (Stanley et al., 2018), who typically form close relationships (Castles et al., 2014; Farine, 2015; Faust, 2006).

Whilst the equipment required for 'GPS' and 'GPS & Activity' based methods did mean that total costs were considerably higher than the observation-based methods, it must be remembered that this equipment represents a 'one-time only' purchase, and as its use greatly decreased researcher time (and subsequent staffing costs), it would likely lead to lower costs in studies running for a greater length of time.

Despite these advantages, an obvious drawback of this GPS-based method is the inability for the directionality of interactions to be identified, which greatly limits the amount of information gathered via this technique (Pinter-Wollman et al., 2014). The use of directed ties would likely have been beneficial in the current study to provide a more comprehensive overview of the interactions taking place, and may have provided additional insight into why some methods do not agree, for example, if close proximity between a pair is due to relentless agonistic advances (apparent ‘bullying’) from one individual, rather than a mutual ‘decision’ to be near one another (Schino and Aureli, 2017).

Subjectivity in interaction classification

The categorisation of interactions as either ‘affiliative’, ‘agnostic’ or ‘neutral’ is likely to have been highly influential in this studies outcome (Fureix, et al., 2012), and whilst every effort was made to base this decision on empirical evidence, the subjectivity surrounding this warrants acknowledgement. An observation was made that when ‘displacement’ interactions were observed, the receiving horse would rarely move further than a few meters away, with many then returning a few minutes later to again be near the individual who initiated the interaction. Whilst this is a purely anecdotal observation, existing work reports that threats involving no physical contact were seen to represent more than 80% of total aggressive interactions within domestic groups (Jørgensen, et al., 2009), with displacement behaviours most commonly seen, and considered these necessary to maintain herd structure (Ladewig, 2018; Sigurjonsdottir, et al., 2012). This may suggest that some agonistic interactions are a ‘normal’ part of co-existing in a stable herd, the presence of which may not necessarily mean that the individuals involved have a more ‘negative’ relationship. Thus, the inclusion of these interactions in the agonistic network may limit its agreement with proximity. Additionally, Sigurjónsdóttir and Haraldsson (2019) chose to discount ‘kick’ and ‘threat to kick’ interactions, as VanDierendonck et al. (2009) argues that these may be defensive in nature, rather than having agonistic intent and, therefore, may provide an unrepresentative overview of agonistic relationships.

Selecting Distance Thresholds for Association

Association thresholds for Equidae within existing literature often equate to 'one horse body length' (approx. 1.5 m) (Kimura, 1998; Proops et al., 2012), or 'two body lengths' (Sigurjónsdóttir et al., 2003), with Jørgensen et al. (2009) observing that horses had their nearest neighbour within 2m for more than 60% of the time. More recently, work by Hildebrandt et al. (2021) suggests that, in large horse groups, 3m may be the most appropriate distance threshold. Consequently, the use of 5m thresholds in the present study may be considered slightly larger than is ideal for equine studies, however, results of a pilot study suggested that smaller distances may not be suitable for use with GPS-based sampling, as the location of GPS units on the head may mean the distance reported between animals is overestimated in relation to their physical distance, as demonstrated in *fig. 5*. This represents a potential limitation of the GPS-based methods if the use of smaller thresholds is desired. However, as the 'ideal' distance for use with domestic horses is currently unknown, the extent to which this poses an issue is not yet fully understood. A study that uses data manipulation to trial different thresholds in domestic horse herds, similar to that of Davis et al. (2018), could further elucidate the impact that changing this element has on the resulting social network, and its subsequent agreement with interaction rates.

Figure 5 - The distance between two horses given by GPS-units positioned on the head (yellow arrow) and their observed physical distance (blue arrow).

Conclusions

The main drivers of this study were the lack of knowledge surrounding group structure in domestically kept horse herds, and the inconsistencies reported in existing literature regarding the methods used to investigate this. Whilst the use of GPS-derived proximity has many practical benefits, and enables several of the limitations surrounding manual observation to be overcome, this study suggests that it may only be a viable alternative when the aim is to monitor affiliative interactions, although more work is recommended to further substantiate these conclusions, and investigate the wider impact of management factors on inter-method agreement. It should also be noted that, whilst the use of GPS-derived proximity is associated with lower staffing and time costs, this approach does require additional equipment to be purchased, although it may be possible to write off these initial costs over the duration of its use. It is worth considering that the use of GPS-derived data alone does not enable directed networks to be created, and could therefore be considered a less informative method, potentially making it inappropriate to meet some research aims. The ability to easily and reliably assess equine social structure is undoubtably of value, to promote and optimise management practices that better align with the ethology of this species, ultimately improving their health, welfare and potentially performance. This study should be considered a useful resource to guide future research, as it has acknowledged the cost and limitations surrounding available methods alongside their reliability, to fully realise their potential for real-life application.

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