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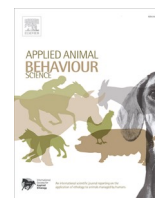
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# Lying in spatial proximity and active social behaviours capture different information when analysed at group level in indoor-housed pigs

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## ABSTRACT

Social preferences, and long-term social associations in the form of social bonds, are commonly assessed through observation of affiliative behaviour and spatial proximity between group members. The aim of this study was to investigate the relationship between active social behaviours and lying in proximity in indoor-housed pigs in order to evaluate their suitability as indicators of social preferences. Social behaviours were recorded by scan sampling over five weeks (75 scans per pig pre-weaning and 240 scans per pig post-weaning), and spatial proximity was recorded while pigs were lying (over six weeks;  $\geq 10$  observations per pig per week) with 23 groups pre-weaning and 12 groups post-weaning. At weaning, pigs were mixed with unfamiliar conspecifics, thus causing social instability, which was compared to the socially stable weeks pre-weaning and 3 weeks post-weaning. Behaviour and spatial proximity were statistically analysed at group level using mixed models, with as predictor variables observation week (age) and group size (8–15 pigs); and ambient temperature in the model for spatial proximity. Nose-to-nose contact (1.3% of scans), allogrooming (0.5%) and agonistic behaviour (1.4%) were observed infrequently, whereas 'other non-agonistic social behaviour' was observed in 8.2% of the scan samples. Nose-to-nose contact, agonistic behaviour and other non-agonistic social behaviour peaked in the week after regrouping (all  $p < 0.001$ ). Allogrooming increased from the 3rd week of life until around 1% (of scans); and occurred more frequently in larger groups ( $p = 0.03$ ). For spatial proximity, pigs were observed in 48.2% of the observations lying in full body contact, in 42.8% partly in body contact, and only in 9% of cases lying alone. They were lying in 57.8% of the cases head-to-head. Pigs were less frequently observed lying in full body contact and head-to-head at higher temperatures, while lying more in part body contact ( $p < 0.05$ ); and at 7 weeks of age they were lying more at distance from each other than when younger ( $p < 0.001$ ). Active social behaviours all significantly correlated with each other ( $r = 0.67$ – $0.84$ ) but did not correlate with lying in proximity or lying orientation. Various methods have been proposed by others to aggregate affiliative behaviour and spatial proximity into an index, but the biological relevance of this in indoor-housed pigs is questionable as active social behaviours and lying in proximity appear to capture different and uncorrelated information when analyzed at group level.

## 1. Introduction

Positive social relationships improve longevity, health and well-being in humans (Smith and Christakis, 2008; Yang et al., 2016; Holt-Lunstad, 2018; Johnson and Acabchuk, 2018) and animals (DeVries et al., 2007; Yee et al., 2008). Social relationships are referring to the content, pattern and quality of interactions between two individuals (Hinde, 1976). When social preferences, i.e., preferential associations,

are consistent over time they are referred to as social bonds (Silk et al., 2013). Social bonds can be defined as long lasting, mutual, affectionate and emotional attachment between two specific individuals and are characterized by affiliative behaviour directed towards each other (Newberry and Swanson, 2008). Social bonds have been shown in a wide range of non-human social animal species (Busia and Griggio, 2020), like primates (e.g. Silk et al., 2010) and domesticated species such as horses (Cameron et al., 2009), dogs (McCreery, 2000), and cattle

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(Val-Laillet et al., 2009). In farm animals, social preferences and social bonds have received only little research attention. In farming practices, social groups and relationships are commonly disrupted by standard management procedures such as early mother-offspring separation and regrouping, potentially breaking social bonds (Newberry and Swanson, 2008). A better understanding of social relationships, and the implications of disrupting social relationships for animal welfare, is needed.

Social preferences are usually studied through quantitative observations of nearest-neighbour proximity (based on spatial information) and affiliative interactions (based on specific behaviours), with allogrooming often recorded separately because of its profound contribution to bonding in some species (primates: Silk et al., 2006; cattle: Val-Laillet et al., 2009; horses: Wolter et al., 2018). These observations are sometimes aggregated in indices (Fischer et al., 2017). The Composite Sociability Index (CSI), for example, has been widely used as an indicator of the strength of social relationships in primates (Silk et al., 2006). Indices often combine multiple measures, e.g., spatial proximity and affiliative behaviour, into a single score (Cairns and Schwäger, 1987; Silk et al., 2013). The benefit of such aggregation is that a single value can be used in analyses to reflect sociality. The limitations of such indices are, among others, that measures compiled in composite indices are often weighed equally in the calculation whereas in practice they may not have equal biological meaning to the relationship quality (Silk et al., 2013). Moreover, if the individual measures do not or only weakly correlate with each other, then the biological relevance of a composite index becomes questionable (Wolter et al., 2018).

Pigs (*Sus scrofa*) appear to form preferential social associations (Durrell et al., 2004; Goumon et al., 2020), although these may not be long-lasting (Durrell et al., 2004; Newberry and Wood-Gush, 1986, but see Schrijver et al., 1998). Preferential associations in pigs have most often been assessed based on spatial proximity, but it has been suggested that the preferences based on proximity may be an artefact of preferred resting areas (Turner et al., 2003; Durrell et al., 2004). In addition, proximity in pigs is also influenced by ambient temperature (Spooler et al., 2012). Some studies have investigated affiliative behaviour in pigs, which may be expressed as social play (Horback, 2014), nose-to-nose contact (Petersen et al., 1990; Camerlink and Turner, 2013; Portele et al., 2019), and allogrooming (Meynhardt, 1982). The expression of social behaviour is not stable across the life time (e.g., play peaks from 2 to 6 weeks of age: Newberry et al., 1988; allogrooming increases at eight weeks of age: Meynhardt, 1982; Portele et al., 2019) and conditions (e.g., agonistic behaviour peaks when regrouping unfamiliar pigs: Verdon and Rault, 2017; Peden et al., 2018). Hence, these contextual effects should be taken into consideration when assessing preferential associations and the relationships between different social behaviours.

The aim of this study was to investigate the relationship between active social behaviours and lying in proximity in indoor-housed pigs over the first seven weeks of life, in order to assess their suitability as indicators of preferential social associations. We hypothesized that lying in proximity and active social behaviours would positively correlate with each other. We also investigated the impact of age, social stability and ambient temperature on those measures.

## 2. Materials and methods

All methods and animal use within this study were approved by the institutional ethics and animal welfare committee of the University of Veterinary Medicine, Vienna, Austria (ETK-04/01/2019), in accordance with the Good Scientific Practice guidelines and national legislation.

### 2.1. Animals and housing

Twenty-three litters (Large White) were studied at the pig research and teaching farm 'Medau' of the University of Veterinary Medicine, Vienna, Austria. Piglets were born to multiparous sows across two

farrowing batches (i.e., farrowing groups) that were five weeks apart. Up to weaning, sows and their piglets were housed in BeFree farrowing pens (Schauer Agrotrotron GmbH, Prambachkirchen, Austria) of 2.22 m × 2.86 m (sow movement area of 4.2 m<sup>2</sup>) with a plastic slatted floor and a concrete lying area. The temporary crating system was left open except during short-term piglet handling. Piglets had a covered and heated creep area of 1.25 m × 0.61 m, one drinker (ad libitum water) and received a commercial piglet feed (pre-starter meal) from seven days of age. Lights were on between 07:00 and 16:00 h and the temperature was automatically regulated to be 20 °C. The average litter size at birth was 14 ± 2 piglets (mean ± SD; range 11 – 18) and average birth weight was 1.56 ± 0.35 kg (range 0.72 – 2.59 kg). Cross-fostering was applied within the first 72 h post-partum in case the number of piglets exceeded the number of functional teats of the sow. Forty-one piglets (13 females, 28 males; approximately 14.4% of the animals studied) were fostered to other litters prior to the start of the study. Due to mortality and fostering, the average litter size at the onset of the study was 12.3 ± 0.95 piglets (mean ± SD; range 10 – 14). In total, before weaning, 285 piglets were studied (140 females, 145 males). Piglets had their teeth ground (day 0), iron administered and were weighed (d 0) and ear-tagged (day 19). Males were castrated (around day 14) as a routine farm practice under general anesthesia, consisting of an intravenous injection of Ketamine and Azaperone (100 mg and 16 mg per 10 kg body weight, respectively), and provided with analgesia with an intramuscular injection of Ketoprofen (33 mg).

At 4 weeks of age, piglets were weaned from the sow, relocated to a different room within the farm, and regrouped (i.e., social mixing) with male and female piglets of different litters. Piglets were relocated in litter pairs (88% of the pigs were moved in pairs and the remaining were alone or in a triad due to variation in litter size and sex balance). New groups were composed of 4–7 litter pairs (average 5.4 ± 0.9 (SD)) while balancing for sex, and balancing the average body weight of the groups so that it was similar within batch. This resulted in 12 groups (across two batches) of in total 130 pigs after weaning. Group size differed due to variation in the number of litters and litter size per batch and due to production practices at the farm, and averaged 10.8 ± 1.91 pigs (mean ± SD; range 8 – 15). Pigs were housed in pens of 3.1 × 4.7 m (14.5 m<sup>2</sup>), giving a space allowance of 1.0 – 1.5 m<sup>2</sup> per ~10 kg pig. Pens had a concrete partly-slatted floor and included a covered, heated creep area of 1.0 × 3.0 m, in which straw or wood shavings were provided as bedding material, and one hanging wood piece (~7 × 7 × 25 cm) per pen as enrichment material. Pens had a multi-space feeder with ad libitum commercial pig meal and four drinkers. Air temperature was regulated through fans and a wall curtain on each side of the room. Ambient temperature, pre- and post-weaning, was on average 22.3 ± 1.53 °C (mean ± SD, min: 21.1, max: 25.0).

### 2.2. Behavioural observations

Pre-weaning, piglets were identified using coloured strips of Kinesiology tape (SensiPlast®; cut at 5 × 3 cm) placed 1 cm from the base of the tail, as well with back number made with a marker pen (MS Schippers, MS Marking Stick, blue). Post-weaning, pigs were marked with animal marker spray (MS Schippers, MS EasySpray, blue) on their back at least 30 min before the start of the observations.

Behaviours were recorded using an ethogram (Table 1), noting the actor and recipient of the behaviour. The focus was on the behaviours nose-to-nose contact, allogrooming and agonistic behaviour, and therefore other non-agonistic social behaviours were grouped together during observation. Behavioural observations were performed using the Animal Behaviour Pro App, version 1.2 (University of Kent, Canterbury, UK), installed on iPads. Live behavioural observations were conducted pre-weaning once a week (days 4 (week 1), 11 (week 2), and 19 (week 3) postpartum (based on Portele et al., 2019), and post-weaning after social regrouping (day 27) on three consecutive days (days 28, 29 and 30; week 4), and three weeks post-weaning (day 47; week 7), a time by

**Table 1**  
Ethogram for social behaviours in pigs.

Behaviour	Description
Nose-to-nose contact	Pig's nose disc or snout makes physical contact with snout or nose disc of another.
Allogrooming	Pig gently nibbles or licks the head (including snout, ear, and eye region, eye lashes) or body of another pig without causing visible skin damage to the recipient.
Other non-agonistic social behaviour	Pig is nosing the head or body of another pig; is engaged in social play; or is jointly exploring whereby their heads are in < 30 cm proximity whilst engaged in an activity <sup>a</sup> .
Agonistic behaviour	Pig is engaged in fighting, biting, head knocking, threat or play fight (alternates displays of play and agonistic elements, without causing injury to the partner).
Other	All other behaviours.

<sup>a</sup> Close proximity during exploration was based on Goumon et al. (2020) but with the distance adjusted to the age of the pigs (Goumon et al. applied 100 cm for 6–7 months old pigs).

which social stability is expected (Stookey and Gonyou, 1994). Observations were carried out for 5 h per day between 10:30 – 12:30 h and 13:00 – 16:00 h using scan sampling, which aimed to target the active hours of the day (pigs were observed regardless of activity). The order in which pens were observed was rotated between observation blocks. Pre-weaning, instantaneous scan sampling was used, taking 2 min per litter and recording all piglets' behaviour. With six sows allocated per batch per observer, there were 5 scans per piglet per hour, resulting in 25 scan samples per pig per day (in total 75 scan samples per pig pre-weaning). Post-weaning, 5-min instantaneous scan sampling per four groups was used, as the pens allowed easier observation of the pigs, resulting in 60 scan samples per pig per day (in total 240 scan samples per pig post-weaning). Observations were simultaneously conducted by two trained observers who rotated between the pens. Inter-observer reliability was calculated from a 30-min. video recording with BORIS (Friard and Gamba, 2016) using Cohen's Kappa, with a time interval of 5 s (average  $K=0.755$ ).

### 2.3. Nearest neighbour proximity

Spatial proximity was recorded by noting the identity of the nearest neighbour when pigs were lying down (either inactive or sleeping), for at least 10 observations per pig per week for weeks 1 – 5 and week 7 of life (during lactation, weaning, and 1 and 3 weeks after weaning) using the Animal Behaviour Pro App with the ad libitum scoring option. The pen walls were marked at 50 cm intervals to estimate the distance between the pigs. Proximity was recorded at random times between 08:00 and 16:00 h when at least half of the pigs were lying down, with at least 30 min between observations or when the pigs had changed location. Each neighbour was recorded, resulting in multiple neighbours being recorded when, for example, a pig was sleeping in body contact with three others (this was then counted as one observation). If a piglet could not be identified due to piglets lying on top of each other then this piglet was scored at a later moment, or the observer waited until the piglets moved. In addition to the identity of the neighbour, it was noted whether pigs were lying in full body contact, part body contact or at distance to each other (Table 2), and if they were lying in a head-to-head orientation with their nearest neighbor or not. Due to low occurrences of lying at > 0.5 m distance (2%) and at > 1 m (1%) the recordings for lying at distance (including nearest neighbour < 0.5 m) were grouped together as 'at distance' for the analyses.

### 2.4. Data analysis

Observations of each behaviour were summed per group per week and expressed as percentage of total observations per group (i.e., pen). Data were analysed in SAS version 9.4 (SAS Institute, Inc. Cary NC,

**Table 2**  
Ethogram of spatial proximity and orientation towards the nearest neighbour.

Proximity	Description
Full body contact <sup>a</sup>	Lying with a minimum of 75% of body against neighbour
Part body contact <sup>a</sup>	Lying with 25 – 74% body against neighbour
Nearest neighbour < 0.5 m <sup>a</sup>	Lying with < 24% body against neighbour or within 0.5 m of neighbour
Nearest neighbour > 0.5 m	Lying > 0.5 m but < 1 m from neighbour
Nearest neighbour > 1 m	Lying > 1 m from neighbour

<sup>a</sup> Recorded whether individuals were lying head-to-head or head-to-tail.

USA). Behaviour and spatial proximity were analysed per group as response variables in mixed models (MIXED procedure, using a Variance Components covariance structure) with as predictor variables: observation week and group size (covariate). The model for spatial proximity in addition included ambient temperature (covariate). The interaction between group size and ambient temperature was initially included in the model but omitted as it had  $p$ -values > 0.10. Group nested within batch was included as random variable, with group specified as subject to account for repeated observations. Models were assessed for assumptions of a normal distribution of the model residuals and homogeneity of variance. Consequently, the models with nose-to-nose contact and allogrooming were fitted with separate residual variances to account for heterogeneity of variances. The expression of behaviour can relate to body weight and the sex of the individual, e.g. males and heavier piglets may play more (Brown et al., 2015). At group level, we found no significant relationships between behaviour and average group body weight or sex (analysed as percentage of males per group) and therefore these variables were not included in the models. Values are LSmeans with standard errors (SE) unless stated otherwise.

Pearson correlations between the variables were conducted at group (i.e., pen) level (23 groups pre-weaning and 12 groups post weaning). Data were averaged by group to avoid dependence between observations (Bakdash and Marusich, 2017). Data were inspected for their normal distribution, homogeneity and outliers; and the proportion of observations of nose-to-nose contact, allogrooming and agonistic behaviour were arcsine square root transformed and consequently met a normal distribution.

Effects were considered significant at  $p$ -values < 0.05, whereas  $p$ -values > 0.05 but < 0.10 are mentioned as tendencies.

## 3. Results

### 3.1. Active social behaviours

Nose-to-nose contact, allogrooming and other non-agonistic social behaviour (social nosing, social play and joint exploration) were observed on average 1.3%, 0.5% and 8.2% of the scan observations, respectively (Table 3). Agonistic behaviour was observed in 1.4% of the observations. The rest of the observations consisted of other behaviours, mainly lying or sleeping. Nose-to-nose contact, other non-agonistic social behaviour and agonistic behaviour peaked in week 4 (i.e., after mixing) (Table 3). Allogrooming increased from the third week of life (Table 3). A larger group size related to a greater percentage of allogrooming ( $b = 0.06 \pm 0.027\%$  per additional pig;  $F_{1,52} = 4.73$ ;  $p = 0.03$ ) and to a non-significant tendency for reduced agonistic interactions ( $b = -0.19 \pm 0.1028\%$  per additional pig;  $F_{1,52} = 3.33$ ;  $p = 0.07$ ). Group size did not affect nose-to-nose contact ( $p = 0.30$ ) or other non-agonistic social behaviour ( $p = 0.87$ ).

### 3.2. Spatial proximity

In total, 8103 observations on lying in spatial proximity were made (on average  $87 \pm 33$  (SD) observations per group per week). Pigs were

**Table 3**

The average percentage of behavioural scans (LSmeans  $\pm$  SEM) when nose-to-nose contact, allogrooming, other non-agonistic social behaviour (social nosing, social play and joint exploration) and agonistic behaviour were observed, by week of age ( $n = 23$  groups in weeks 1–3 and 12 groups in weeks 4 and 7).

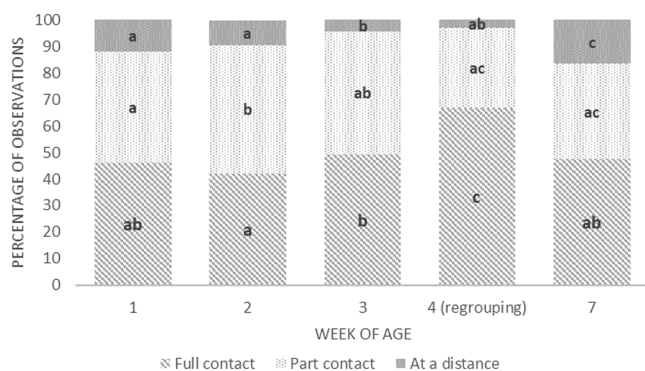
Behaviour	Week 1	Week 2	Week 3	Week 4 (mixing)	Week 7	<i>p</i> -value
Nose-to-nose contact	0.6 $\pm$ 0.09 <sup>a</sup>	1.0 $\pm$ 0.16 <sup>b</sup>	1.1 $\pm$ 0.22 <sup>bc</sup>	3.2 $\pm$ 0.45 <sup>d</sup>	1.7 $\pm$ 0.30 <sup>b</sup>	<
Allogrooming	0.1 $\pm$ 0.04 <sup>a</sup>	0.1 $\pm$ 0.08 <sup>a</sup>	0.4 $\pm$ 0.09 <sup>b</sup>	1.0 $\pm$ 0.15 <sup>c</sup>	1.3 $\pm$ 0.12 <sup>c</sup>	<
Other non-agonistic social behaviour	4.6 $\pm$ 0.71 <sup>a</sup>	8.3 $\pm$ 0.68 <sup>b</sup>	7.7 $\pm$ 0.68 <sup>bc</sup>	16.1 $\pm$ 0.98 <sup>d</sup>	7.2 $\pm$ 0.97 <sup>b</sup>	<
Agonistic behaviour	0.5 $\pm$ 0.27 <sup>a</sup>	0.5 $\pm$ 0.26 <sup>a</sup>	0.3 $\pm$ 0.25 <sup>a</sup>	8.2 $\pm$ 0.37 <sup>b</sup>	0.0 $\pm$ 0.37 <sup>a</sup>	<

ab Categories with letters without common superscript differ by  $p < 0.01$ .

lying mostly in full body contact (48.2% of the observations) or in part body contact (42.8%), whereas pigs were lying at a distance away from other pigs in only 9.0% of the observations (7%  $\leq 0.5$  m and 2%  $> 0.5$  m away). Pigs were lying head-to-head in 57.8% of lying events in proximity of another pig. Between the weeks there was a difference in lying in full body contact ( $p = 0.04$ ) or at distance ( $p < 0.001$ ) and a tendency for a difference of lying in part body contact ( $p = 0.09$ ) (Fig. 1). However, lying head-to-head did not differ between the weeks (59%, 53%, 55%, 71% and 65% in week 1, 2, 3, 4 and 7, respectively;  $p = 0.27$ ). Larger groups tended to lie more head-to-head ( $b = 2.20 \pm 1.11\%$  per additional pig;  $F_{1,45} = 3.94$ ;  $p = 0.053$ ). Group size was, under the group size and space allowance range in this study, unrelated to lying in full body contact ( $p = 0.76$ ), part body contact ( $p = 0.64$ ), or lying at a distance ( $p = 0.14$ ). Temperature was, across batches, highest in week 4 (25.0 °C), whereas for the other weeks it averaged around 21.1 (weeks 1 and 2), 21.7 (week 3) and 22.3 °C (week 7). An increase in ambient temperature strongly reduced the percentage of lying in full body contact ( $b = -8.21 \pm 2.09\%$  per °C;  $F_{1,45} = 15.39$ ;  $p < 0.001$ ), and instead pigs were lying more in part body contact ( $b = 7.21 \pm 1.77\%$  per °C;  $F_{1,45} = 16.56$ ;  $p < 0.001$ ). An increase in ambient temperature reduced lying head-to-head ( $b = -4.91 \pm 1.77\%$  per °C;  $F_{1,45} = 7.75$ ;  $p = 0.008$ ), but did not affect lying at a distance under the variation observed in this study ( $p = 0.42$ ).

### 3.3. Correlation between behaviours

Social behaviours positively and moderately to strongly correlated



**Fig. 1.** The average percentage of observations (spatial proximity scans,  $n = 8103$ ; LS-means) lying in full body contact, part body contact, or at distance from each other, by week of age ( $n = 23$  groups in weeks 1–3 and 12 groups in weeks 4 and 7). <sup>ab</sup> Weeks with letters without common superscript differ between weeks by  $p < 0.05$ .

with each other, but were largely unrelated to lying in spatial proximity and lying orientation (Table 4).

## 4. Discussion

The occurrence of social behaviours varied across age and differed with group size and before vs. after social mixing. Lying in proximity remained relatively prevalent across age and group size, but was influenced by ambient temperature. Active social behaviours and lying in proximity did not correlate with each other. Based on these results, we discuss the value of these measures for assessing preferential social associations in pigs.

### 4.1. Active social behaviours

Social behaviours in general were relatively infrequent in the first week of life, when piglets commonly spent the majority of their time suckling the dam and sleeping (Jensen et al., 1995). Nose-to-nose contact and allogrooming were infrequently observed when using scan sampling. Although continuous sampling is more suitable to observe short-lived behaviours such as allogrooming (Bateson and Martin, 2007), scan sampling has the advantage of allowing to observe more subjects and observe them more frequently, and has been applied in similar studies (e.g., Schweinfurth et al., 2017). With continuous sampling, we (Portele et al., 2019) previously recorded piglet-to-sow nose contact on average once every minute. Comparable research on the social behaviour of pigs using continuous sampling showed a similar prevalence (Goumon et al., 2020), which suggests that nose contacts occur relatively frequently. In our previous work, data from continuous observations and scan sampling provided similar results for such behaviours (Camerlink et al., 2021), although frequencies under both observation methods were low. In hindsight, given the amount of inactive behaviour in the piglets, continuous sampling would have been preferred. Low occurrences would nevertheless result in missing values, and this hamper calculations for dyadic interactions. For example, the Simple Ratio Index (SRI, Cairns and Schwäger, 1987), in which the frequency at which individuals are observed together is divided by the total observations for these animals, would result in very low values; whereas indices (e.g., CSI; Silk et al., 2013) in which the rate of observations for the dyad are divided by the average rate for the group would result in high values for any interaction as the population average would include many zeroes due to non-occurring dyadic associations. In primates, affiliative behaviours are relatively frequent long lasting sequences and therefore sufficient data can usually be obtained (Cords, 1997). For pigs, however, different social behaviours would either need to be combined to give sufficient data points for dyadic relationships, or require continuous sampling for an extended period of time (e.g., 2 h per day for 18 days as applied in Goumon et al., 2020). However, the accuracy of all-occurrence sampling as used by Goumon et al. (2020) in groups of individuals is challenging per se and usually requires focal individual sampling, thereby dramatically multiplying observation time by the number of individuals. Alternatively, observations can benefit from progress in novel technologies for the automated detection of social behaviour combined with individual recognition (e.g. Psota et al., 2020).

The low frequency for nose-to-nose contact may also be due to the difference in the current study when only direct physical contacts between the snouts was scored and not when noses were in close proximity (as in Camerlink and Turner, 2013). Allogrooming increased with age, which is in line with literature on wild boars, in which it becomes more prominent from eight weeks of age (Meynhardt, 1982). Allogrooming was more frequently observed in larger groups, possibly because there are more individuals to interact with. The behaviour only showed marginal changes after social mixing. Allogrooming in pigs is understudied but it has been suggested to function for removal of ectoparasites (Meynhardt, 1982), and can induce relaxation (Hansen and von Borell,

**Table 4**

Pearson correlation coefficients ( $r$ ) between social behaviours and spatial proximity, based on data expressed at group level (averaged across the weeks pre-weaning and post weaning). The behavioural category 'other non-agonistic social behaviour' includes social nosing, social play and joint exploration.

	Allogrooming	Other non-agonistic social behaviour	Agonistic	Full contact	Part contact	Head-to-head
Nose-to-nose contact <sup>a</sup>	0.84 <sup>***</sup>	0.79 <sup>***</sup>	0.67 <sup>***</sup>	0.12	-0.20	0.10
Allogrooming <sup>a</sup>		0.72 <sup>***</sup>	0.67 <sup>***</sup>	0.01	-0.07	0.07
Other non-agonistic social behaviour			0.78 <sup>***</sup>	0.05	-0.16	0.08
Agonistic <sup>a</sup>				0.04	-0.16	0.01

\*  $p < 0.05$ ,

\*\*  $p < 0.01$ ,

\*\*\*  $p < 0.001$ .

<sup>a</sup> Transformed with arcsine square root to obtain a normal distribution.

1999). Allogrooming in primates strongly relates to social hierarchy, social tension and the maintenance of social bonds (Dunbar, 1991; Schino, 2001; Wittig et al., 2008).

Agonistic behaviour hardly occurred, with the exception of the expected peak after social mixing (Peden et al., 2018). We do place a caveat that, in the week after social mixing, observations were conducted for three consecutive days in order to capture the variation in behaviour during this highly dynamic event (e.g., Parratt et al., 2006), vs. observations once a week during the other weeks, and may thus affect the interpretation of the results. Agonistic behaviour tended to occur less in larger groups, which is in line with previous work (Turner et al., 2001). Other non-agonistic social behaviours were more frequent and also increased after social mixing, which suggests that new social relationships after mixing can be established both through agonistic and non-agonistic social interactions.

#### 4.2. Lying in spatial proximity

Pigs were lying most of the time in full or part body contact to one another; more frequently so than in a study with 30–100 kg pigs (Ekkel et al., 2003: 20–40% of the time observed lying in contact at 1 m<sup>2</sup> per pig space allowance). Indeed, at seven weeks of age pigs were lying less in full body contact. Newborn piglets have very little brown fat, and hypothermia is a main cause of neonatal mortality (Villanueva-García et al., 2020). Huddling and lying together for thermoregulation is therefore an evolutionary adaptive behaviour for early-life survival, which becomes less important when they get older. Pigs were also lying less in body contact, and lying less head-to-head, at higher ambient temperatures, whereby the highest temperature in this study was recorded in week 4. Ambient temperature is known to influence lying behaviour of pigs (Spoolder et al., 2012). Hence, when recording spatial proximity, ambient temperature should be taken into consideration. Nonetheless, despite variation in ambient temperature, pigs lie the majority of the time still in full or part body contact, demonstrating a strong motivation in pigs to lie together.

Pigs preferred lying head-to-head, which implies a degree of social tolerance (Fichtel et al., 2018), which is uncommon in unacquainted (Camerlink et al., 2014) or subordinate pigs (McCort and Graves, 1982). However, lying head-to-head remained prevalent across the weeks and was thus not influenced by social instability. Social mixing did not influence any of the spatial proximity measures in the current study, in contrast to findings on 8-week old pigs where unacquainted pigs kept larger spatial distances from each other (Camerlink et al., 2014).

Larger groups tended to lie more head-to-head but group size was unrelated to spatial proximity. A larger group size reduces the space per individual, although the stocking density in this study was low relative to common farming conditions (1–1.5 m<sup>2</sup> per animal). Space allowance may alter social and spacing behaviour (e.g., proximity in sheep: Sibbald et al., 2000; social interactions in pigs: Weng et al., 1998; Rault, 2016). As there were two different pens (pre- and post-weaning phase), group size and space allowance varied between groups and were partly confounded factors, but we decided to account for group size as a

biologically more relevant parameter than space allowance for social interactions.

Some studies determined social preferences solely on observations of spatial proximity (in wild boar: Podgórski et al., 2014; in pigs: Durrell et al., 2004), which may be a less specific indicator of social preference than affiliative interactions (horses: Wolter et al., 2018). Whether spatial proximity alone can distinguish between social and spatial preferences (e.g., preferences for lying locations) has been questioned (pigs: Durrell et al., 2004; cattle: Gygas et al., 2010). Prior studies found no evidence of consistent spatial preferences in indoor-housed pigs (McCort and Graves, 1982; Turner et al., 2003), but pigs with outdoor access (where they have more space) showed non-random social preferences in lying behaviour (Goumon et al., 2020).

#### 4.3. Lack of relationship between active social behaviours and lying in proximity

Nose-to-nose contact and allogrooming, which can have an affiliative function (Meynhardt, 1982; Petersen et al., 1990; Camerlink and Turner, 2013; Portele et al., 2019), did not correlate with lying in proximity. Goumon et al. (2020) also found no significant correlation between social nosing (nose-to-nose contact and nose-to-body contact) and spatial proximity in pigs, but found a very weak correlation ( $r = 0.157$ ) between resting in proximity and exploring in proximity. Our measure of other non-agonistic social behaviour includes Goumon's measure of exploring in proximity, but in our study other non-agonistic social behaviour showed no correlation with spatial proximity. Hence, it seems that there is no relationship between active social behaviours and lying in proximity, at least in indoor-housed farm pigs. It should be noted that we analysed the links between behaviour at group level and this may have blurred possible correlations between behaviours at individual level or between specific individuals. This finding of a lack of correlation between active social behaviours and spatial proximity is especially relevant to farm animals due to the space constraints in which they are often kept, whereby the physical space to prefer one individual over another, or to avoid another, is limited (Gygas et al., 2010). In primate studies in (semi)natural environments a closer proximity relates to more socio-positive interactions (Silk et al., 2013), but not all studies find such correlations. Johnson et al. (2014), for example, found that spatial proximity may be less indicative of social bonds in female geladas (*Theropithecus gelada*) as compared to other Old World monkey species. In horses, Wolter et al. (2018) tested different types of social indicators and found a strong correspondence between mutual grooming and friendly approaching, but not between mutual grooming and spatial proximity.

The lack of correlation does not necessarily imply that one measure relates to social preferences whereas the other measure does not, but instead may reflect different dimensions of sociality (Goodson, 2013; Pearce et al., 2017), such as proactive sociality (Wolter et al., 2018) or social rank (Newton-Fisher and Lee, 2011). A similar issue exists in personality research, where the behaviours in different tests do not necessarily correlate, and the measures may rather reflect different

aspects (Carter et al., 2013). However, because factors such as group size, ambient temperature and social stability may have affected social behaviours and lying in proximity, possibly each to different degrees, we cannot ascertain that these are indeed different dimensions or aspects of sociality. This hypothesis of dissociating different dimensions of sociality is an interesting hypothesis to test in further research, as shown in humans (Pearce et al., 2017), in order to elucidate the complexity of social life. It would be worthwhile to test the correlation between affiliative behaviour and spatial proximity in pigs housed in conditions where restrictive space plays a lesser role, such as in free-ranging pigs.

Agonistic behaviour showed a positive correlation with other social behaviours, which has also been found in grazing dairy cattle (Machado et al., 2020). The balance between agonistic behaviour (or hostility) and affiliative behaviour has sometimes been used to describe relationship quality (Weaver and de Waal, 2002) and tenor ('the relative frequency of affiliative and hostile behaviours within a dyad', Silk et al., 2006, 2013). For groups with limited space availability or resources, and thus greater risks for conflict, the inclusion of such measures can provide meaningful information on hostility, tolerance and potential reconciliation (Cords and Aureli, 2000).

Affiliative behaviour, allogrooming and proximity seem to be reliable measurements of social relationships in many primate species because of their positive correlation (Cords, 1997). The current study shows a lack of correlation between these measures for indoor-housed pigs, when analysed at group level, and this has implications for the assessment of social preferences, as we therefore argue that these behaviours should be considered separately rather than combined into an index.

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## Conflict of interest

The authors declare to have no conflict of interest.

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