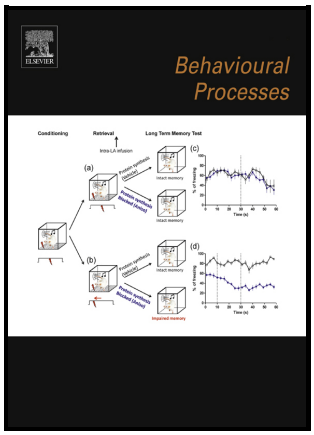
Play Fighting Versus Real Fighting In Piglets (Sus scrofa): Similar Patterns, Different Structure

Journal Pre-proof



Play Fighting Versus Real Fighting In Piglets (*Sus scrofa*): Similar Patterns, Different Structure

Giada Cordoni, Edoardo Collarini, Marika Gioia, Ivan Norscia

PII: S0376-6357(22)00195-4

DOI: https://doi.org/10.1016/j.beproc.2022.104778

Reference: BEPROC104778

To appear in: *Behavioural Processes*

Received date: 20 July 2022
Revised date: 9 November 2022
Accepted date: 10 November 2022

Please cite this article as: Giada Cordoni, Edoardo Collarini, Marika Gioia and Ivan Norscia, Play Fighting Versus Real Fighting In Piglets (*Sus scrofa*): Similar Patterns, Different Structure, *Behavioural Processes,* (2022) doi:https://doi.org/10.1016/j.beproc.2022.104778

PLAY FIGHTING VERSUS REAL FIGHTING IN PIGLETS (*Sus scrofa*): SIMILAR PATTERNS, DIFFERENT STRUCTURE

Giada Cordoni[a], Edoardo Collarini[a], Marika Gioia[a], Ivan Norscia[a]

[a] Department of Life Sciences and Systems Biology, University of Torino, Via Accademia Albertina 13, 10123 Torino (Italy)

* Giada Cordoni e Edoardo Collarini share the first author

Corresponding authors: giada.cordoni@unito.it; ivan.norscia@unito.it

Ivan Norscia ORCID: 0000-0002-1618-7717

Giada Cordoni ORCID: 0000-0001-7093-0025

Edoardo Collarini ORCID: 0000-0003-0789-4089

Declarations of interests: none

Abstract

When animals engage in 'non-serious' fighting (play-fighting) they 'borrow' motor patterns especially from the aggressive context. It may be difficult to distinguish play- and real-fighting. This is particularly true for piglets (*Sus scrofa*), which can use play-fighting as a substitute for aggression. To check for the structural differences between play- and real-fighting in piglets, we: i) video recorded 496 interactions from three litters (at Parva-Domus extensive ethical farm; Turin, Italy); ii) extracted (by video analyses) duration, patterns, and data on involved individuals; iii) calculated session structural/ecological indices; and iv) compared the indices (play- vs real-fighting). Compared to real-fighting – play-fighting was longer (informing its rewarding nature), more symmetrical (lower asymmetry index) and variable (higher Shannon index). Moreover, play-fighting showed less pattern repetition (lower Repetition Index) and was not more polyadic and evenly distributed (comparable polyadic and Pielou indices). By being longer, and more variable and symmetrical than real-fighting, play-fighting could serve some of its functions such as motor training, social assessment and training for the unexpected. However, play-fighting in piglets did not comply with all the expected play features, possibly because play is a fluid behavioural system that under certain circumstances may escalate into or replace aggression.

Key Words:

Play, aggression, domestic pig, asymmetry index, Shannon variability index, Pielou evenness index

1. Introduction

Play - including social play - is a behaviour that can serve different functions depending on the species, the social dynamics, the context, the hierarchical relations, and the individual characteristics of the players (e.g. sex, age, rank, body size; Fagen, 1981; Burghardt, 2005; Pellis, Pellis, & Bell, 2010; Norscia & Palagi, 2011; Palagi, 2011). Play can enhance cognitive, physical and social skills and it can increase the ability of individuals to flexibly adjust their behavioural responses when they face unpredictable situations (Špinka, Newberry, & Bekoff, 2001; Pellis & Pellis, 2009; Burghardt, 2010; Trezza, Baarendse, & Vanderschuren, 2010; Vanderschuren, Achterberg, & Trezza, 2016).

Play involves and reorganizes motor patterns that are typical of other behavioural systems (Pellis, Pellis, Pelletier, & Leca, 2019). Among the different types of play (including object and solitary play, and different social play patterns; Fagen, 1981; Burghardt, 2005), play fighting (or Rough-&-Tumble, R&T) is probably the most complex in that animals physically and variably interact in close contact during play sessions (Palagi et al., 2016; Pellis & Pellis, 2017). Animals can combine different types of play during play fighting (Burghardt, 1998, 2005) but this form of play mostly 'borrows' and re-organizes patterns from the aggressive domain (Pellis & Pellis, 2017). Indeed, play fighting can be related to the development of aggressive behaviour and dominance relationships in different mammalian species, including humans (e.g. Takahashi & Lore, 1983; Smith & Boulton, 1990; Paquette, 1994; Blumstein et al., 2013).

Play markers have evolved in many species as honest indicators that the behavior is harmless (Graham & Burghardt. 2010). Typical play markers for example include play bows in canids and open-mouthed play faces in primates and carnivores (Bekoff, 1975; Pellis & Pellis, 1996; Cordoni, Nicotra & Palagi, 2016). However, such markers are not always expressed in a consistent way and the 'non-seriousness' of the interaction may not be evident to the human observer (Palagi, Antonacci & Cordoni, 2007; Petrů et al., 2009; Palagi et al., 2016). Even though play fighting is normally harmless and real fighting may result in injuries (possibly associated with

pain vocalizations), this is not always the case (Rushen & Pajor, 1987; Palagi & Cordoni, 2012; Pellis & Pellis, 2016, 2017). As a result, play fighting and real fighting can differ in target and attack tactics (Pellis and Pellis, 1987) but are sometimes confused due to their structural similarity (Bekoff & Allen, 1998; Bekoff, 2014).

Following previous literature describing social play structural elements in human and non-human animals (Smith 1989, 1997; Burghardt, 2005; Bauer & Smuts, 2007; Petrů et al., 2009; Cordoni et al., 2021; Collarini et al., 2022) play fighting (compared to real fighting) may be composed by motor patterns that can be: i) incomplete, exaggerated and more variable in their form and timing and ii) more repeated (but not stereotyped); iii) possibly – but not necessarily - modified to maintain balance during the interaction . Moreover, in several social mammalian species (including humans) both play fighting and real fighting can involve more than two individuals (polyadic play and coalitionary aggression; e.g., van Schaik et al., 2004; Palagi et al., 2014; Norscia & Palagi, 2015; Cordoni & Palagi, 2016 Cassidy & McIntyre, 2016; Cordoni et al., 2018; Sugiyama et al., 2018).

To assess what structural elements differ between play fighting and real fighting, we gathered behavioural data on immature domestic pigs (*Sus scrofa*), which are particularly suitable to investigate this aspect because they show both play- and real-fighting from the first week of life, with play fighting being also used as substitute for aggression (Cordoni et al., 2021). Indeed, right after birth, piglets compete with one another to access the most productive, frontal teats and to start establishing dominance relationships (Blackshaw, Swain, Blackshaw, Thomas, & Gillies, 1997; Ruis et al., 2000; D'Eath & Turner, 2008; Horback, 2014; Schmitt, Baxter, Boyle, & O'Driscoll, 2018). Even if some level of aggregation is retained in adulthood, social interactions tend to decrease - and social play to almost disappear - after sexual maturity (Petersen et al., 1989; Horback, 2014; Cordoni et al. 2021). Indeed, in the early phases of life piglets engage in play fighting sessions, almost never observed in adults (Newberry & Wood-Gush, 1988; Horback, 2014; Brown, Peters, Nevison, & Lawrence, 2018). Play fighting in piglets includes one or more play markers that are not present in real fighting, such as scamper, pivot, head tossing and object shaking

(Newberry & Wood-Gush, 1988; Rauw, 2013; Horback, 2014; Ŝpinka, 2017). However, the majority of patterns used by piglets during play fighting are also used during real fighting: head-to-head wrestling, hitting at each other's flanks, head knocking the playmate, pushing, lifting, and/or biting the partner (Rushen & Pajor, 1987; Newberry & Wood-Gush, 1988; Chaloupková, Illmann, Bartoš, & Špinka, 2007; Šilerová, Špinka, Šárová, & Algers, 2010; Horback, 2014; Pellis & Pellis, 2016; Brown et al., 2018; Cordoni et al., 2021). Hence, the distinction between play- and real fighting sessions in piglets may not be always obvious. To understand what structural elements differ between the two versions of fighting (non-serious *vs* serious) we formulated and verified the following predictions.

Prediction 1 - Real- and play-fighting duration and dimension

Play is supposed to be rewarding for players (Burghardt, 2005, 2011; Pellis and Pellis, 2009; Trezza, Baarendse, & Vanderschuren, 2010; Vanderschuren, 2010; Vanderschuren, Achterberg, & Trezza, 2016) and the facilitation of play expression can increase play duration (Van Kerkhof et al., 2013). Hence - although both play fighting and real fighting can vary in their duration - we expected that a significant proportion of play fighting sessions would be longer than real fighting sessions (*Prediction 1a*).

Piglets can engage in play sessions that can be either dyadic (involving two individuals) or polyadic (involving more than two individuals) (Worsaae and Schmidt, 1980; Chaloupková et al., 2007; Brown et al. 2018). Although conflicts in pigs usually involve two individuals, gang aggression involving multiple individuals has been described in adults (Camerlink et al., 2020; Cordoni et al., 2021). Hence, we expected to observe comparable frequencies of polyadic play fighting and real fighting (*Prediction 1b*).

Prediction 2 - Real- and play-fighting pattern structure

In piglets, play fighting can be used in a competitive way and the balance between offensive and defensive patterns may not be maintained, as it occurs in real fighting used to establish dominance (Weller et al., 2019; Cordoni et al., 2021). Another feature that appears to structurally distinguish either play fighting or real fighting in *Sus scrofa* immature subjects is pattern distribution, which can be more or less uniformly distributed within sessions (Collarini et al., 2022).

Based on the main features of play mentioned above and the species biology (Burghardt, 2005, 2011; Cordoni et al., 2021; Collarini et al., 2022), we expect that – compared to real fighting - play fighting sessions in piglets would: *2a)* not necessarily be more balanced in terms of offensive/defensive pattern exchange and distribution (with no possibility to predict – based on the present knowledge - if less or equally balanced) ; *2b)* be more variable in terms of different types of motor patterns performed within a single session and; *2c)* include more repeated patterns.

2. Methods

2.1 Study site, subjects and data collection

The research was carried out on three domestic pig litters (Parma Black x Parma Black and Parma Black x Large White) at ethical extensive farm Parva Domus, Cavagnolo, Turin, Italy. The study included 24 piglets (11 females, 13 males; Table 1) with different mothers (Linda, Nina, Black Beauty) and the same father (Bob). The three sows were kept isolated (by the farmer) with their offspring until weaning, which occurred at around 8 weeks of life. Each pre-weaning enclosure measured around 100 m^2 and was in an area of natural habitat equipped with straw, troughs for food, water and a shed. The individuals were able to move freely throughout the enclosure and avoid conspecifics if wanted. Sows received food pellets (Ciclo Unico P, SILDAMIN) each morning between 08:30 and 10:30 hours, whereas the maternal milk represented the major food source for piglets until weaning. No food was specifically given to piglets before weaning although they could opportunistically feed on the pellets given to the sow. Piglets could supplement maternal

milk with roots, leaves and fruits found in the natural environment or with pellets left by their mother. The tails and teeth of piglets were kept intact, and males were castrated during the first 3 days of life. The animals followed the natural day/night cycle and did not perform any aberrant or stereotyped behaviour.

During the first week after birth, all subjects were habituated to the presence of the observers (E. D. and M. G.) and data collection started around the end of the first week of life. The behavioural patterns of piglets were video-recorded from September to December 2018 using HD/Full HD Sony HDR-XR200 and Panasonic HC-W3580 cameras. We collected and analysed 15.92 h (Mean ± SE per litter: 5.31h ± 0.60) of play-fighting/real-fighting videos for all three litters (Linda's litter 6.50 h, Nina's litter 4.60 h, Black Beauty's litter 4.82 h of videos). During the first week after birth the observers underwent a training period by I.N. and G.C. to become skilled at animal identification and behavioural pattern distinction. Actual data collection lasted from day 6 to day 50 after birth. Behavioural observations took place 6 days per week from 08:00 to 17:00 hours following a rotation that allowed the balance of the observation time slots across litters. During the video recording the observers stayed around 10 m from the piglets and sows. To facilitate the identification of each subject, piglets were marked with animal painting spray (Raidex) by using different combinations of colours (i.e., blue, red and green) and symbols (i.e. dots, circles and lines). Marking was renewed every 4-7 days depending on weather conditions.

2.2 Video analysis and operational definitions

By using the all-occurrences animal sampling method (Altmann, 1974) we collected 388 play sessions and 108 aggressive interactions between piglets (Figure 1). Prior to starting the video analysis, videocoders (M.G. and E.C) were supervised by G.C. and I.N. in behavioural coding and the video analysis started when the interobserver reliability scores measured via Cohen's *k* reached 0.83. The interobserver reliability between video coders was calculated using the R function ‘cohen.cappa’ and libraries ‘irr’ and ‘psych’ (R version 3.5.3). The videos were analysed frame by

frame and slow motion via freeware software VLC 2.2.1 (Jump-to-time extension). For each play fighting session and real fighting session, we extracted from videos the following information: (1) the identity of the subjects involved, (2) individual features (sex, age), (3) behavioural patterns performed (Table 2), (4) time of each pattern and session duration (s).

According to previous reports (Newberry & Wood-Gush, 1988; Rauw, 2013; Horback, 2014; Špinka, 2017; Collarini et al., 2022), we classified as play fighting sessions the interactions where the piglet performed at least one behavioural item that is specifically found in the play context and not in the aggressive context (Figure 1; Table 2; Video_S1). Although the relaxed open mouth (play face) is considered a widespread play signal across mammals (Palagi et al., 2016), it is not listed as a play marker in piglets (e.g. Newberry & Wood-Gush., 1988; Rauw, 2013; Horback, 2014; Ŝpinka, 2017). Consistently, we only observed the open mouth associated with attempted bites but we did not observe relaxed open mouth displays (or play faces) during social play. A play session started when a piglet directed any playful pattern (see Table 2) towards the littermate and finished when both players stopped the interaction, with one of them moving away or with a third subject interrupting the session.

We categorised as real fighting sessions the interactions where there was no play specific behavioural pattern (Figure 1; Table 2; Video_S2). A real fight started when a piglet directed any aggressive pattern (see Table 2) towards a litter-mate and it ended with one of the opponents moving or fleeing away. When play- or real fighting sessions were interrupted for at least 10s, we considered the subsequent play- or real-fighting interaction as a new session (Cordoni et al. 2021). For both play- and real fights, the patterns were classified as Offensive (O, unidirectional patterns performed to attack the opponent), Defensive (D, patterns aimed at eluding the contact or attack by another individual) and Neutral (N, neither offensive nor defensive; Table 2). For each play fighting and real fighting session, we calculated different indices to evaluate the distribution and variability of the motor patterns performed within the session and the symmetry of the interaction. In particular, we considered the indices listed below.

Polyadic Index

At the individual level, we assessed the number of dyadic and polyadic play- and real-fighting sessions and we determined the Polyadic Index for the two types of session as "the number of polyadic sessions *minus* the number of dyadic sessions" divided by "the number of polyadic sessions *plus* the number of dyadic sessions". Positive values of Polyadic Index indicate a higher frequency of polyadic over dyadic sessions.

Asymmetry Index

The play Asymmetry Index (Cordoni et al., 2016, 2018, 2021) was used to quantify the level of play fighting asymmetry. For each interaction we calculated play Asymmetry Index as follows: "the number of offensive patterns by A towards B plus the number of defensive patterns by B towards A" subtracted from "the number of offensive patterns by B towards A plus the number of defensive patterns by A towards B" divided by "the total number of patterns performed by both playmates". The formula of play Asymmetry Index is reported below:

$$pAI = \frac{(offensive_{A\rightarrow B} + defensive_{B\rightarrow A}) - (offensive_{B\rightarrow A} + defensive_{A\rightarrow B})}{(offensive_{A\rightarrow B} + defensive_{B\rightarrow A}) + (offensive_{B\rightarrow A} + defensive_{A\rightarrow B}) + neutral_{A+B}}$$

Based on the play Asymmetry Index, we also calculated the aggression Asymmetry Index to quantify the level of real fighting asymmetry. For each interaction we calculated aggression Asymmetry Index as follows: "the number of offensive patterns by A towards B plus the number of defensive patterns by B towards A" subtracted from " the number of offensive patterns by B towards A plus the number of defensive patterns by A towards B" divided by "the total number of patterns performed by both opponents". The formula of aggression Asymmetry Index is reported below:

$$aAI = \frac{(offensive_{A\rightarrow B} + defensive_{B\rightarrow A}) - (offensive_{B\rightarrow A} + defensive_{A\rightarrow B})}{(offensive_{A\rightarrow B} + defensive_{B\rightarrow A}) + (offensive_{B\rightarrow A} + defensive_{A\rightarrow B}) + neutral_{A+B}}$$

Both play Asymmetry Index and aggression Asymmetry Index range from -1 to +1 with main values indicating i) a complete symmetry of the session (zero), ii) a complete asymmetry of the session in favour of A (+1) and, iii) a complete asymmetry of the session in favour of B (-1).

Repetition Index

To evaluate the level of repetition of the same pattern within a single real fighting or play fighting session, this index was calculated by dividing the number of different types of patterns that were repeated during a session over the total number of patterns that composed the session, normalized over the session duration.

The indices listed below were adapted from indices used to measure biodiversity in ecological studies (Türkmen & Kazanci, 2010; Morris et al., 2014; Supriatna, 2018). In particular, we considered each play/real- fight session as an 'ecosystem' including individuals (i.e. in our case all the behavioural patterns included in the session) belonging to different species (i.e. in our case the different types of behavioural patterns included in the session). Based on this approach, we calculated the Shannon and the Pielou indices.

Shannon Index (H')

Shannon index is the most common diversity index used in ecological studies and expresses the richness of the specific ecosystem whilst also taking into account the relative abundance of species (Shannon & Weaver, 1949; Wilsey & Potvin, 2000; Mandaville, 2002; Keylock, 2005; Eliazar & Sokolov, 2012; Daly et al. 2018). The mathematical formula of Shannon index is:

$$H' = - \Sigma [(n_i / N) * (\ln n_i / N)]$$

In particular, n_i is the number of individuals belonging to the species i and N is the total number of individuals in a specific ecosystem. Shannon Index values are generally between zero and five; when they are equal to, or higher than four, it indicates a high level of biodiversity and a balanced ecosystem structure. In our study n_i is represented by numbers of patterns belonging to the

type i and N is represented by the total number of patterns composing a session. A high value of Shannon Index indicates a great behavioural pattern variability in terms of different types of patterns performed in a single session.

Pielou Index (J; also known as Species evenness).

It derives from the Shannon index and focuses on how individuals are distributed across species (more or less evenly) within a specific ecosystem (Pielou, 1966). The mathematical formula of Pielou index is:

$J = H' / H'_{max}$

H' is the observed value of Shannon index, H'_{max} is the lnS with S representing the total number of species. The values of Pielou Index vary between zero and one; when they are close to one it means that individuals are even distributed among species (Pielou, 1966). In the present study S is represented by the total number of different types of behavioural patterns. To calculate the indices and run analyses on them we selected the individuals with at least two sessions of either play- or real fighting, with at least two patterns per session.

2.3 Statistics

Owing to normal data distribution (Kolmogorov Smirnov, $n_{individuals} = 22$, $0.074 \leq p \leq 0.325$), at the individual level we applied the parametric t-test for dependent samples to compare the mean duration and Polyadic Index, play/aggression Asymmetry Index, Shannon Index, Pielou Index, and Repetition Index values between real- and play fighting. The tests were carried out via SPSS 26.0. The threshold of statistical significance for all tests was set at $\alpha=0.05$ (Data_S1).

3. Results

3.1 Prediction 1

The mean duration was significantly lower in real- than play fighting sessions (t-test for dependent samples, $n_{individuals}$ =22; t=3.949; p=0.001, 95% CI: 1.249/4.027; Figure 2). We detected no significant difference in the Polyadic Index values between real- and play fighting (t-test for dependent samples,; $n_{individuals}$ =22; t=-1.526; p=0.142, 95% CI: -0.944/0.145), which indicates that the proportion of polyadic sessions in real- and play fighting was comparable.

3.2 Prediction 2

The Asymmetry Index was significantly higher in real- than play fighting (t-test for dependent samples, $n_{individuals}$ = 22; t=-13.927; p<0.001; 95% CI: -0.723/-0.535; Figure 3a). The level of pattern variability (Shannon Index, H') was significantly lower in real- than in play fighting (t-test for dependent samples, $n_{individuals}$ = 22; t=4.932; p<0.001; 95% CI: 0.168/0.414; Figure 3b). Individual analysis of pattern evenness (Pielou Index) levels showed no difference between real fighting and play fighting sessions (t-test for dependent samples, $n_{individuals}$ = 22; t=1.681; p=0.107; 95% CI: -0.020/0.191; Figure 3c). Finally the Repetition Index was significantly higher in real- than in play fighting (t-test for dependent samples, $n_{individuals}$ = 22; t=-4.102; p=0.001; 95% CI: -0.058/0.019; Figure 3d).

4. Discussion

In this study we found that - as expected - play fighting sessions lasted longer than real fighting sessions (*Prediction 1a* supported; Figure 2) and there was no difference in the polyadic index values between play fighting and real fighting sessions (*Prediction 1b* supported). We also found that - compared to real fighting - play fighting sessions could be more balanced as informed by the fact that they: i) included more symmetrically exchanged patterns (offensive/defensive) (Figure 3a) but such patterns were not more uniformly distributed (Figure 3b; *Prediction 2a* partly supported). Compared to real fighting, play fighting sessions: i) were more variable in terms of different types

of motor patterns within a single session (*Prediction 2b* supported; Figure 3c); and ii) showed lower repetition levels (*Prediction 2c* not supported; Figures 3d).

The fact that play fighting sessions lasted longer than real fighting sessions (Figure 2) might inform the rewarding nature of play. Indeed, according to previous literature, the expression of playful behaviours is supposed to be pleasurable and could be rewarding for individuals involved in such behaviours (Burghardt, 2005, 2011). The pleasure and reward that emerge from the expression of playful behavior could induce the involved individuals to increase the duration of play sessions (Held & Špinka, 2011; Van Kerkhof et al., 2013; Pellis et al., 2014). Thus, the individuals involved in play fighting sessions could gain more time in the social assessment process by prolonging the duration of these playful interactions (Palagi et al., 2015; Palagi et al., 2019; Bertini et al., 2022).

The lack of a significant difference in the level of 'polyadicity' between play- and real fighting can be explained by the fact that aggressive events in adult pigs can involve more than two individuals, with several pigs (which can be males and/or females) forming gang alliances and carrying out targeted aggression towards other conspecifics (Camerlink et al., 2020). In the piglets under study, we did not observe gang attacks but we observed that more than two individuals (typically three) could be involved in the same aggressive sessions. The possibility of forming alliances is consistent with the high cognitive abilities of pigs that can include anticipatory and problem-solving skills (Croney and Boysen, 2021; Norscia et al., 2021b), post-conflict management abilities (reconciliation and triadic affiliative contacts after aggression; Cordoni et al., 2022), and the capacity to express, detect and share, others' physiological states (Turner et al., 2001; Jensen, 2002; D'Eath & Turner, 2008; Reimert et al., 2013; Camerlink et al., 2018; Norscia et al. 2021a, b). Consistently, polyadic conflicts (with alliances) have been observed in cognitively advanced species, such as wolves and great apes (van Schaik et al., 2004; von Rohr et al., 2012; Cassidy & McIntyre, 2016) in which group mates can form coalitions during agonistic events.

In the piglets under study, play fighting sessions were more symmetrical (higher Asymmetry Index values) than real fighting ones. Increased symmetry levels can enhance the continuation of

play, thus increasing the functional benefits that play can have for immature subjects such as motor training, social assessment, and receiving less injuries during contests at a later stage (Byers & Walker, 1995; Pellis & Iwaniuk 1999, 2000; Cordoni & Palagi, 2011; Turner et al., 2020). Commonly mentioned strategies that allow the achievement of symmetry are the role reversal (e.g., balancing subordinate/dominance patterns) and self-handicapping (when the most skilled player restrains itself to decrease its advantage over the playmate; Cordoni et al., 2016; Cordoni & Palagi, 2016). However, pigs may use a different strategy. A study by Pellis and Pellis (2016) found that Visayan warty pigs (*Sus cebifrons*) did not show restraint during play, as when one animal gained the advantage they most probably attacked their partner. However, frequently the disadvantaged partners could launch a counter-attack and increase the session balance. Consistently, in the same litters under study, Cordoni et al. 2021 found that only the piglets of similar size could maintain the play session longer, probably because self-restraint was not necessary when neither playmate could outcompete the other by using force. Even though play fighting in piglets can be used as a substitute for real fighting and lead to a similar outcome as real fighting (Cordoni et al., 2021), our results on the Asymmetry Index show that real fighting maintains the highest degree of directionality. Indeed, asymmetrical aggressive events are pivotal to gain a dominant status, as the ranking position of an individual within a group increases as the number of agonistic encounters consistently won by that individual increases (Landau, 1951; Appleby, 1983; Drews, 1993; De Vries, 1995; Kendall, 2021). High ranking individuals have priority in the access to resources (food, mating), which increases their fitness (Clutton-Brock, 1982; Preuschoft & Van Schaik, 2000; Andersen, et al., 2004; Sapolsky, 2005; Krebs & Davies, 2012; Norring et al 2019).

We also found that play fighting possessed higher pattern variability (increased Shannon Index values; Figure 3c) than real fighting. Overall, the increased heterogeneity of play fighting patterns is in line with the main characteristics of play, which involve patterns that are variably recombined from other social behaviour domains, including (among others) mating or aggression (Pellis & Pellis 2017; Pellis et al., 2019; Cordoni et al., 2021). This feature is adaptive to maximize the

benefits of play, especially the training for the unexpected (Špinka et al., 2001). As a matter of fact, during play there are no pre-fixed rules so individuals must improvise and quickly counteract in a flexible but appropriate way the actions of the playmate (Pellegrini 2009; Pellis et al., 2010; Palagi et al., 2016).

The higher repetition levels found in real fighting compared to play fighting may be due to the fact that real fighting - as said above - is more asymmetrical and during aggression individuals can repeat the same offensive pattern (head knocking, pushing, etc.) over and over to outcompete the opponent. Our result seems not to entirely fit with one of the very criteria that define play (Smith, 1989, 1997; Burghardt, 2005, 2011). This aspect deserves further investigation in future studies to better understand what other measures can be used to assess the repetition levels and what is the term of comparison.

The comparable levels of evenness (Pielou Index values) in play fighting and real fighting may be the result of the convergence of different features: play fighting sessions were more symmetrical and longer whereas real fighting sessions showed higher levels of repetition of the same patterns. These diverging structural characteristics might have dampened the differences in the uniformity levels between the 'serious' and 'non-serious' context and made evenness a less reliable criterion to assess the playful mood in piglets.

In conclusion, this study shows that play fighting sessions in piglets did not fully comply with the features that should allow the differentiation between play and real fighting sessions, for example in terms of repetition levels. This finding is in line with the observation that play fighting in piglets not only resembles but it also shares some functions of real fighting such as the establishment of dominance relations (Weller et al., 2020; Cordoni et al., 2021). A similar function has been found in other species, including for example humans and chimpanzees (Smith & Boulton, 1990; Paquette, 1994). Interestingly, in humans it has been hypothesized that play fighting - when polyadic (or coalitional) - can lead to the deployment of coordinated aggression because it is found

across a diverse range of hunter-gatherer groups and regularly recruits motor patterns used in lethal raiding (Sugiyama et al., 2018).

Despite the fact that in piglets play fighting can substitute real fighting under certain circumstances (Weller et al., 2020; Cordoni et al., 2021), this study shows that play fighting can still maintain the key features that make play adaptive for the individuals that engage in it. Real fighting increases in piglets whereas social play decreases over the first two months of life, with play fighting also working as a substitute of real fighting (Cordoni et al., 2021; Collarini et al., 2022). Thus, age may in part explain our results showing that play fighting maintains elements of play but also includes elements of real fighting, which will prevail at a later stage. Future studies could focus on the difference between play fighting and real fighting at different ages in the first months of life. By including more variable and symmetrical patterns, play fighting sessions in a competitive arena can serve any one, or a combination, of the proposed functions of play fighting (motor training, social assessment and training for the unexpected). On a broader perspective, this study can provide the ground for measuring the play structure in a quantitative and repeatable way across species and contexts and to assess whether interactions that are apparently playful can be actually labelled as play.

Acknowledgments

This study is part of the broader projects So.Pig (Socially Pig) and the PhD project GREENPIG (Development of a new protocol to reduce the impact on biodiversity and increase animal welfare in domestic pigs raised in natural protected areas) funded to Edoardo Collarini (PON R&I 2014-2020 by the Italian Ministry of University and Research). The authors wish to thank Cristina Desdera and Davide Lovera, who own and manage the ethical farm Parva Domus located in Cavagnolo (Torino, Italy) for their interest, encouragement, and availability since the very beginning of the study. The authors also thank Parva Domus' staff for practical help during the field work, Elisabetta Coco and Marta Comin who helped with data collection.

Ethical Statement

This study was approved by the University of Turin. Since the study was purely observational and was conducted with no manipulation of animals, no further permit was needed.

Funding

The present study was funded by the University of Torino, Department of Life Sciences and Systems Biology (@DBIOSUnito), via research funds granted to IN, code: NORI_RILO_18_01; NORI_RILO_19_01; NORI_RILO_20_01; NORI_RILO_21_01. PON R&I 2014-2020 by the Italian Ministry of University and Research.

Declarations of interests

The authors declare that there are no conflicts of interest.

Data Availability Statement

The raw data supporting the conclusions of this article are provide as supporting material to this article.

References

Aldis, O., 2013. Play Fighting. Elsevier Science.

Altmann, J., 1974. Observational study of behavior: Sampling methods. Behaviour 49, 227–266. https://doi.org/10.1163/156853974x00534

Andersen, L.B., Hasselstrøm, H., Grønfeldt, V., Hansen, S.E., Karsten, F., 2004. The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. Int. J. Behav. Nutr. Phys. Act. 1, 6. https://doi.org/10.1186/1479-5868-1-6

Appleby, M.C., 1983. The probability of linearity in hierarchies. Anim. Behav. 31, 600–608. https://doi.org/10.1016/s0003-3472(83)80084-0

Bauer, E.B., Smuts, B.B., 2007. Cooperation and competition during dyadic play in domestic dogs, *Canis familiaris*. Anim. Behav. 73, 489–499. https://doi.org/10.1016/j.anbehav.2006.09.006

Bekoff, M., 1975. The communication of play intention: Are play signals functional? Semiotica 15. https://doi.org/10.1515/semi.1975.15.3.231

Bekoff, M., 2014. The significance of ethological studies: Playing and peeing, in: Domestic Dog Cognition and Behavior. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 59–75.

Bekoff, M., Allen, C., 1998. Intentional communication and social play: how and why animals negotiate and agree to play, in: Byers, J.A. (Ed.), Animal Play: Evolutionary, Comparative, and Ecological Perspectives. Cambridge University Press, Cambridge, pp. 97–114.

Bertini, M., Annicchiarico, G., Bresciani, C., Cordoni, G., Palagi, E., 2022. Playful interactions and facial mimicry in infant bonobos (*Pan paniscus*). Ethology Ecology & Evolution 34, 344–359. https://doi.org/10.1080/03949370.2021.1988723

Blackshaw, J.K., Swain, A.J., Blackshaw, A.W., Thomas, F.J.M., Gillies, K.J., 1997. The development of playful behaviour in piglets from birth to weaning in three farrowing environments. Appl. Anim. Behav. Sci. 55, 37–49. https://doi.org/10.1016/s0168-1591(97)00034-8

Brown, S.M., Peters, R., Nevison, I.M., Lawrence, A.B., 2018. Playful pigs: Evidence of consistency and change in play depending on litter and developmental stage. Appl. Anim. Behav. Sci. 198, 36–43. https://doi.org/10.1016/j.applanim.2017.09.018

Burghardt, G.M., 1998. The evolutionary origins of play revisited. Animal play: Evolutionary, comparative, and ecological perspectives 3–26.

Burghardt, G.M., 2005. The genesis of animal play. Testing the Limits. MIT Press, Cambridge, MA.

Burghardt, G.M., 2011. In The Oxford Handbook of the Development of Play. Nathan, P.

Burghardt, G.M., 2010. The Comparative Reach of Play and Brain: Perspective, Evidence, and Implications. American Journal of Play 2, 338–356.

Byers, J.A., Walker, C., 1995. Refining the motor training hypothesis for the evolution of play. Am. Nat. 146, 25–40. https://doi.org/10.1086/285785

Camerlink, I., Coulange, E., Farish, M., Baxter, E.M., Turner, S.P., 2018. Facial expression as a potential measure of both intent and emotion. Sci. Rep. 8, 17602. https://doi.org/10.1038/s41598-018-35905-3

Camerlink, I., Chou, J.-Y., Turner, S.P., 2020. Intra-Group Lethal Gang Aggression in Domestic Pigs (*Sus scrofa domesticus*). Animals (Basel) 10, 1287. https://doi.org/10.3390/ani10081287

Cassidy, K.A., McIntyre, R.T., 2016. Do gray wolves (*Canis lupus*) support pack mates during aggressive inter-pack interactions? Anim. Cogn. 19, 939–947. https://doi.org/10.1007/s10071-016-0994-1

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Appl. Anim. Behav. Sci. 103, 25–34. https://doi.org/10.1016/j.applanim.2006.04.020

Clutton-Brock, T.H., 1982. The functions of antlers. Behaviour 79, 108–124. https://doi.org/10.1163/156853982x00201

Collarini, E., Gioia, M., Cordoni, G., Norscia, I., 2022. Does the domestication syndrome apply to the domestic pig? Not completely. Animals (Basel) 12, 2458. https://doi.org/10.3390/ani12182458

Cordoni, G., Comin, M., Collarini E., Robino, C., Chierto, E., Norscia I., 2022. Domestic Pigs (*Sus scrofa*) engage in non-random post-conflict affiliation with third parties: cognitive and functional implications. Anim. Cogn. https://doi.org/10.1007/s10071-022-01688-4

Cordoni, G., Gioia, M., Demuru, E., Norscia, I., 2021. The dark side of play: play fighting as a substitute for real fighting in domestic pigs, *Sus scrofa*. Anim. Behav. 175, 21–31. https://doi.org/10.1016/j.anbehav.2021.02.016

Cordoni, G., Nicotra, V., Palagi, E., 2016. Unveiling the "secret" of play in dogs (*Canis lupus familiaris*): Asymmetry and signals. J. Comp. Psychol. 130, 278–287. https://doi.org/10.1037/com0000035

Cordoni, G., Norscia, I., Bobbio, M., Palagi, E., 2018. Differences in play can illuminate differences in affiliation: A comparative study on chimpanzees and gorillas. PLoS One 13, e0193096. https://doi.org/10.1371/journal.pone.0193096

Cordoni, G., & Palagi, E. (2011). Ontogenetic trajectories of chimpanzee social play: similarities with humans. PLoS One, 6(11), e27344.

Cordoni, G., Palagi, E., 2016. Aggression and hierarchical steepness inhibit social play in adult wolves. Behaviour 153, 749–766. https://doi.org/10.1163/1568539x-00003326

Croney, C.C., Boysen, S.T., 2021. Acquisition of a Joystick-Operated Video Task by Pigs (*Sus scrofa*). Front. Psychol. 12, 631755. https://doi.org/10.3389/fpsyg.2021.631755

Daly, A., Baetens, J., De Baets, B., 2018. Ecological diversity: Measuring the unmeasurable. Mathematics 6, 119. https://doi.org/10.3390/math6070119

D'Eath, R.B., Turner, S.P., 2008. The natural behaviour of the pig, in: The Welfare of Pigs. Springer Netherlands, Dordrecht, pp. 13–45.

de Vries, H., 1995. An improved test of linearity in dominance hierarchies containing unknown or tied relationships. Anim. Behav. 50, 1375–1389. https://doi.org/10.1016/0003-3472(95)80053-0

Donaldson, T.M., Newberry, R.C., Špinka, M., Cloutier, S., 2002. Effects of early play experience on play behaviour of piglets after weaning. Appl. Anim. Behav. Sci. 79, 221–231. https://doi.org/10.1016/s0168-1591(02)00138-7

Drews, C., 1993. The concept and definition of dominance in animal behaviour. Behaviour 125, 283–313. https://doi.org/10.1163/156853993x00290

Eliazar, I.I., Sokolov, I.M., 2012. Measuring statistical evenness: A panoramic overview. Physica A 391, 1323–1353. https://doi.org/10.1016/j.physa.2011.09.007

Fagen, R., 1981. Animal Play Behaviour. Oxford University Press, New York, NY.

Graham, K.L., Burghardt, G.M., 2010. Current perspectives on the biological study of play: signs of progress. Q. Rev. Biol. 85, 393–418. https://doi.org/10.1086/656903

Held, S.D.E., Špinka, M., 2011. Animal play and animal welfare. Anim. Behav. 81, 891–899. https://doi.org/10.1016/j.anbehav.2011.01.007

Horback, K., 2014. Nosing around: Play in pigs. Anim. Behav. Cogn. 2, 186. https://doi.org/10.12966/abc.05.08.2014

Kendall, M.G., 2021. Rank correlation methods; 3rd edition. Hassell Street Press.

Keylock, C.J., 2005. Simpson diversity and the Shannon-Wiener index as special cases of a generalized entropy. Oikos 109, 203–207. https://doi.org/10.1111/j.0030-1299.2005.13735.x

Krebs, J.R., Davies, N.B., 2012. An Introduction to Behavioural Ecology. John Wiley & Sons, Hoboken, NJ, USA

Landau, H.G., 1951. On dominance relations and the structure of animal societies: II. Some effects of possible social factors. Bulletin of Mathematical Biophysics 13, 245–262. https://doi.org/10.1007/bf02477920

Mandaville, S.M., 2002. Benthic Macroinvertebrates in Freshwater - Taxa Tolerance Values, Metrics, and Protocols, Project H - 1. Soil & Water Conservation, Nova Scotia.

Morris, E.K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T.S., Meiners, T., Müller, C., Obermaier, E., Prati, D., Socher, S.A., Sonnemann, I., Wäschke, N., Wubet, T., Wurst, S., Rillig, M.C., 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecol. Evol. 4, 3514–3524. https://doi.org/10.1002/ece3.1155

Newberry, R.C., Wood-Gush, D.G.M., 1988. Development of some behaviour patterns in piglets under semi-natural conditions. Anim. Sci. 46, 103–109. https://doi.org/10.1017/s0003356100003160

Norscia, I., Coco, E., Robino, C., Chierto, E., Cordoni, G., 2021a. Yawn contagion in domestic pigs (*Sus scrofa*). Sci. Rep. 11, 1851. https://doi.org/10.1038/s41598-020-80545-1

Norscia, I., Collarini, E., Cordoni, G., 2021b. Anxiety behavior in pigs (*Sus scrofa*) decreases through affiliation and may anticipate threat. Front. Vet. Sci. 8, 630164. https://doi.org/10.3389/fvets.2021.630164

Norscia, I., Palagi, E., 2011. When play is a family business: adult play, hierarchy, and possible stress reduction in common marmosets. Primates 52, 101–104. https://doi.org/10.1007/s10329-010-0228-0

Norscia, I., Palagi, E., 2015. The socio-matrix reloaded: from hierarchy to dominance profile in wild lemurs. PeerJ 3, e729. https://doi.org/10.7717/peerj.729

Norring, M., Valros, A., Bergman, P., Marchant-Forde, J.N., Heinonen, M., 2019. Body condition, live weight and success in agonistic encounters in mixed parity groups of sows during gestation. Animal 13, 392–398. https://doi.org/10.1017/s1751731118001453

Palagi, E., 2011. Playing at every age: modalities and potential functions in non-human primates.

Palagi, E., Antonacci, D., Cordoni, G., 2007. Fine-tuning of social play in juvenile lowland gorillas (*Gorilla gorilla gorilla*). Dev. Psychobiol. 49, 433–445. https://doi.org/10.1002/dev.20219

Palagi, E., Burghardt, G.M., Smuts, B., Cordoni, G., Dall'Olio, S., Fouts, H.N., Řeháková-Petrů, M., Siviy, S.M., Pellis, S.M., 2016. Rough-and-tumble play as a window on animal communication: Social play and communication in animals. Biol. Rev. Camb. Philos. Soc. 91, 311–327. https://doi.org/10.1111/brv.12172

Palagi, E., Cordoni, G., 2012. The right time to happen: play developmental divergence in the two Pan species. PLoS One 7, e52767. https://doi.org/10.1371/journal.pone.0052767

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

Palagi, E., Norscia, I., Pressi, S., Cordoni, G., 2019. Facial mimicry and play: A comparative study in chimpanzees and gorillas. Emotion 19, 665–681. https://doi.org/10.1037/emo0000476

Palagi, E., Norscia, I., Spada, G., 2014. Relaxed open mouth as a playful signal in wild ring-tailed lemurs: Relaxed Open Mouth as a Play Signal In Lemurs. Am. J. Primatol. 76, 1074–1083. https://doi.org/10.1002/ajp.22294

Paquette, D. (1994). Fighting and playfighting in captive adolescent chimpanzees. Aggress. Behav. 20, 49-65. https://doi.org/10.1002/1098-2337(1994)20:1<49::AID-AB2480200107>3.0.CO;2-C

Pellegrini, A.D., 2009. The role of play in human development. Oxford University Press, USA.

Pellis, S.M., Iwaniuk, A.N., 1999. The problem of adult play fighting: A comparative analysis of play and courtship in primates. Ethology 105, 783–806. https://doi.org/10.1046/j.1439-0310.1999.00457.x

Pellis, S.M., Iwaniuk, A.N., 2000. Adult-adult play in primates: Comparative analyses of its origin, distribution and evolution. Ethology 106, 1083–1104. https://doi.org/10.1046/j.1439-0310.2000.00627.x

Pellis, S. M., & Pellis, V. C. 1987. Play-fighting differs from serious fighting in both target of attack and tactics of fighting in the laboratory rat *Rattus norvegicus*. Aggress. Behav. 3, 227-242. https://doi.org/10.1002/1098-2337(1987)13:4<227::AID-AB2480130406>3.0.CO;2-C

Pellis, S.M., Pellis, V.C., 1996. On knowing it's only play: The role of play signals in play fighting. Aggress. Violent Behav. 1, 249–268. https://doi.org/10.1016/1359-1789(95)00016-x

Pellis, S.M., Pellis, V.C., 1998. Play fighting of rats in comparative perspective: a schema for neurobehavioral analyses. Neurosci. Biobehav. Rev. 23, 87–101. https://doi.org/10.1016/s0149-7634(97)00071-7

Pellis, S.M., Pellis, V.C., 2009. The Playful Brain: Venturing to the Limits of Neuroscience. Oneworld.

Pellis, S.M., Pellis, V.C., 2017. What is play fighting and what is it good for? Learn. Behav. 45, 355–366. https://doi.org/10.3758/s13420-017-0264-3

Pellis, S.M., Pellis, V.C., Bell, H.C., 2010. The function of play in the development of the social brain. American Journal of Play 2, 278–296.

Pellis, S.M., Pellis, V.C., Himmler, B.T., 2014. How play makes for a more adaptable brain: a comparative and neural perspective. American Journal of Play 7, 73–98.

Pellis, S.M., Pellis, V.C., Pelletier, A., Leca, J.-B., 2019. Is play a behavior system, and, if so, what kind? Behav. Processes 160, 1–9. https://doi.org/10.1016/j.beproc.2018.12.011

Petersen, H.V., Vestergaard, K., Jensen, P., 1989. Integration of piglets into social groups of free-ranging domestic pigs. Appl. Anim. Behav. Sci. 23, 223–236. https://doi.org/10.1016/0168-1591(89)90113-5

Petrů, M., Špinka, M., Charvátová, V., Lhota, S., 2009. Revisiting play elements and self-handicapping in play: a comparative ethogram of five Old World monkey species. J. Comp. Psychol. 123, 250–263. https://doi.org/10.1037/a0016217

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13, 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Preuschoft, S., Van Schaik, C.P., 2000. Dominance and communication. Natural conflict resolution 77–105.

Rauw, W.M., 2013. A note on the consistency of a behavioral play marker in piglets. J. Anim. Sci. Biotechnol. 4, 33. https://doi.org/10.1186/2049-1891-4-33

Rohr, V., Koski, C.R., Burkart, S.E., Caws, J.M., Fraser, C., Ziltener, O.N., Van Schaik, A., 2012. Impartial third-party interventions in captive chimpanzees: a reflection of community concern. PloS one 7.

Ruis, M.A.W., te Brake, J.H.A., van de Burgwal, J.A., de Jong, I.C., Blokhuis, H.J., Koolhaas, J.M., 2000. Personalities in female domesticated pigs: behavioural and physiological indications. Appl. Anim. Behav. Sci. 66, 31–47. https://doi.org/10.1016/s0168-1591(99)00070-2

Rushen, J., Pajor, E., 1987. Offence and defence in fights between young pigs (*Sus scrofa*). Aggress. Behav. 13, 329–346. https://doi.org/10.1002/1098-2337(1987)13:6<329::aid-ab2480130602>3.0.co;2-3

Sapolsky, R.M., 2005. The influence of social hierarchy on primate health. Science 308, 648–652. https://doi.org/10.1126/science.1106477

Schmitt, O., Baxter, E.M., Boyle, L.A., O'Driscoll, K., 2019. Nurse sow strategies in the domestic pig: II. Consequences for piglet growth, suckling behaviour and sow nursing behaviour. Animal 13, 590–599. https://doi.org/10.1017/s1751731118001702

Shannon, C.E., Weaver, W., 1949. The mathematical theory of communication. University of Illinois Press, Baltimore, MD.

Šilerová, J., Špinka, M., Šárová, R., Algers, B., 2010. Playing and fighting by piglets around weaning on farms, employing individual or group housing of lactating sows. Appl. Anim. Behav. Sci. 124, 83–89. https://doi.org/10.1016/j.applanim.2010.02.003

Smith, P.K., 1989. The role of rough-and-tumble play in the development of social competence: Theoretical perspectives and empirical evidence, in: Social Competence in Developmental Perspective. Springer Netherlands, Dordrecht, pp. 239–255.

Smith, P.K., 1997. Play fighting and real fighting. Perspectives on their relationship.

Smith, P. K., & Boulton, M. 1990. Rough-and-tumble play, aggression and dominance: perception and behaviour in children's encounters. Hum. Dev. 33, 271-282. https://doi.org/10.1159/000276524

Špinka, M. (Ed.), 2017. Advances in pig welfare. Woodhead Publishing, Cambridge, England.

Špinka, M., Newberry, R.C., Bekoff, M., 2001. Mammalian play: training for the unexpected. Q. Rev. Biol. 76, 141–168. https://doi.org/10.1086/393866

Sugiyama, M. S, Mendoza, M., White, F., & Sugiyama, L. 2018. Coalitional play fighting and the evolution of coalitional intergroup aggression. Hum. Nat. 29, 219-244. https://doi.org/10.1007/s12110-018-9319-1

Supriatna, J., 2018. Biodiversity indexes: Value and evaluation purposes. E3S Web Conf. 48, 01001. https://doi.org/10.1051/e3sconf/20184801001

Takahashi, L.K., Lore, R.K., 1983. Play fighting and the development of agonistic behavior in male and female rats. Aggress. Behav. 9, 217–227. https://doi.org/10.1002/1098-2337(1983)9:3<217::aid-ab2480090303>3.0.co;2-4

Trezza, V., Baarendse, P.J.J., Vanderschuren, L.J.M.J., 2010. The pleasures of play: pharmacological insights into social reward mechanisms. Trends Pharmacol. Sci. 31, 463–469. https://doi.org/10.1016/j.tips.2010.06.008

Türkmen, G., Kazanci, N., 2010. Applications of various biodiversity indices to benthic macroinvertebrate assemblages in streams of a national park in Turkey. Review of Hydrobiology.

Turner, S.P., Horgan, G.W., Edwards, S.A., 2001. Effect of social group size on aggressive behaviour between unacquainted domestic pigs. Appl. Anim. Behav. Sci. 74, 203–215. https://doi.org/10.1016/s0168-1591(01)00168-x

Turner, S.P., Weller, J.E., Camerlink, I., Arnott, G., Choi, T., Doeschl-Wilson, A., Farish, M., Foister, S., 2020. Play fighting social networks do not predict injuries from later aggression. Sci. Rep. 10, 15486. https://doi.org/10.1038/s41598-020-72477-7

van Kerkhof, L.W.M., Damsteegt, R., Trezza, V., Voorn, P., Vanderschuren, L.J.M.J., 2013. Social play behavior in adolescent rats is mediated by functional activity in medial prefrontal cortex and striatum. Neuropsychopharmacology 38, 1899–1909. https://doi.org/10.1038/npp.2013.83

van Schaik, C.P., Pandit, S.A., Vogel, E.R., 2004. A model for within-group coalitionary aggression among males. Behav. Ecol. Sociobiol. 57, 101–109. https://doi.org/10.1007/s00265-004-0818-1

Vanderschuren, L.J., 2010. How the brain makes play fun. American Journal of Play 2, 315–337.

Vanderschuren, L.J.M.J., Achterberg, E.J.M., Trezza, V., 2016. The neurobiology of social play and its rewarding value in rats. Neurosci. Biobehav. Rev. 70, 86–105. https://doi.org/10.1016/j.neubiorev.2016.07.025

Weller, J.E., Turner, S.P., Farish, M., Camerlink, I., Arnott, G., 2020. The association between play fighting and information gathering during subsequent contests. Sci. Rep. 10, 1133. https://doi.org/10.1038/s41598-020-58063-x

Wilsey, B.J., Potvin, C., 2000. Biodiversity and ecosystem functioning: Importance of species evenness in an Old Field. Ecology 81, 887. https://doi.org/10.2307/177163

Worsaae, H., Schmidt, M., 1980. Plasma cortisol and behaviour in early weaned piglets. Acta Vet. Scand. 21, 640–657. https://doi.org/10.1186/bf03546852

Figures

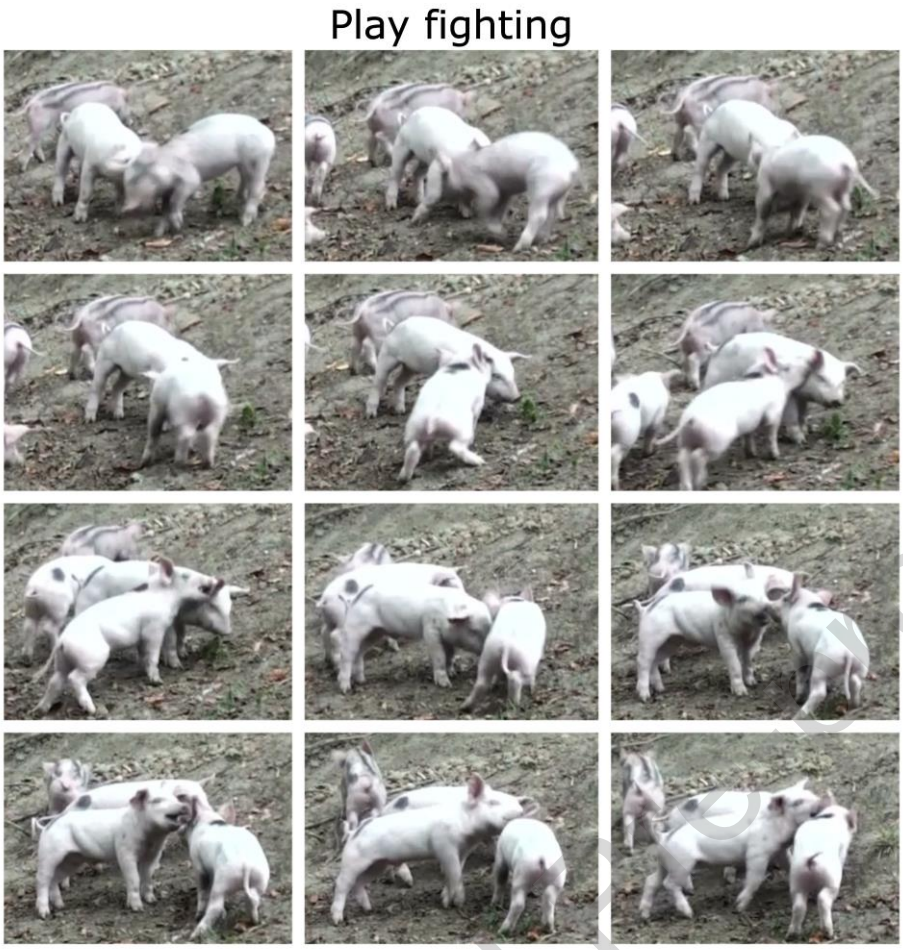


Fig. 1 At the top a play fighting session between piglets. The individual on the right performs a pivot and bites (play-bite) another individual (pig B). Pig B performs a play-push and attempts to bite (attempt play bite) Pig A. Pivot is one of the play markers. At the bottom a real fighting session between piglets. The piglet in the center of the group (pig C) repeatedly bites (aggressive bites) another individual (pig D). Pig D flees. There are no play markers in this session

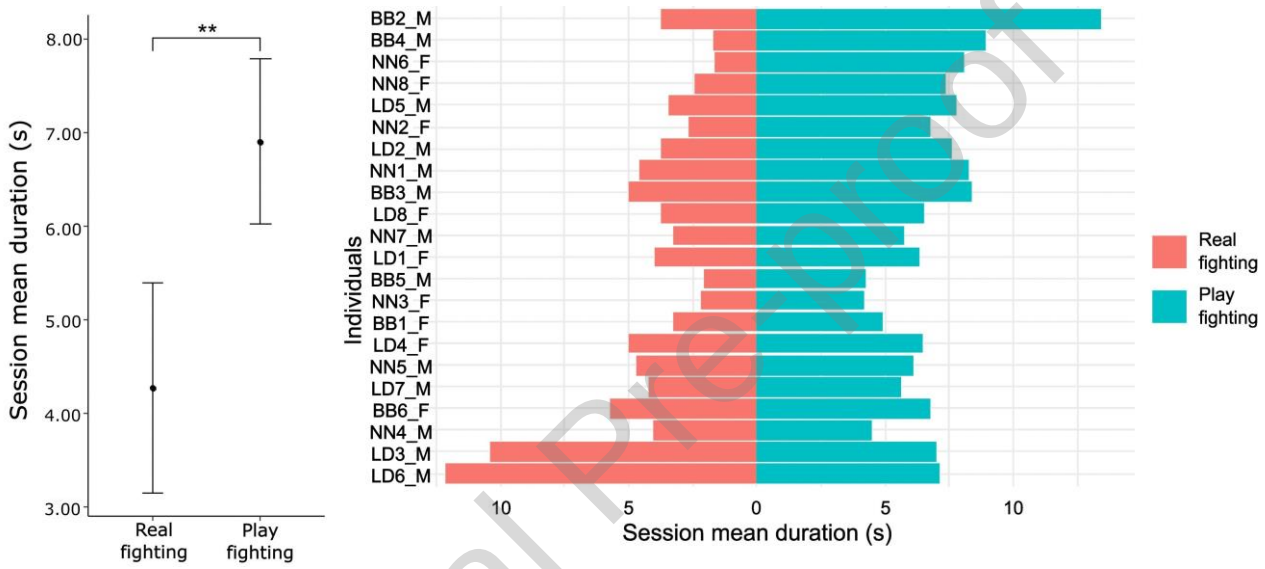


Fig. 2 Difference between the mean duration of real fighting and play fighting sessions shown as error bar (left) and bar plot (right). The mean duration was significantly lower in real fighting than play fighting sessions (t-test for dependent samples; p=0.001). Labels on the Y axis indicate the litter code, with piglet number and sex (F=female; M=male); ** = p< 0.01

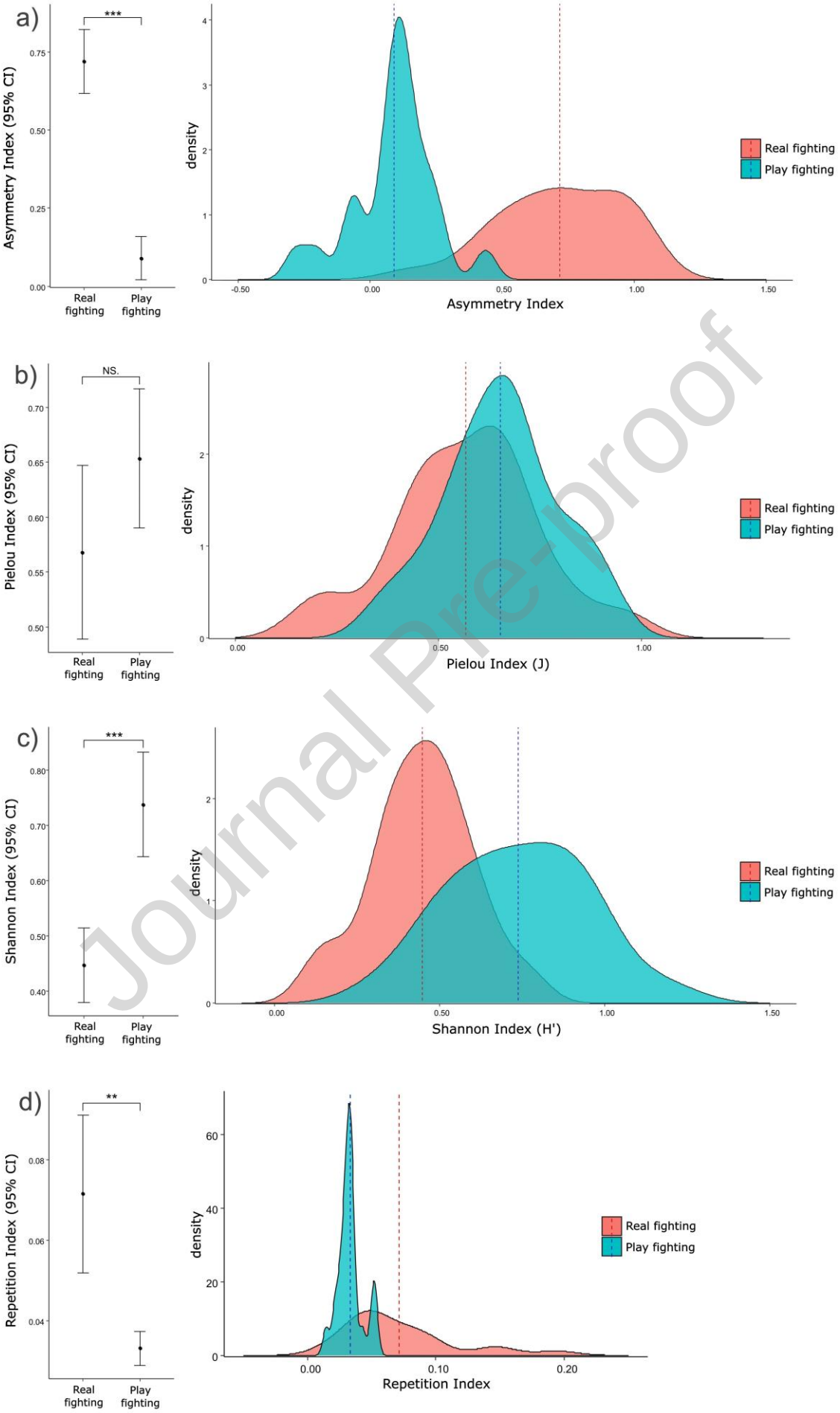


Fig. 3 Difference between real fighting and play fighting (verified via t-test for independent samples) in piglets shown as error bar (left) and density plot (right). a) Asymmetry Index values; real fighting shows the highest levels of asymmetry ($p < 0.001$). b) Pielou Index values; real fighting and play fighting show comparable levels of evenness ($p = 0.107$). c) Shannon Index values; real fighting shows the lowest levels of variability ($p < 0.001$). d) Repetition index values: real fighting shows higher levels of repetition ($p = 0.001$). Error bars: 95% confidence interval (bars) around the mean (circles). NS = non significant, ** = $p< 0.01$, *** = $p< 0.001$

Tables

Table 1

Composition of the litters of piglets (F: female; M: male)

Litter	Individuals	Date of birth
LD	10 (5 F; 5 M)	16 Sept 2018
BB	6 (2 F; 4 M)	3 Oct 2018
NN	8 (4 F; 4 M)	5 Nov 2018

Table 2

Description of piglets' behavioural patterns recorded in the current study. Integrated or modified from other ethograms (Newberry & Wood-Gush, 1988; Donaldson et al., 2002; Chaloupková et al., 2007; Rauw, 2013; Horback, 2014; Špinka, 2017; Brown et al., 2018; Cordoni et al. 2021). LA = locomotor/acrobatic pattern, C = contact pattern.

Patterns exclusive to play context		
Category	**Pattern**	**Description**
Neutral	Flopping	A piglet drops to the ground from the upright position to a sitting or lying position. There is no contact with an object or another individual that could cause the change in position.
	Head tossing	A piglet swings its head from one side to another
	Hopping	A piglet has either its two front feet or all four feet off the ground at one time through a upwards jumping movement. The piglet continues facing the same original direction for the whole of the behaviour
	Leg spreading	A piglet spreads its fore and hind limbs and it moves quickly from side to side
	Nudging	A piglet uses its snout to touch and push another piglet's body (excluding nose-nose contact) without causing the displacement of the contacted piglet
	Playing with object	A piglet manipulates an item or securely holds it in its mouth, shaking it or carrying it around
	Pivoting	A piglet twirls its body on the horizontal plane by a minimum of 90°
	Scampering	A piglet performs two or more forward directed hops in rapid succession
Defensive	Kneeling	A piglet goes down on its forelimb knees
Patterns exclusive to aggressive context		
Category	**Pattern**	**Description**
Neutral	Threatening	A piglet arches its back to the opponent or makes a forward movement of its head and stares at the opponent with no physical contact
	Asymmetric parallel	The piglets face the same direction, standing side by side with one of them staying slightly ahead of the other. A piglet ahead moves forward, pushing the opponent away with its shoulder and moves its head away from the opponent
Defensive	Avoiding	A piglet moves away with a depressed tail when the opponent approaches
	Fleeing	A piglet runs away from the opponent
	Withdrawing	A piglet tries to move away from the opponent while the opponent continues to bite it repeatedly

Patterns shared by play and aggressive contexts		
Category	**Pattern**	**Description**
Neutral	Head tilting	A piglet turns its head away from the opponent when the opponent passes or approaches
Defensive	Resting	A piglet sits or lies down during the session.
Offensive	Biting	A piglet opens its mouth and closes its teeth on the opponent's flesh
	Head knocking	A piglet hits another individual with its head (while keeping its mouth closed)
	Kicking	A piglet hits with one or both hindlimbs the opponent
	Lifting	A piglet puts its snout or head below the others neck or belly and pushes upwards.
	Mounting	A piglet rises upon the rear of the partner
	Pushing	A piglet presses its head, neck, shoulder or body against the opponent
	Biting attempt	A piglet opens its mouth, directs or turns its head towards the body of the opponent and closes its mouth but misses contact
	Running after	A piglet rapidly follow another individual

Highlights

- Play- and real-fights share many patterns so it may be hard to tell the two apart
- Via structural indices we measured play- and real-fight differences in piglets
- Play-fights had less repeated but more symmetrical patterns than real-fights
- Piglets' play-fights retain some but not all of the features expected in play
- Play-fights are probably competitive and serve also some functions of real-fights