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„Investigating temporal features as indicators of the quality of positive human-animal interactions“

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Contents

1. Abstract

In this exploratory study, we investigated temporal features of positive human-animal interactions (HAI). Positive HAI have potential benefits on animal welfare, and though their overall effects are well-documented, their underlying mechanisms remain poorly understood. Temporal features have been linked to emotional states during human interactions, but this link remains unexplored in the context of HAI. This research aimed to characterise temporal features of different HAI and their potential link with the pigs' engagement and affective state. Specifically, this study focused on temporal behavioural synchrony, assessing the temporal organisation of the pig and human behaviours. We compared two types of interactions: free-form (FF) and imposed contact (IC). In the FF interactions, the human's responses were contingent upon the pig's actions, offering gentle tactile contact (such as strokes, rubs, and scratches) in response to the pig's cues, to which the pigs had been habituated. Conversely, the IC interactions involved non-contingent human behaviour, following a standardised protocol consisting of a repeated sequence of approaching, imposed contact, and withdrawing. Using cross-recurrence quantification analysis (CRQA), we extracted three metrics of synchrony to describe this temporal organisation: recurrence rate (behavioural matching), entropy (predictability), and Qlos (leader-follower relationship). Contrary to our expectations, the results showed higher entropy in FF interactions (P=0.024) and a tendency towards higher recurrence rate in IC interactions (P=0.073), while no significant effect could be found regarding Qlos. These results likely reflect the structured nature of the IC interactions versus the unstructured nature of the FF interactions. However, two behavioural profiles, Component 1 'Conflict of motivation: Engage with human versus stress behaviour' and Component 2 'Human versus environment', identified by principal component analysis, were found to be associated with the synchrony metrics, where higher recurrence rate was associated with higher engagement and less indicators of stress (P=0.017), while higher recurrence rate (P=0.002) and lower entropy (P=0.005) were associated with higher interest in the human. Further analysis is required to measure level of contingency and its associations with the pigs' general behavioural responses in both interaction contexts.

Key words: positive human-animal interactions, temporal synchrony, behavioural matching, entropy, leader-follower relationship, cross-recurrence quantification analysis

2. Theoretical background

2.1. Human-animal interactions (HAI)

Interactions between humans and animals, referred to as Human-Animal Interactions (HAI), encompass mutual and dynamic exchanges between humans and animals and their psychophysiological effects (Griffin et al., 2011). The intricate and multifaceted interactions between humans and animals have drawn the focus of researchers, professionals, and the wider public for a considerable period. As Hosey and Melfi (2014) state in their review, although research on HAI dates back to the 1980s, there remains an existing gap in understanding positive aspects of HAI. They found that historically, investigations have primarily concentrated on the consequences of negative interactions, yet a transformative change in animal welfare research has led to an increasing focus on positive welfare in recent times. This shift towards focusing on positive interactions in human-animal research can be explained by changing societal values and a deeper scientific understanding of animal welfare (Webster, 2005), as well as the recognition of the mutual benefits derived from these interactions, for example the rise of companion animals and pets, strengthening the bond between humans and animals, offering emotional support, companionship, and therapeutic benefits (Serpell, 2011). These HAI exist amongst a broad range of human-animal relationships (HAR), spanning from the domestication of animals for companionship, farming, working, to animal-assisted therapy and interactions within ecosystems. These engagements possess a substantial role across diverse cultures, societies, and ecological systems, impacting not just the welfare of both humans and animals, but also moulding our comprehension of empathy, mutual existence, and the interconnectedness shared among different life forms (Beetz et al., 2012). HAI hold direct and indirect implications for animal welfare, given their potential implementation as social enrichment and significant role in shaping HAR (Hosey & Melfi, 2014; Rault et al., 2020). The direct implications of HAI for animal welfare can be seen in the employment of HAI as social enrichment (Windschnurer et al., 2022). Social enrichment can take the form of training sessions, which have been shown to have a positive effect on animal welfare by creating opportunities for positive engagement between the animal and its caregiver or keeper (Claxton, 2011; Melfi, 2013, 2014). A study by Fernandez, Upchurch and Hawkes (2021) has shown a positive effect of public feedings, during which visitors of the zoo are allowed to feed the animals, by increasing social activity, foraging and decreasing inactivity in zoo-housed elephants. HAI have been shown to be perceived as the third most important form of enrichment for mammals in captivity, after feeding and tactile enrichment (Hoy, Murray & Tribe, 2010). In contrast to the direct implications of HAI, the indirect implications through facilitating positive HAR has been extensively documented.

HAR refer to the complex and dynamic bonds involving interactions, companionship, caregiving, and coexistence between humans and animals (McCardle et al., 2011). This interplay can subsequently elicit positive emotions (Boissy et al., 2007), confer intrinsic benefits to the animals, and thereby improve overall animal welfare (Rault et al., 2020). HAR have an extensive and intricate history that dates back thousands of years. Throughout different civilisations and cultures, humans and animals have shared diverse and interconnected roles, ranging from companionship and work partnerships to spiritual significance and food sources (Bulliet, 2005; Clottes & Lewis-Williams, 1998; Diamond, 2002; Teeter, 2011). A positive HAR involves the animal displaying voluntary engagement, proximity, and indications of anticipation, enjoyment, relaxation, or other cues signalling a rewarding interaction with humans (Rault et al., 2020). A better understanding of HAR holds significant importance for animal welfare, as it enhances our comprehension of the dynamics between humans and

animals, ultimately contributing to enhanced care, treatment, and overall well-being for animals. This understanding can facilitate the identification of factors that impact animal well-being, thus enabling the development of enhanced living conditions, enrichment practices, and healthcare strategies (Serpell, 2011).

As the domestication of animals has brought humans and animals into closer contact, the increased proximity has enabled more frequent and intricate interactions, leading to more frequent HAI, which in turn transformed how the public perceives animals, shifting them from mere sources of food or labour to cherished companions and family members (Grandin, 2009). Understanding the dynamics of HAI is pivotal for animal welfare, with both positive and negative interactions profoundly influencing the well-being of animals. Insights into HAI assist in recognising stress and mental health issues in animals, enabling timely interventions, particularly relevant for companion animals and those in captivity (Fraser, 2006). Additionally, this understanding raises ethical awareness and encourages responsible stewardship, influencing the establishment of guidelines and policies promoting humane treatment and ethical practices towards animals (Webster, 2005). The shift towards understanding and promoting positive interactions between humans and animals not only has implications for animal welfare but also has important applications in various therapeutic contexts. Research in the area of animal-assisted interventions is growing, and these interventions are being recognized for their positive impacts in healthcare, education, and mental well-being. (Fine, 2010). Animal-Assisted Interventions (AAI), encompassing therapies and activities, alleviate stress in humans and can provide enrichment for certain animals, creating a mutually beneficial welfare enhancement (Cherniack & Cherniack, 2014). AAI and the resulting HAI have shown to promote social benefits for dogs, as they naturally desire contact with humans, sometimes even preferring it to contact with their own species (Wells, 2004; Wolfe, 1990). There are also physiological benefits for dogs, as their heart rate and blood pressure has been shown to decrease during interactions with humans (Gantt, Newton, Royer & Stephens, 1966; Baun et al., 1984, Odendaal and Meintjes, 2003, Vormbrock and Grossberg, 1988). Furthermore, ensuring proper care and environmental enrichment through positive interactions further augments animal welfare by addressing their physical and psychological needs (Garner, 2005). Therefore, HAI yield benefits for both humans and animals alike.

2.2. Pigs as a model species

Pigs serve as a fitting model species for HAI research, as pigs are domesticated animals that exhibit a strong inclination to engage with humans and are increasingly being embraced as pets. They have already gained recognition as a pertinent subject for the exploration of HAI, evidenced by previous studies (Hemsworth & Coleman 2011; Rault 2016; Tallet et al 2018). Furthermore, research has demonstrated their responsiveness to human interactions, notably changes in brain activity triggered by human touch as observed through electroencephalography (Rault et al 2019). Behaviourally, pigs showcase expressiveness and robust sociability, alongside advanced cognitive capabilities, rendering them a fitting choice for behavioural research (Jensen, 2016). A notable advantage lies in the uniformity of the pigs on Vetmeduni Vienna's research farm, possessing well-documented life history traits. This characteristic provides an edge over studying animals with varied experiences stemming from different owners, which could potentially confound findings.

Fostering positive HAI plays a pivotal role in enhancing the well-being of domestic pigs and establishing a harmonious relationship. Positive social interactions, encompassing activities like playing, and grooming, cater to pigs' social nature and contribute to their welfare (Hemsworth & Coleman, 2011). The act of providing gentle tactile contact to pigs yields a range of beneficial outcomes. This includes a decreased fear response towards humans and husbandry procedures (Hayes et al., 2021a; Hayes et al., 2021b; Wang et al., 2020). Moreover, such contact has been associated with lower basal cortisol levels and heightened immunological responsiveness, as indicated by Pedersen et al. (1998). Pigs subject to this interaction demonstrate distinct behaviours, including the production of shorter grunts, which are linked to a positive affective state (Briefer et al., 2019; Friel et al., 2019; Villain et al., 2020). Additionally, pigs exposed to gentle tactile contact exhibit a positive judgment bias, an effect demonstrated by Brajon et al. (2015). Gentle handling and touch by caregivers can instil positive associations, reducing fear and stress and nurturing a favourable human-pig dynamic (Boissy et al., 2007). Therefore, cultivating positive HAI that align with pigs' behavioural and welfare needs, such as their social nature, emotional well-being, stress reduction and cognitive stimulation, can significantly enhance their welfare and promote a more harmonious relationship between humans and pigs. Such considerations are paramount for ensuring the well-being of these animals in various contexts.

2.3. Synchrony

Synchrony can contribute to the understanding and cultivation of positive HAI, as it is an important factor in various interaction related research.

2.3.1. Temporal synchrony

For this study, we have operationally defined temporal synchrony as interaction rhythms and coordination between pairs of individuals or dyads (Feldman, 2006; Greenfield et al., 2021),. Interaction rhythms encompass synchronised and simultaneous movements, actions, or conduct exhibited by individuals or groups, and vary widely across different contexts. It also entails precise timing and coordination of actions, gestures, or expressions among individuals, reflecting a sense of mutual or coordinated engagement (Richardson et al., 2009). However, synchrony in the form of rhythmic patterns can be simultaneous and identical or mirrored and alternating (Fogel et al., 1992).

In relation to our study, synchrony in dyadic interactions is of particular interest, where individuals sharing common interests, such as parent-offspring pairs or social companions, engage in synchronised behaviours (Feldman, 2006; Greenfield et al., 2021). Even adversarial pairs, such as those competing for territory, might be considered a dyad, if they maintain a consistent relationship over a prolonged period. Examples for synchrony in interactions between human dyads include musical (Keller, Novembre & Hove, 2014) or social engagements (Hove & Risen, 2009; Wiltermuth & Heath, 2009), while alternation is common during conversation (Nguyen et al., 2020; Wilson & Wilson, 2005). Among non-human animals, like dolphins (Nakahara & Miyazaki, 2011), harbour seals (Ravignani, 2019), bats (Carter, Fenton & Faure, 2009), rodents (Okobi et al., 2019; Rado et al., 1987), anurans (Caldwell & Shepard, 2007) and insects (Bailey & Hammond, 2003) alternation is more prevalent during social interactions, except for a few instances where pairs synchronise their

signals (Backwell et al., 1998; Grafe, 1999; Greenfield, 1994; Hall, 2009; Moore et al., 2020). This alternation, often guided by rules that prevent overlapping, aids in ensuring distinct communication for both the sender and receiver (Caldwell & Shepard, 2007; Demartsev et al., 2018; Klump & Gerhardt, 1992). Overlapping sounds or visual signals can obscure clarity, as a non-human animal focused on conveying its own message might find it mentally challenging to attend to its partner's signal (Demartsev et al., 2018; Levréro et al., 2019). Synchronised signals in non-human primates, although rare, could serve as a mechanism for a pair to communicate the strength of their bond and to predict grooming rates and behavioural coordination (Geissmann & Orgeldinger, 2000). Furthermore, displays of animal communication signalling encompass some of the most prominent instances of synchronisation in the realm of biology. Thus, the variation in synchrony patterns across species highlights the need for comparative studies to gain insights into the underlying mechanisms and evolutionary aspects of synchrony (Bouwer et al., 2021).

Moreover, while certain species exhibit several adaptive reasons for favouring synchronisation, in other cases, synchronisation arises incidentally from signalling behaviours and does not confer any specific advantage to the individuals signalling (Greenfield et al., 2021). In the realm of social interactions between humans, the importance of temporal synchrony has been underscored in the context of fostering rapport (La France, 1979) and cooperation between individuals (Chartrand & Bargh, 1999). Conversations and coordinated activities provide opportunities for synchronising behaviours and gestures, thereby fostering a sense of connection and mutual understanding (Chartrand & Bargh, 1999). This can be seen in the mirroring and mimicry of postures, gestures and mannerisms, which have been shown to play a role in enhancing social bonds. (Chartrand & Bargh, 1999; Lakin et al., 2003). This affiliative tendency to synchronise behaviour is pivotal in sustaining harmonious relationships, possibly playing a significant role in the evolution of human social dynamics (Lakin et al., 2003), thereby highlighting the importance of synchrony in human interactions.

Additionally, parent-infant synchrony in humans assumes a crucial role in the development of infants' cognitive, social-emotional, and self-regulatory abilities (Feldman & Eidelmann, 2004). Synchrony contributes to fostering a secure attachment between infants and their caregivers by playing a vital role in nurturing the infant's sense of safety and security (Feldman, 2007a). Furthermore, as shown in studies by Feldman (2007a; 2007b), it enables the infant to acquire the skills of managing stress and emotions by observing and responding to the caregiver's emotional cues. These studies also found that interactions characterised by synchrony between caregivers and infants hold a significant role in fostering the latter's brain development, particularly in regions linked to emotional processing and regulation, as well as social competence and empathy. Additionally, the degree of behavioural synchrony tends to increase with greater affiliation between humans (Chartrand & Bargh, 1999). This principle extends to human-canine relationships, where evidence showcases robust temporal and activity synchrony between dogs and their owners (Duranton et al., 2017). Hence, these studies show the importance of synchrony in forming strong human-infant and human-animal relationships.

Furthermore, temporal synchrony within the context of HAI can serve as an indicator of positive HAR (Duranton et al., 2017), as it holds a pivotal role within positive HAR for various reasons. For one, it serves as a facilitator of effective communication and mutual comprehension between humans and animals (Pirrone et al., 2017). Moreover, synchrony is intrinsically linked to health advantages. It has been correlated with the reduction of stress hormone levels and the enhancement of physiological well-being for both humans and animals, underscoring its far-reaching positive influence on overall health and quality of life (Feldman,

2007a; Odendaal & Meintjes, 2003). However, even though synchrony plays a crucial role in human and animal interactions, the tendency for synchronous behaviour is still understudied in the context of interspecific communication like HAI.

2.3.2. Entropy

The exploration of temporal synchrony serves as a fundamental cornerstone in understanding the dynamics of behavioural exchanges, especially within HAR (Rault et al., 2020). The concept of entropy, however, introduces a fascinating layer to this understanding, providing a measure of disorder and unpredictability within systems, which proves invaluable in deciphering the intricacies of synchrony and its implications for communication and connection between individuals or dyads (Hirsh, Mar & Peterson, 2012; Vanoncini et al., 2022). Entropy as an aspect of synchrony refers to the level of unpredictability within a system, quantifying the level of uncertainty within a distribution (Vanoncini et al., 2022). This concept is vitally important in the realms of physical information, as well as psychological sciences (Hirsh, Mar & Peterson, 2012). The notion of entropy originated within the domain of thermodynamics; nevertheless, it has also found application in the investigation of linguistic and social interactions. (Vanoncini et al., 2022). In a psychological context, entropy is linked to an individual's capacity to effectively engage in work and alleviate anxiety by reducing the uncertainty encountered in daily life, as this increased uncertainty often corresponds to elevated levels of anxiety (Hirsh, Mar & Peterson, 2012). Therefore, higher levels of entropy are related to higher uncertainty, while lower levels of entropy stand for higher predictability (Vanoncini et al., 2022). According to a study by Guevara et al. (2017) an increase in complexity and ambiguity of dyadic exchanges within social interactions leads to a corresponding elevation in entropy, whereas low entropy indicates regularity. They found that elevation in entropy indicates that the coordination of the dyadic system becomes less regular and more complex. Given that entropy reflects the notion of unpredictability, thus having the ability to quantify the inherent uncertainty within a distribution which, in the context of synchrony, translates to the level of agreement between two entities, it emerges as a suitable metric for assessing synchrony (Guevara et al., 2017; Vanoncini et al., 2022).

2.3.3. Leader-follower relationship

The examination of leader-follower relationships in a human-animal context adds another layer of insight into synchrony, as it delves into the temporal coordination of behaviours between individuals, revealing patterns of interaction and communication (Feldman, 2006; Griffioen et al., 2019). A leader-follower relationship refers to the temporal coordination of behaviours or actions, for example between a human and an animal or between two humans, where one participant's actions either precede (lead) or follow (lag) the actions of the other participant (Feldman, 2006; Feldman, 2007a; Griffioen et al., 2019). This type of relationship can reveal patterns of interaction, communication, or influence between humans and animals (Griffioen et al., 2019). A leader-follower relationship can provide insights into the dynamics of cooperation, coordination, and social bonding between species (Range et al., 2019). In essence, leader-follower relationships are a manifestation of synchrony, where individuals take turns in guiding interactions, resulting in a rhythmic and coordinated exchange (Feldman, 2006; Feldman, 2007a). Exploring leader-follower relationships provides insights into how synchrony unfolds within interactions between humans and animals, shedding light

on the dynamics of shared engagement and cooperation (Feldman, 2006; Feldman, 2007a; Griffioen et al., 2019; Range et al., 2019).

In a study conducted by Range et al. (2019), the dynamics of leader-follower relationships were explored in interactions involving humans and wolves, as well as humans and dogs. Notably, distinctive variations between wolves and dogs become apparent upon delving into the specifics of cooperative interactions. The analysis indicated that wolves tend to display a higher tendency to initiate actions and assume leadership roles, whereas dogs frequently exhibit a preference for waiting for the human partner to initiate actions before following suit. This suggests the potential existence of unique variations in the leader-follower dynamics between humans and various animal species. Such leader-follower relationships are frequently observed in studies involving mothers and infants, aiming to identify the initiator of interactions and the direction of influence within the relationship (Feldman et al., 1999; Feldman, 2006). For example, an infant-leads/mother-follows relationship indicates a better form of synchrony for the infant at 3 months of age, also implying a mother's responsiveness to microlevel shifts in the infant's affective state (Feldman et al., 1999).

2.4. Reciprocity

Reciprocity can be defined as a behavioural adjustment involving responses that are contingent and directed (Burgoon et al., 1993). Numerous diverse mechanisms underlie reciprocal exchanges, some of which interact with bonding processes (Freidin et al., 2017). Examples of these mechanisms include associative learning in social contexts (Hauser et al., 2009; Carter, 2014), emotional contagion (Palagi et al., 2014), behavioural mimicry (van Baaren et al., 2004), empathy, and a sense of fairness (Yamamoto & Takimoto, 2012). These broad and varied social affective mechanisms may explain why direct reciprocity, which refers to reciprocity between individuals who have benefitted directly from one another, is common among social vertebrates (Freidin et al., 2017). Furthermore, Yee et al. (2008) defined affiliative reciprocity as the balance between received and initiated affiliation between individuals, serving as a protective buffer against daily stressors. They found that rats have exhibited a safeguarding effect of affiliative reciprocity during stressors, particularly in relation to early mammary tumour development and overall early mortality. Conversely, low affiliative reciprocity has been identified as a potential risk factor for early mammary tumour growth, early mortality and neophobia in rats (Cavigelli & McClintock, 2003; Cavigelli, Yee & McClintock, 2006; Yee et al., 2008). This link between reciprocity and health has also been found in mother-infant studies, where reciprocity between mothers and infants has been linked to better adjustment and reduced adolescent depression (Feldmann, 2010). Additionally, the reciprocity experienced between mothers or fathers and their children in early childhood predicts higher social competence and lower aggression during preschool years (Flanders et al., 2009; Feldman et al., 2013). Reciprocity has significance in evolutionary and mental health contexts, playing a pivotal role in close relationships, aiding in adapting to the social world (Feldman et al., 2013).

The intricate relationship between reciprocity and synchrony becomes clearer as we directly compare the components of reciprocity and the temporal coordination inherent in synchrony. Reciprocity and synchrony are two distinct yet interconnected concepts in the realm of social and psychological research. Although both reciprocity and synchrony are both temporal aspects of interactions between individuals, they focus on different qualities. The key difference between reciprocity and synchrony lies in the nature of the interaction. Reciprocity

emphasises the mutual exchange of actions or responses, highlighting the give-and-take aspect of the interaction (Fehr & Gärtner, 2000), whereas synchrony focuses on the temporal coordination and alignment of behaviours, emphasising the simultaneous or coordinated engagement (Feldman, 2007a). Thus, in reciprocity, individuals respond to each other's actions in a balanced manner, whereas in synchrony, individuals engage in activities or behaviours simultaneously and in coordination with each other. In the end, both concepts contribute to the complexity of social dynamics and relationships in various social and psychological contexts. Feldman (2012) emphasises that "Synchrony lays a crucial foundation for the development of social communication skills, joint attention, and reciprocity." Thus, synchrony facilitates effective communication and shared experiences, which are essential for the emergence of reciprocal social interactions and cooperation in social relationships, thereby facilitating reciprocity. In intraspecies contexts, synchrony and reciprocity are often intertwined concepts where synchronous actions are assumed to have reciprocal causality (Lorenz et al., 2016). Positive synchronous interactions have been characterised as being adaptive, flexible and reciprocal (Reyna & Pickler, 2009). However, in interspecies contexts, this assumption is less clear. Our lack of understanding of interspecific communication prevents us from ascertaining this causality. This parallels the research in mother-infant interaction studies, where a specific focus has been placed on the contingent aspect of interactions.

2.4.1. Contingency

Contingency refers to the concept that one event or outcome is dependent on, or contingent upon, the occurrence of another event or set of circumstances, implying that there is a cause-and-effect relationship between different elements or variables (Abbott, 2001; Steinmetz, 1998). It signifies that certain events are contingent on the presence or absence of other events or circumstances, introducing an element of uncertainty and interdependence (Abbott, 1988; Abbott, 2001; Ragin, 1987). In a psychological context, contingency is often being researched in studies related to behaviourism (Skinner, 1953), learning theories (Houwer & Beckers, 2002) and mother-infant studies (Beebe et al., 2011; Beebe et al, 2016b; Markova & Legerstee, 2006). Research by Gergely and Watson (1996; 1999) showed, that contingency is the ability to recognise and understand the relationships between an infant's actions or responses and the external world based on temporal, spatial, and intensity-related factors. This innate capacity helps infants develop an early understanding of cause-and-effect relationships and their own agency in the world. Thus, in these studies, researchers examine how specific behaviours are contingent on certain outcomes or results. Examining contingency in the context of HAI could yield valuable insights into reciprocal causality within synchronous patterns, thereby enhancing our understanding of HAI dynamics.

2.5. Interaction paradigms

Mother-infant and HAI studies share several parallels. As stated by Höhl (2017), research techniques such as questionnaires and self-reports cannot be used to gather introspective information via verbal communication, and behavioural studies with infants and animals face limitations related to assessable motor actions. These challenges arise in research involving dogs and other non-human animals as they are also non-verbal subjects, mirroring the complexities encountered in psychological investigations of social and emotional development in human infants (Kujala, 2017; Höhl, 2017). Therefore, mother-infant studies utilise a range of non-verbal paradigms to explore the intricate dynamics, relationships, and

developmental processes between mothers and their infants, several of which could be applied to HAI studies. For instance, observational research, which entails methodically observing and documenting interactions between mothers and infants in real-life environments, is commonly employed (Babbie, 2016). Furthermore, researchers may utilise coding systems to classify behaviours, including maternal responsiveness, infant communication, and displays of emotional expressions (Ainsworth & Bell, 1970). Other mother-infant paradigms have already been applied to HAI. For example, the Still Face Paradigm was adapted for dogs and used to study their affiliative behaviour changes according to changes in human's behaviour (Barrera, Guillén-Salazar & Bentosela, 2023). Furthermore, the Emotion Recognition Paradigm has been adapted to human-dog research as well, exploring dogs' ability to infer emotional states from human facial expressions (Albuquerque et al., 2022). Given the shared characteristics of non-verbal communication between infants and non-human animals, and their reliance on behavioural paradigms, the methodologies employed to investigate mother-infant interactions appear suitable to be adapted for the study of HAI. The exploration of non-verbal paradigms in comparative research can provide a foundation for understanding interaction dynamics across social and psychological contexts.

2.5.1. Ecological validity

In addition to the aforementioned parallels, human interaction studies and HAI studies also share similar issues in their approaches. Conventional interaction paradigms pose certain challenges due to factors such as constrained and unnatural contexts (Dale et al., 2013) that may not accurately reflect real-life scenarios. In behavioural research, the context in which observations are made are of great importance regarding the ecological validity of study findings, as behaviour is often altered in controlled settings as opposed to natural settings, thus not accurately depicting natural behaviours and behavioural responses (Martin & Bateson, 2007). Embracing free-flow interactions (Dale et al., 2013) and ecologically valid paradigms enables a more realistic exploration of HAI, moving beyond artificial settings and enhancing the understanding of genuine social dynamics. Thus, in the realm of HAI research, authentic and ecologically valid approaches are of great importance. For instance, in a study of dog-human play interactions, researchers have shifted their focus from controlled laboratory settings to unscripted, free-flow play sessions at dog parks, which allowed for the capture of more genuine social dynamics and better understanding of the play behaviour of dogs and their owners (Bekoff & Fagen, 1981). Similarly, in therapeutic horse-riding programs for individuals with disabilities, therapists and participants have engaged in ecologically valid activities, such as grooming and riding horses, in naturalistic settings, as this approach provides deeper insights into the therapeutic benefits of human-horse interactions beyond clinical environments (Schultz, Remick-Barlow, & Robbins, 2007). Moreover, a study by Falk et al. (2007) assessed the impact of zoo visits on visitors' attitudes and conservation support, by transitioning from guided tours to allowing visitors to explore zoo exhibits freely, which provided a more genuine understanding of the influence of zoo experiences. Similarly, in healthcare settings, researchers investigating the effectiveness of Animal-Assisted Therapy (AAT) conducted therapy sessions in patients' rooms or designated therapy spaces rather than sterile clinical environments. These ecologically valid sessions yielded deeper insights into the therapeutic benefits of interactions with therapy animals (Barak et al., 2001). Furthermore, when assessing animal welfare on farms, researchers engaged in on-site, ecologically valid observations to comprehensively evaluate the well-being of livestock, ensuring assessments align with the animals' daily experiences (Von Keyserlingk et al., 2013). Embracing free-flow interactions and ecologically valid paradigms thus enhances the authenticity of HAI research and contributes to a deeper

understanding of the dynamics underlying human interactions with animals across various contexts. In this paper, we aim to address this issue of ecological validity by comparing free-flow and unnatural interactions.

3. Present study

This research project is part of the FWF funded project (P 33006-B) titled "Fond of each other: Positive Human-Animal Interactions", which aims to explore and understand the underlying mechanisms of positive interactions between humans and animals.

3.1. Research aim and hypotheses

In this study, the focus is on understanding positive HAI, which are essential building blocks to establish and facilitate positive HAR (Hosey & Melfi, 2014; Rault et al., 2020). The aim of this exploratory study is to characterise the temporal behavioural features of these interactions, with a particular focus on temporal synchrony. As this is an exploratory study which aims at investigating the applicability of the methodology used in mother-infant interaction studies to HAI, there is currently no understanding of how this temporal feature is characterised in human-pig interactions or its potential association with engagement and affective states.

To better understand the characterisation of synchrony in HAI, two objectives need to be fulfilled. The first objective, Objective 1, is to characterise the different HAI in both experimental conditions, free-form (FF) and imposed contact (IC) (see 4.2. Experimental Procedure), in terms of temporal synchrony. Temporal synchrony refers to the temporal matching of touch between the pig and human, encompassing behavioural matching, predictability as in entropy, and the leader-follower relationship (Wallot and Leonardi, 2018; Griffioen et al., 2019; Vanoncini et al., 2022). The second objective, Objective 2, is to determine a possible correlation between the temporal features and the pigs' general behavioural response pertaining to each type of interaction in the FF and IC conditions respectively.

Therefore, our hypotheses are the following:

Regarding Objective 1, we expect to find:

1) higher Recurrence Rate (RR), indicating more behavioural matching, during FF condition and lower RR, indicating less behavioural matching, during IC condition (Griffioen et al., 2019; Vanoncini et al., 2022),
2) lower Entropy (ENTR), indicating more predictability, during FF condition and higher ENTR, indicating less predictability, during IC condition (Vanoncini et al., 2022),
3) more pig-leads/human-follows (Qlos) during FF condition and less pig-leads/human-follows during IC condition (Feldman., 2006; Griffioen et al., 2019).

Regarding Objective 2, we hypothesised that pigs show more indicators of engagement, indicated by contact by pig, and positive affect, indicated by approach behaviour, tail wagging, low frequency calls, during interactions characterised by:

1) higher RR (Griffioen et al., 2019; Vanoncini et al., 2022),
2) lower ENTR (Vanoncini et al., 2022),
3) more pig-leads/human-follows (Feldman, 2006; Griffioen et al., 2019)

See 4.3.2. Cross-recurrence quantification analysis (CRQA) for further details regarding the metrics above. The control and outcome measures can be found in the supplementary material in Table 1.

4. Methods

This study was approved by the ethics committee of the University of Veterinary Medicine Vienna (approval number: ETK-182/12/2020), in accordance with the EU Directive 2010/63/EU.

4.1. Participants

The study was conducted at the research farm of the University of Veterinary Medicine Vienna (Vetfarm 'Medau') using a total of 30 female pigs (n = 30), which were a crossbreed of Large White and Pietrain. The pigs were divided into two batches of 15 pigs each. Before weaning, the sows and their piglets were housed in BeFree farrowing pens of 2.22 m × 2.86 m, featuring a plastic slatted floor and a concrete lying area. Pigs' tails were kept intact. At approximately 28 days of age (weaning), 15 female pigs from three litters (five per litter) were selected for the study based on their health condition, avoiding extreme weight differences among the litters. They were then housed in groups of three pigs (one pig from each litter) in weaner pens equipped with a multi-place feeder, a drinker, and a shelter area. Pen enrichment was provided to the pigs in the form of straw, sawdust, a braided jute rope, and an orange dog toy ball. The pens were spot-cleaned as needed and deep cleaned twice weekly. The room temperature was regulated at around 22°C, and thermal comfort was ensured for the pigs through floor heating, while natural lighting was provided through room windows. From these 30 pigs, three pigs were excluded from the analyses. For two of them, the test sessions were under 300 seconds as they had to be ended early due to stress reactions by the pigs. The third exclusion was made because the pig did not make contact with the human during the session, rendering the synchrony metrics incalculable.

4.2. Experimental procedure

This study was conducted in two parts, with the first part having been previously coded and analysed prior to my involvement. In this first part, the general behaviour exhibited by the pigs was assessed to explore potential differences in their behavioural responses when subjected to the two types of interactions. In the second part of the study, the focus was placed on studying synchrony to ascertain probable differences in the dynamics of interactions that might impact these behavioural responses.

For the first part of the study, the pigs underwent a gradual three-week habituation process to human presence, human contact, and the test pen environment. During this period, the same familiar human provided gentle tactile contact to the pigs during the habituation and test sessions. The human entered the pen and encouraged the pigs to approach through soft speech and eye contact, allowing the pigs to initiate contact. Stress reactions were closely monitored, and if the pigs showed signs of stress, the sessions were immediately ended to ensure the animals' welfare. To facilitate individual identification, the pigs were marked on their back with an animal marker spray. After the habituation period, all pigs underwent testing in both

the FF and IC conditions twice. A counterbalanced design was implemented, where half of the pigs started with the FF condition, while the other half began with the IC condition, utilising a pseudo-randomized approach. To minimise carryover effects between test situations, the pigs were tested twice in each condition on alternate days.

In the free-form (FF) condition, the pigs were allowed to voluntarily approach and interact with the kneeling familiar human, who was located in the corner of the test pen opposite the door. The human remained in this position throughout the 5-minute session and responded to the pigs' solicitations using unrestricted, free-form contacts, such as stroking, scratching, belly-rubbing, and visual cues like eye contact. In contrast, the imposed contact (IC) condition involved the human delivering standardised contact to the pig, disregarding the pig's intent to interact. The human imposed contact by approaching the pig for 8 seconds and gently stroking along the side of the body every 2 seconds for 15 seconds. Subsequently, the human withdrew and assumed a seated position for 7 seconds before repeating the entire sequence 10 times over the 5-minute session, while disregarding any interaction solicitations from the pig. All test sessions were audio and video recorded with 29.97 frames per second continuously.

It is noteworthy that the fieldwork involving the pigs was previously conducted by Vetmeduni Vienna, and this thesis specifically focuses on the video coding and statistical analyses relating to the investigation of temporal synchrony in the study. The ethogram employed was designed to be comparable in both test conditions, ensuring consistent behaviours between the pig and the human participants.

4.3. Data acquisition

4.3.1. Video coding

For the second part of the study, a behavioural analysis was conducted by micro-coding second-by-second in the program BORIS (Friard & Gamba, 2016). The observed behaviours of the pigs and the human were coded for 30 dyads over 60 interaction sessions, later excluding three dyads, thus six sessions, from the statistical analysis (see 4.1 Participants). For each interaction session, 300 seconds from the video-recordings were coded based on a pre-defined ethogram (Table 2). The ethogram was developed by using simple and comparable behaviours between the human and the pig, thus enabling the possibility of “behavioural matching”.

The coded data was then exported as two categorical time-series with second-by-second data for time-series analysis. Furthermore, to ensure the reliability of the ethogram and the coded behaviours, the inter-rater reliability was explored for four of the 60 total videos, making sure to be balanced for batch and test condition, as well as covering all behaviours included in the ethogram. The videos were coded by two trained coders, achieving high results (average kappa = 0.855). To ensure the consistent coding of behaviours, we explored the intra-rater reliability for one of the videos, achieving excellent results (kappa = 0.955).

Table 2. Ethogram for behavioural observation of the interaction bouts during test sessions. Behaviours within subject are mutually exclusive but between subject are not mutually exclusive.

Subject	Behaviour	Description
Pig	Pig approaching	Pig takes more than two steps in a direction that decreases the distance between pig and human, until making physical contact (within 3s). Also includes moves snout (by extension of the neck) towards the human.
	Pig active contact[a]	Pig makes active physical contact with human. Includes sniffing, nosing, oral manipulation, rubbing, pawing.
	Pig passive contact	Pig is standing, sitting or lying in physical contact with human's body but not giving active contact.
	Pig no contact	Pig is not in physical contact with the human but may be receiving contact by human whilst exploring or immobile.
	Pig withdrawing	Pig takes more than two steps in a direction that increases the distance between pig and human.
Human	Human approaching	Human moves hand (by extension of the arm), face or body towards the pig, until making physical contact (within 3s). Includes walking towards.
	Human active contact[a]	Human makes active physical contact with pig (stroking, rubbing, scratching).
	Human passive contact	Human has hand on pig but is not actively moving it.
	Human no contact	Human is not touching pig with hand or face but may be receiving contact by pig. Excludes while human is approaching or withdrawing.
	Human withdrawing	Human moves hand, face or body away from pig, and contact by human is stopped.

[a]An interruption of >1s is considered a new bout.

4.3.2. Cross-recurrence quantification analysis (CRQA)

To examine temporal synchrony and fulfil Objective 1, the analysis method Cross-Recurrence Quantification Analysis (CRQA) based on the work of Coco et al. (2014; 2020a) and Wallot and Leonardi (2018) was used, which investigates the similarity and extent of correspondence between two or more time series. This method enables the extraction of numerous different synchrony measures, of which the following were of interest for this study: Recurrence rate (RR), Entropy (ENTR) and Qlos.

CRQA is visually represented through a recurrence plot (RP), a two-dimensional graph showing the simultaneous occurrences of states in one system alongside another. In this study, the x-axis represents the pig's behaviour over time, while the y-axis represents the human's behaviour over time, as can be seen in Figure 1. When both pig and human display the same behaviour at a given time point (sampled every second), a black square appears, denoting a "recurrence point." Conversely, a white dot, termed a "non-recurrence point," signifies different behaviours.

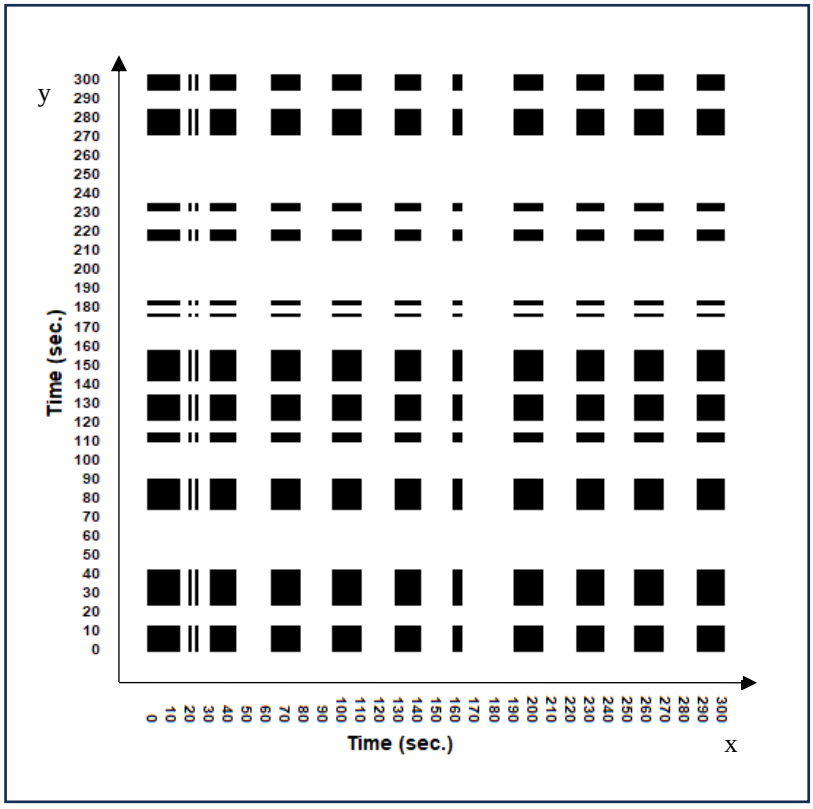

Figure 1. Recurrence Plot (RP) of Cross-Recurrence Quantification Analysis (CRQA). Showing the matching behaviours of the pig (x-axis) and the human (y-axis) in form of black squares over the 300s session.

Different measures can be derived to quantify RP's structure, including recurrence rate (RR) and entropy (ENTR). RR represents the percentage of time points in temporal synchrony within the two-dimensional time matrix. It is calculated by dividing the number of recurrence points (instances where both pig and human show the same behaviour) by the total number of points (recurrence and non-recurrence points). In this study, the sampling rate is 1 sec. RR reflects the extent to which the dyadic system tends to repeat itself. Higher RR values signify more temporal synchrony in terms of behavioural matching, while lower values indicate less synchronisation. The measure ENTR represents the degree of stability or certainty in the length of temporal synchrony intervals. If the length of these intervals remains consistent and predictable, the ENTR value will be lower. On the other hand, if the length fluctuates and becomes less predictable, the ENTR value will be higher. In summary, both RR and ENTR provide insights into emotional synchrony concerning time. However, RR considers both recurrence and non-recurrence points, expressed as a proportion. On the other hand, ENTR only takes recurrence points into account. Additionally, RR does not consider intervals but focuses on how often the dyad behaviourally synchronises. In contrast, ENTR evaluates the uncertainty or fluctuation in the length of behavioural synchrony intervals, emphasising the consistency in duration of recurring synchrony between the dyad rather than the frequency of synchronisation in their behaviours. (Konvalinka et al., 2011; Vanoncini et al., 2022)

To investigate the leader-follower relationship between the pig and the human, i.e. which partner within the dyad more often lead, or drove, the interaction, the measure Qlos was used. Qlos is a measure defined by Griffioen et al. (2019), which quantifies the ratio of recurrent points on the left side of the Line of Synchrony (LOS) to those on the right side of the LOS. The LOS describes the main diagonal in the RP. The proportion of synchrony

signifies the ratio of recurrences aligned with the LOS. This measure of synchrony is relatively simple, capturing instances where both the human and the pig exhibit analogous movements precisely at the same moment, without any time lag (i.e. with a zero-second delay). A Qlos value surpassing 1 implies that the pig frequently assumes a leading role in terms of timing during the interaction. Conversely, a Qlos value below 1 signifies that the human takes the lead more often. Collectively, these metrics shed light on the temporal dynamics and patterns of leadership between the human and the pig throughout their interaction (Feldman, 2006; Griffioen et al., 2019).

For the statistical analysis, two dichotomous time series were defined: time-series 1 (pig_touch) for the pig and time-series 2 (human_touch) for the human.

In order to obtain the synchrony metrics, we followed the tutorial by Coco et al. (2020b), using the following code for the CRQA in the statistical analysis program R (version 4.1.2; R Core Team, 2022):

```
delay = 1; embed = 1; rescale = 0; radius = 0.001;
normalize = 0; mindiagline = 2; minvertline = 2;
tw = 1; whiteline = FALSE; recpt = FALSE; side = "both"
method = 'crqa'; metric = 'euclidean';
datatype = "categorical"

ans = crqa(pig_touch, human_touch, delay, embed, rescale, radius, normalize,
      mindiagline, minvertline, tw, whiteline, recpt, side, method, metric,
      datatype)
```

We based our code for these parameters on the code provided by Coco et al. (2020b). For the parameters 'delay', 'embed' and 'radius', we explored different parameters to find the best fit for our data, as there are no previous studies using CRQA to research human-pig interactions to base them on. Since the results did not change, we decided to use the parameters used in the code of the tutorial by Coco et al. (2020b), which suggested the parameters ‘delay =1’ and ‘embed =1’ for categorical data. This was confirmed to be the appropriate parameter setting through a consultation with Dr. Moreno Coco, who furthermore suggested the parameter ‘radius =0.001’ for categorical data.

Furthermore, we used this code to obtain the drpfromts measures, using the same code as Coco et al. (2020b).

```
res = drpfromts(pig_touch, human_touch, windowsize = 100,
            radius = 0.001, delay = 1, embed = 1, rescale = 0,
            normalize = 0, mindiagline = 2, minvertline = 2,
            tw = 0, whiteline = F, recpt = F, side = ‘both’,
            method = ‘crqa’, metric = ‘euclidean’,
            datatype = ‘continuous’)
```

The drpfromts code is used to define the number of lags around the LOS (Griffioen et al., 2019), providing us the data for the subsequent Qlos calculations, for which we divided the amount of recurrent points on the left side of the LOS by the amount of recurrence points on the right side, based on the method by Griffioen et al. (2019).

5. Statistical analysis

For the statistical analyses, generalised linear mixed models (GLMMs) were carried out using the ‘lmer’ function of the package lme4 (version 1.1-27.1; Bates et al., 2015) in R Studio (version 4.1.2; R Core Team, 2022). The statistical analyses performed for Objective 1 were considered manipulation checks since the behaviour of the human was directly manipulated. Therefore, the GLMMs were performed to confirm whether the experimental manipulations resulted in distinct characteristics for each type of interaction. To fulfil Objective 1, the CRQA metrics RR; ENTR and Qlos were tested separately utilising an alpha level of .05, which was used for all statistical tests. The synchrony metrics, RR and ENTR and Qlos, were entered as response variables, and the variables ‘test’, ‘day’ and their interaction were incorporated in our analysis as fixed effects. The interaction term was included as the impact of the ‘test’ variable on behaviour might vary depending on the sequence in which the tests were conducted. Additionally, to account for any potential influences, ‘batch’ was included as additional fixed effect. Furthermore, random intercept effects for the individual pigs were included in the model (see Appendices Tables 2-3). Prior to fitting the model, an inspection was conducted on all quantitative predictors and the response variable to assess whether their distributions were roughly symmetrical. The metric RR was log-transformed to reduce the skewed distribution of the data to approximate it to normality. Following model fitting, assumptions of normally distributed and homogeneous residuals were checked by visual inspection of a QQ-plot (Field, 2005) of residuals and residuals plotted against fitted values (Quinn and Keough, 2002). These indicated no deviations from these assumptions. The residuals versus fitted values for Qlos revealed a trimodial pattern, which could have been effectively addressed by employing a more complex model. However, it is noteworthy that this increased complexity, which included additional random slopes and intercepts, posed convergence issues when applied to the ENTR variable. In order to maintain consistency within the scope of this thesis, the decision was made to adhere to the simpler model for analysis. Additionally, when evaluating collinearity, it was observed that it was not a concern for a model lacking the interaction term, with the highest Variance Inflation Factor being 1.04, in accordance with the criteria outlined by Quinn and Keough (2002).

To comprehensively assess the influence of the ‘test’ variable and its interaction with ‘day’, a thorough comparison was conducted between a full model and a null model, following the approach outlined by Forstmeier and Schielzeth (2011). This approach helps avoid cryptic multiple testing. In the null model, these two effects were excluded, while retaining the random effect of individual. This comparison relied on a likelihood ratio test, as described by Dobson (2002). To assess the impact of individual fixed effects, the Satterthwaite approximation method (Luke, 2017) was employed using the "lmer" function from the ‘lmerTest’ package (version 3.1-3, Kuznetsova et al., 2017), along with a model fitted with restricted maximum likelihood. Lastly, posthoc pairwise comparisons were conducted using the ‘emmeans’ package (Lenth, 2020) from which estimated marginal means were calculated.

To address Objective 2, a Principal Component Analysis (PCA) was used to reduce the number of dimensions of the general behaviours of the pigs. Distinct behavioural profiles could then be identified, from which we could extract individual values for each pig attributed to these profiles. The PCA was conducted using the R packages FactoMineR (Lê, Josse & Husson, 2008) and psych (Revelle, 2023). Before conducting PCA, a pre-test known as 'Horn's parallel analysis' (Horn, 1965) suggested that two principal components should be retained. With the results from the PCA, a GLMM was conducted including the same fixed and random

effects as in Objective 1, with the addition of RR, ENTR and Qlos as predictors to investigate the associations between temporal synchrony and the pigs' general behavioural response.

Prior to commencing the main statistical analyses, preliminary analyses were conducted to check for potential learning effects in the IC condition. A repeated measure design was originally employed during testing, where each pig underwent both test conditions twice, and a subset of the data was analysed to compare the first and second repetitions. The results revealed no significant difference between these repetitions, leading to a focus on the analysis solely of the data from the first repetition (i.e. day 1 and day 2 of testing) and excluding the second repetition (i.e. day 3 and day 4). Additionally, preliminary analyses also included checking for the influence of order effects. The analysis considered whether the sequence, i.e. whether starting with FF or IC, had a significant effect. Notably, the analysis indicated that there was no significant sequence effect.

The model outcomes of the main analyses are separated by metric and can be found in Appendices (RR in Table 3, ENTR in Table 4, Qlos in Table 5). The loadings of the PCA (Table 6) and the model outcomes for the Objective 2 analysis (Table 7 and Table 8) can be found in Appendices.

See Appendices, Figure S1 for a comprehensive overview of the statistical analysis.

6. Results

6.1. Objective 1: Characterising the temporal features

First, we tested the effect of the test condition on the temporal features RR, ENTR, and Qlos extracted from CRQA. For each metric, we conducted a full-null model comparison. The null models comprised of each synchrony metric as a response variable and only retaining the pig ID as the random intercept. In order to test the main effect of test condition, we entered into the full model 'test' as a fixed-effect predictor variable, as well as 'day', 'batch', and interaction between 'test' and 'day' as additional fixed effects to account for the potential confounding factors mentioned under Statistical analyses (Model 1.1.-3.1). For RR, the model fit did not improve significantly when compared to the null model, suggesting no association between test and RR. For ENTR, while the difference between full model and null model was borderline significant, the difference between AIC scores were negligible (< 4, see Appendices, Table 4.), which suggests no association between test and ENTR. Lastly, for Qlos, the full model fit also did not significantly improve in comparison to the null model, thus suggesting no association between test and Qlos.

To estimate individual effects, a type III ANOVA using the Satterthwaite's method was conducted. This method revealed a tendency with the effect of 'test' on RR, and while resulting in a moderate F-value, this was not statistically significant at the conventional alpha level (e.g., 0.05) with a p-value of 0.0726 (see Appendices, Table 3.). There was no significant effect of 'day', 'batch' or interaction between 'test' and 'day' (see Appendices, Table 3.). For ENTR however, a significant effect of 'test' was found, with a F-value of 5.801 and a p-value of 0.024 (see Appendices, Table 4.). There was also no significant effect of 'day', 'batch' or interaction between 'test' and 'day' (see Appendices, Table 4.). Lastly, for Qlos, no significant effect of 'test, 'day', 'batch' or interaction between 'test' and 'day' could be found (see Appendices, Table 5.).

In a posthoc pairwise comparison, the estimated marginal means were calculated for RR, ENTR and Qlos (Table 9). For the RR metric, the values were 1.56 ± 0.336 (SE) with a 95% confidence interval (CI) of 0.88 to 2.24 for the FF interaction and 2.3 ± 0.336 (SE) with a 95% CI of 1.62 to 2.98 for IC, resulting in a p-value of 0.073, which indicates a trend (see Figure 2A). Regarding ENTR, the FF interaction yielded a value of 2.42 ± 0.118 (SE) with a 95% CI of 2.19 to 2.66, while IC had a value of 2.08 ± 0.117 (SE) with a 95% CI of 1.85 to 2.32, with a significant p-value of 0.024 (see Figure 2B). For the Qlos metric, the values were 0.92 ± 0.063 (SE) with a 95% CI of 0.80 to 1.05 under FF and 0.94 ± 0.063 (SE) with a 95% CI of 0.81 to 1.06 under IC, yielding a not significant p-value of 0.831 (see Figure 2C). These results show the significance of the 'test' factor on the metric ENTR and indicate a trend for the metric RR. However, no significant effect of the factor 'test' on the metric Qlos could be found.

Table 9.: Effect of test on Recurrence rate, Entropy and Qlos

Metric	**Type of interaction**		**p-value**
	Free-form [CI]	Imposed contact [CI]	
Recurrence Rate	1.56 ± 0.34 [0.88, 2.24]	2.30 ± 0.34 [1.62, 2.98]	0.073
Entropy	2.42 ± 0.12 [2.19, 2.66]	2.08 ± 0.12 [1.85, 2.32]	**0.024***
Qlos	0.92 ± 0.25 [0.80, 1.05]	0.94 ± 0.25 [0.81, 1.06]	0.831

Significance level: *p<0.05

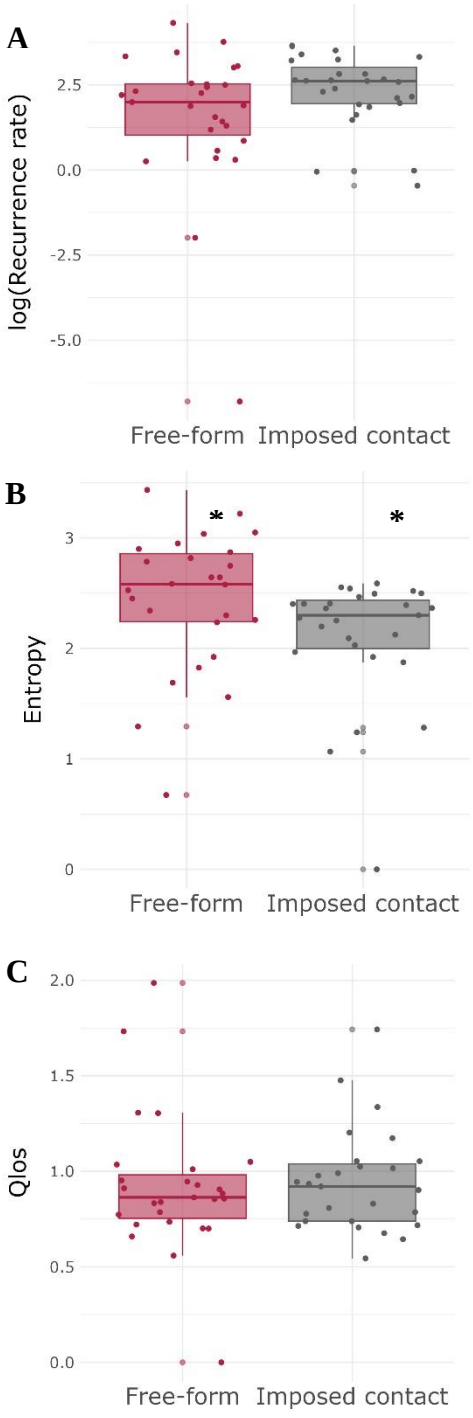

Figure 2. A) Recurrence rate (RR), B) Entropy (ENTR) and C) Qlos in each test condition: Free-form (red) and Imposed contact (grey). N = 27 dyads per test. Significance level: *p<0.05 for pairwise comparison.

6.2. Objective 2: Linking temporal features to engagement and affective states

For Objective 2, we first used PCA to explore possible correlations between the pig´s behaviours. We found that the first two principal components explain a total of 48.2% of the variance in the data, with Dimension 1 explaining 31.7% and Dimension 2 explaining 16.5% (see Supplementary material, Figure S2.). For the loadings, a threshold of 0.5 was used to determine which variables contribute significantly to the interpretation of the dimensions (see Appendices, Table 6). The first component displayed a positive correlation with behaviours associated with negative affective states (e.g. elimination, immobility, withdrawing, low- and high-pitched vocalisations) and an inverse correlation with behaviours indicating engagement (e.g. body contact, contact by pig, following, physical interaction). This component, Component 1, was labelled as 'Conflict of motivation: Engage with human versus stress behaviour', where a high score suggests low engagement and higher indicators of stress. The second component showed a positive correlation with behaviours indicating interest in the human (e.g. following, physical interaction) and an inverse correlation with behaviours unrelated to the human (e.g. exploring). This component, Component 2, was labelled as 'Human versus environment', where a high score indicates heightened interest in human interactions compared to the environment. Component scores for each individual pig extracted from PCA were used for the subsequent GLMM.

The PCA-derived Component 1 and Component 2 scores were used as response variables in separate GLMMs. For each response variable, we conducted a full-null model comparison. The null models comprised of the original fixed effects (´test´ and ´day´ interaction, ´batch´) and random effect (´pig´) pertaining to our hypotheses were included in the model, with the addition of the synchrony metrics (RR, ENTR, Qlos) as predictors to address Objective 2 (Model 4.1.-5.1). For both Component 1 and Component 2, the model fit improved significantly in comparison to the null model, which suggests an effect of the inclusion of the synchrony metrics in these models.

To estimate the individual effects, a type III ANOVA using the Satterthwaite’s method was conducted. This method revealed a significant effect of RR on 'Component 1 - Conflict of motivation: Engage with human versus stress behaviour' with an F-value of 6.213 and a p-value of 0.017 at the conventional alpha level (e.g. 0.05) (see Appendices, Table 7.). There was no significant effect of ‘day’, ‘batch’, interaction between ‘test’ and ‘day’, ENTR or Qlos (see Appendices, Table 7.). For ' Component 2 – Human versus environment', a significant effect of RR, with a F-value of 10.360 and a p-value of 0.002, and a significant effect of ENTR, with an F-value of 8.623 and a p-value of 0.005 were found (see Appendices, Table 8.). There was also no significant effect of ‘day’, ‘batch’, interaction between ‘test’ and ‘day’ or Qlos (see Appendices, Table 8.).

6.3. Exploratory Analysis: Correlation between RR and ENTR

As the model fit for RR did not improve significantly when compared to the null model (see 6.1 Objective 1), we explored the correlation between ENTR and RR via a Pearson correlation to ascertain whether we would observe a similar relationship as identified by Vanoncini et al. (2022), in which ENTR would provide a more comprehensive evaluation of the complexity and variability within the dyadic interaction. This revealed a strong positive correlation between these metrics with a Pearson correlation coefficient of r = 0.81 and a p-value of < 0.001 (see Figure 3.).

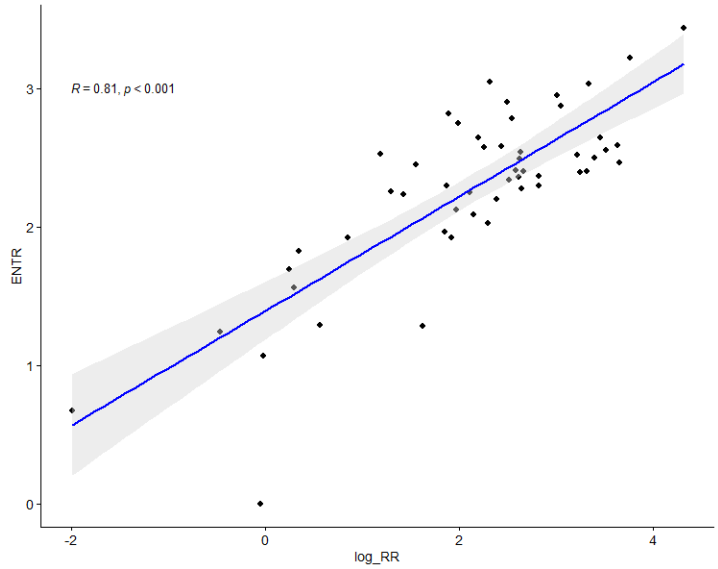

Figure 3. Scatterplot of correlation between RR and ENTR. Significance level: ***p<0.001

7. Discussion

The study's primary aim was to characterise the temporal behavioural features of HAI, focussing on measures of temporal synchrony. We quantified temporal synchrony by using CRQA to generate the metrics RR, ENTR and Qlos, and we tested whether behavioural matching (RR) would be higher in the FF and lower in the IC condition (Griffioen et al., 2019; Vanoncini et al., 2022), predictability (ENTR) would be lower in the FF and higher in the IC condition (Vanoncini et al., 2022) and if there would be more pig-leads/human-follows (Qlos) during the FF and less pig-leads/human-follows during IC condition (Feldman., 2006; Griffioen et al., 2019). Furthermore, this study also aimed to link temporal features to engagement and affective states. We hypothesised that pigs would show more indicators of engagement, indicated by contact by pig, and positive affect, indicated by approach behaviour, tail wagging, low frequency calls, during interactions characterised by higher behavioural matching (RR) (Griffioen et al., 2019; Vanoncini et al., 2022), lower predictability (ENTR)

(Vanoncini et al., 2022) and more pig-leads/human-follows (Feldman, 2006; Griffioen et al., 2019).

Contrary to our hypotheses, some of the temporal features differed according to the type of interaction, whilst others did not. Our findings indicate that the predictability (indicated by ENTR) of human-pig interactions differed between two distinct test conditions. This predictability pertains to entropy, more precisely, it describes more uncertainty associated with the length of the intervals spent in behavioural synchrony. Our findings also indicate a tendency regarding a differentiation in behavioural matching (indicated by RR) between the two test conditions. We did not find a difference between the test conditions in regard to the leader-follower relationship (indicated by Qlos), with the results suggesting the human more often temporally led than the pig in both types of interactions although only marginally. Analysis of the pigs' general behavioural response by Vetmeduni suggested that the pigs experienced a more negative affective state during the IC condition compared to the FF condition, where pigs displayed more withdrawing and high-pitched vocalisations during the IC interactions and explored more during the FF interactions (Truong et al., unpublished). When these observations are combined with the results of the temporal features, it suggests that higher RR may be linked to a more negative affective state, and higher ENTR may be linked to a more positive affective state. However, these associations require further investigation to be confirmed.

Through further correlation analyses of the PCA components and temporal features, we found associations between RR, entropy, engagement and interest of the pig. Our findings suggest that interactions with higher behavioural matching (indicated by RR) were linked to higher engagement of the pig and lower indicators of stress. Moreover, our results also showed that higher behavioural matching (indicated by RR) and lower predictability (indicated by ENTR) were associated with a higher interest of the pig in the human. These findings support our hypotheses. However, we did not find a significant influence of the leader-follower relationship on the engagement of the pig or its interest in the human. These findings show conflicting results with the previous results from the first part of the study when the analyses of the synchrony measures and pigs' general behavioural response were conducted separately. This could be due to the number of behavioural variables that were included in each type of analysis. As for the first part of the study, we ran a model for each behaviour separately, therefore comparing the effect of ´test´ one behaviour at a time. For the PCA, we combined all behaviours to find meaningful groupings, therefore considering multiple behaviours in the analysis simultaneously, capturing the complexity of the pigs' behavioural response. Typically, behaviours are interpreted in combination as there are no single behavioural indicators that can act as gold standards or markers of affective state and engagement. Assessing these variables in isolation, as had been done in the first part of the study, without accounting for the influence of other behavioural and synchrony variables simultaneously may, therefore, yield divergent outcomes.

The higher RR during the IC condition along with indicators of negative affective state is contrary to the findings of previous studies that have linked higher RR with positive outcomes (Griffioen et al., 2019, Vanoncini et al., 2022). Our findings suggest that a higher RR value does not necessarily equate to a more favourable outcome for human-pig interactions. The relationship between behavioural matching and affective state in animals is complex and can vary depending on the species and context. In some cases, a higher degree of behavioural matching may be associated with more positive affective states, indicating that the animals are experiencing positive emotions or are in a state of comfort and social cohesion. For example,

in social species like primates, synchronised grooming behaviours are often seen as indicators of strong social bonds and positive affective states (Dunbar, 1988). However, in other situations, behavioural matching can also be a response to stress or negative affective states. Animals may synchronise their behaviours as a coping mechanism or as a way to reduce conflict within a group. For instance, in some bird species, increased flock cohesion and synchronised flight patterns can occur during predator encounters, indicating a heightened state of alertness and potential stress (Ballerini et al., 2008).

The higher entropy during the FF condition along with indicators of positive affective state is contrary to the findings of previous studies that have linked lower entropy with positive outcomes (Vanoncini et al., 2022). Our findings suggest that higher entropy during interactions between humans and pigs does not necessarily imply a less desirable outcome. Furthermore, the relationship between predictability and affective state in animals can also be complex and context-dependent. In some cases, a higher level of predictability can be associated with positive affective states in animals. For example, when animals can reliably predict positive outcomes, such as access to food, safety, or social rewards, it can lead to a sense of security and well-being, which was shown in research with rodent in laboratory settings, as predictable access to food rewards lead to increased positive affect and reduced stress responses (e.g., Berridge et al., 1989; Berridge & Robinson, 1998). Contrarily, in situations where predictability is low or when animals face unpredictable and uncontrollable stressors, it can lead to negative affective states, such as anxiety or distress. Unpredictable events, especially those that are perceived as threats or challenges, can trigger physiological stress responses and negative emotions, as has been observed in studies involving various animal species, including rodents and non-human primates (McEwen, 2004; Kalin et al., 1998). Considering that pigs typically display neophilic tendencies (D'Eath et al., 2010), it is plausible that they might prefer greater variety, potentially explaining the preference for unstructured, free-form interactions.

Moreover, the characteristic rhythm of typical mother-infant interactions comprises both matching and mismatching states, along with the subsequent repair of the latter, which describe a crucial dynamic in dyadic exchanges (Vanoncini et al., 2022). As stated by Vanoncini et al. (2022), the presence of matched states signifies engagement and coordination between partners, while being in mismatched states offers an opportunity for conflict resolution. The mending of mismatched states reflects adaptive behaviours and flexibility within the interaction (Beebe et al., 2016a; Biringen et al., 1997; Tronick, 2017). However, as mentioned by Vanoncini et al. (2022), solely calculating RR or the overall proportion of behavioural synchrony might not capture the time allocation within each matched behavioural interval, as the measure ENTR, by gauging the uncertainty of interval lengths, provides insights into the predictability of behavioural synchrony. Notably, predictable aspects of the environment tend to command more attention compared to unpredictable elements (Wass, 2022). Self-organising entities inherently strive to decrease the entropy of their sensory states, consequently reducing their 'free energy', which signifies the variance between an organism's predictions and sensory experiences (Friston, 2010). The cognitive demand to minimise free energy is substantial (Vanoncini et al., 2022). Therefore, environments characterised by lower uncertainty and unpredictability reduce 'free energy' and optimise cognitive efficiency (Peters et al., 2017). Interestingly, our findings regarding the indicators of affective state suggest the contrary, as we found a more positive affective state in pigs during FF interactions, which was characterised by higher ENTR. This might be the case, as the pigs were able to freely initiate contact with the human in the FF condition, which has been shown to enhance pigs approaching behaviour (Hemsworth, Gonyou & Dziuk, 1986).

In the realm of temporal and behavioural synchrony, the concept of the ‘ideal’ level of synchrony can take on different meanings depending on the specific context and relationships involved. For instance, in mother-infant interactions among humans, a high degree of temporal and behavioural synchrony is widely regarded as ideal, as it fosters secure attachments and nurtures the emotional and social development of infants (Feldman, 2007a). Conversely, interactions between mothers and older children may require a more balanced approach that allows for increased autonomy as the child matures (Granic et al., 2003). When considering human-dog interactions, the ideal level of synchrony may fluctuate among different contexts, with high synchrony beneficial in tasks like agility training, but a more relaxed approach being preferable during leisurely moments (Rooney & Bradshaw, 2003). In romantic relationships, the ideal level of synchrony can be influenced by individual preferences and the stage of the relationship, with high synchrony contributing to emotional connection and relationship satisfaction (Gottman & Notarius, 2002). These examples underscore the variability in the 'ideal' level of synchrony, emphasising that it is intricately tied to the nature of the relationship, species-specific behaviours, and the specific goals of the interaction.

Our conflicting findings appear to be influenced by contextual variations, particularly when comparing interactions between mother-infant pairs and those between humans and pigs. Our predictions drew upon findings from mother-infant studies (Vanoncini et al., 2022), as well as human-dog studies (Griffioen et al., 2019) that established a connection between higher synchrony and increased affiliation. However, it is essential to recognise the significant contextual distinctions that exist. One aspect could encompass survival implications for mother-infant interactions, which are not necessarily present in human-pig interactions. Survival implications in mother-infant interactions, are characterised by the critical roles that mothers play in protecting, nurturing, and imparting survival skills to their offspring. For example, the bond between mother and infant contributes to feelings of security, emotional regulation (Feldman, 2007a), and skill acquisition (Kobayashi, 2001) necessary for thriving and survival. Furthermore, attachment theory in humans underscores the importance of a secure attachment between infants and caregivers, which can have lasting effects on an individual's well-being (Ainsworth et al., 1978). This attachment theory has been extended to human-dog bonds, as their attachment bonds are believed to be similar to those of mother-infant dyads (Serpell, 1996). In contrast, human-pig interactions, particularly with farm-bred pigs, lack the same level of survival implications. Pigs raised in controlled environments rely less on maternal care, and the ecological and evolutionary contexts of these interactions differ substantially. Interactions between humans and pigs within these settings primarily revolve around managerial activities, including tasks like feeding, healthcare, and transportation, thus having a notable influence on their stress levels and overall welfare (Mellor, 2016). Consequently, the survival-related bonding, skill acquisition, and emotional development observed in mother-infant interactions are not as applicable in the context of human-pig interactions. Another aspect describes the degree of bonding between a mother-infant dyad and a human-pig dyad. Notably, our study involved farm-bred pigs intended for experimentation, rather than pigs that had formed bonds with humans as pets, whereas it is still unclear if such a bond would be comparable to the bond between a mother-infant dyad. Research has shown that biological kinship plays a beneficial role in parent-child relationships compared to parent-step-child relationships (Schnettler & Steinbach, 2011). Thus, the missing biological relation might have even stronger implications between humans and animals. As the pigs underwent a habituation process and a positive HAR was established, this length of time for the trial might still not be enough to establish a strong bond like in mother-infant or human-dog relationships to show similar patterns of synchronicity.

There are also morphological differences between a human infant and a weaner pig which describe another contextual variation. While there are a few studies on interspecies interactions, such as those conducted by Duranton in 2017 and 2019, as well as Griffioen in 2019, this domain of research is still in its infancy. Cognitive processing in infants and pigs differs significantly due to their distinct neuroanatomy, sensory capacities, and evolutionary history. In terms of neuroanatomy, human infants possess complex and highly developed brains, featuring a neocortex that plays a pivotal role in advanced cognitive functions such as language, memory, and problem-solving (Kostović & Jovanov-Milošević, 2006). In contrast, pigs have less complex brain structures relative to their brain size, with a smaller neocortex. Their cognitive abilities are adapted to their ecological niche, emphasising sensory perception and navigation (Roth & Dicke, 2005). Regarding sensory capacities, human infants are born with well-developed sensory systems, including vision, hearing, and touch, which enable them to explore and learn about their environment from an early age (Streri, 2014). In contrast, pigs rely on different sensory capacities, prominently featuring a keen sense of smell and robust olfactory capabilities that are central to their communication and exploration of their surroundings (Vieuille & Signoret, 1992). In terms of social learning, human infants engage in complex social interactions and are highly receptive to social learning, often imitating and learning from caregivers and peers throughout their development (Meltzoff & Moore, 1977; Paulus, Hunnius & Bekkering, 2013). On the other hand, while pigs are social animals, their social learning abilities may differ from humans, with an emphasis on behaviours related to group cohesion and foraging (Bateson & Laland, 2013; Nicol & Pope, 1994). Lastly, communication varies between these two species. Human infants engage in complex vocal and nonverbal communication from an early age, which serves as the foundation for language acquisition (Kuhl, 2004). In contrast, pigs communicate through vocalisations, body language, and scent marking, with their communication strategies adapted to their social structure and environmental context (Manteuffel et al., 2004). Thus, the differences in cognitive processing between human infants and pigs might explain our contrasting findings. Therefore, contextual factors play a pivotal role, and our study's results underscore this aspect, especially given the contrasting findings we have observed.

Regarding the lack of difference in the leader-follower relationship between the types of interactions, it might be possible that the type of relationship, degree of bonding, or context, as discussed above, could have influenced the results. In mother-infant studies, researchers have investigated the dynamics of interaction between mothers and their infants to understand who leads and who follows in various aspects of their relationship. Attachment behaviour, as observed in the "Strange Situation" study, often demonstrates that infants tend to follow their mothers, seeking proximity and security from them as they explore unfamiliar environments (Ainsworth et al., 1978). Additionally, infants frequently imitate their mothers' facial expressions, gestures, and vocalisations, a phenomenon evident in studies by Meltzoff and Moore, where even very young infants engage in early imitation (Meltzoff & Moore, 1977). Conversely, a study by Feldman (1999), which studied mother-infant freeplay interactions at 3 and 9 months old, found that an infant-leads/mother-follows relationship is considered more optimal at 3 months of age, whereas mutual synchrony was more common at 9 months of age. Furthermore, it is worth mentioning that the study by Griffioen et al. (2019) also did not find a significant difference in the leader-follower relationship. Based on these studies, in order to gain more insight into the human-pig leader-follower relationship, it might be necessary to consider the appropriateness of the context to study this relationship.

Additionally, another factor to consider is the influence of humans on pig behaviour, as it is worth contemplating whether human behaviour possess a more substantial impact on the

pig's behaviour than we thought. Research suggests different behavioural responses by pigs when interacting with humans, based on the human's behaviour, showing more approach behaviour when the human was squatting, not approaching, having bare hands and not initiating interactions (Hemsworth, Gonyou & Dziuk, 1986). Based on these findings, we would expect more synchrony in the FF condition, contrary to our findings. However, it might be possible that the human approaching the pigs gave them more opportunity for behavioural matching. Therefore, the pattern of human approach during interactions might potentially enhance the opportunities for synchrony. This invites the consideration that human behaviour could potentially play a role in altering the synchronicity aspect of the interaction dynamic.

Consequently, according to Vanoncini et al. (2022), measures evaluating behavioural synchrony should encompass the uncertainty inherent in sequences of states. Furthermore, the study states that the measure ENTR offers a more comprehensive evaluation of the complexity and variability within the dyadic interaction, as in contrast, RR primarily reflects the general proportion of temporal synchrony. This distinction arises because ENTR effectively captures the uncertainty inherent in interactions (Howland et al., 2021). Based on our findings regarding the high correlation between RR and ENTR, we support the findings of Vanoncini et al. (2022) and also contend that ENTR, which accounts for the duration of behavioural matching over time and their predictability, stands as a more insightful metric compared to RR.

Furthermore, this explorative study aimed to assess the applicability of methodologies employed in mother-infant interaction studies to HAI, which so far have been successfully employed in research regarding human-dog interactions. This study expanded on this, using methodologies of mother-infant research to explore how the temporal feature synchrony manifests in human-pig interactions for the first time. Furthermore, the previously unexplored link in human-pig interactions between synchrony and affective state have been investigated in this study. Our findings indicate a difference in affective state of the pigs between the two test conditions, showing that this study was able to create two distinct types of interactions, which resulted in distinct characteristics. This highlights the viability of employing this methodology to the realm of human-pig interactions. The precedent for these measures in mother-infant research (Vanoncini et al., 2022) as well as a recent application in human-dog research (Griffioen et al., 2019) lends support to their adaptation in the study of HAI.

7.1. Limitations and implications for further research

It is crucial to take into account certain limitations in this study. The primary concern lies in the absence of a precedent in this type of study, making it challenging to compare our findings with existing results. Consequently, the methodologies employed have not undergone prior testing within this specific context. First, an important limitation concerns the influence of stressed animals on our data, as some pigs still exhibited signs of stress during the test sessions. To address this, we suggest taking measures in future studies to ensure the animals are well habituated to the testing environment and the research procedures, minimising potential stress-related confounding variables. Another limitation to consider is the relatively short interaction time, a factor highlighted by Vanoncini et al. (2022). Extending the duration of the trial to a few months instead of a few weeks might allow for more substantial bonding between humans and animals, which may yield more pronounced effects. From our results, understanding of the leader-follower relationship in human-pig interactions is still lacking. This could be addressed by implementing these methods in studies where these relationships could be expected to be more pronounced, for example task-based paradigms such as the

unsolvable task paradigm in a study by Pérez Frage et al. (2021) with family dogs and miniature pigs. Furthermore, the reliance on a single modality for our assessments presents another limitation. We chose to focus on a single modality in this study as it is the first application of methodology used in mother-infant research to human-pig interactions, and understanding of other sensory modalities such as vocalisations and gaze in the context of human-oriented socio-communication is still lacking. To enhance the comprehensiveness of future studies, multiple modalities could be explored and included, as this could provide a more holistic understanding of the animals' affective states. For example, it is typical in mother-infant studies to also look at synchronisation in gaze (i.e., Feldman, 2007a; 2007b). One notable limitation when studying gaze in pigs is the need to consider their use of both panoramic and binocular vision. While some studies have employed head orientation (Tallet et al., 2014) or snout direction (Oldham et al., 2021) as proxies for gaze or attention, these measures may not fully account for the non-binocular field of vision characteristic of pigs. This underscores the importance of accounting for species-specific differences and emphasises the necessity for further research to gain a comprehensive understanding of the various modes of communication, which can then be integrated into the study of human-pig interactions. The study primarily concentrates on human-pig interactions, and our results highlight that the implications of temporal synchrony could differ between different contexts, potentially limiting the generalisation of findings to interactions involving different species. Interpreting the significance of changes in synchrony measures within the context of animal behaviour and welfare might be challenging. The assumption that observed pigs' behaviour directly reflects intentions or emotions might oversimplify the complexity of pigs' behaviour, which was emphasised by our conflicting findings between the different analyses of behaviour and temporal features. To ensure a more encompassing reflection of the pig's affective state, it might be beneficial in future studies to pair the behavioural observations with physiological measurements suitable for animal research, such as heart rate (Mendl et al., 2010), heart rate variability (von Borell et al., 2007) and cortisol levels (Hemsworth, 2003). Another limitation worth noting is that, due to issues with model convergence, we were unable to include the effect of the sow in our statistical analysis. This suggests that our results must be interpreted with caution. Furthermore, future studies could explore other metrics generated by CRQA, which could provide further insight into the complexity of temporal synchrony in HAI research. A possible metric could be MAXline, which pertains to the length of longest diagonal line in the RP, other than the main diagonal, quantifying the strength of strongest attracting trajectory in the time-series; thereby representing a measure of dynamical stability of the system (Konvalinka et al., 2011). In the context of this study, another temporal feature, reciprocity, could be assessed, as it also represents an important aspect of social interactions (see 2.4. Reciprocity). Reciprocity could be assessed through contingency, focusing on interactive contingency as a marker of partner influence (Beebe et al., 2016b). As this aspect of contingent responses has not been confirmed in HAI yet, research regarding this temporal feature would be an important area of study for future HAI research.

8. Conclusions

All in all, the present study added to the understanding of the role of temporal features in social interactions. In contrast to previous studies regarding temporal behavioural matching in human-animal (Griffioen et al., 2019) and mother-infant interactions (Vanoncini et al., 2022), we found more behavioural matching in interactions that involved imposed contact. Contrary to previous studies regarding entropy and predictability in a psychological context (Peters et al., 2017; Vanoncini et al., 2022), we observed a more positive affective state in pigs during interactions characterised by less predictability. However, further correlation analyses revealed a link between higher recurrence rate, lower entropy, and higher interest in the human, which highlighted the complexity of the behavioural response in pigs. As this was the first study to successfully apply CRQA to human-pig interactions, it could encourage further studies to apply the methodology used in mother-infant research in human-animal interaction studies. Moreover, as our findings regarding the leader-follower relationship did not yield significant results, further research regarding this relationship is needed to better understand its implications. Additionally, future studies should further explore the relationship between pig's affective state and predictability during interactions with humans, as our findings have shown a new perspective of human-pig interactions. Further research in this regard could be instrumental in gaining more insights into facilitating positive interactions with pigs, thereby enhancing pig welfare.

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10. Appendices

10.1. Abstract

In this exploratory study, we investigated temporal features of positive human-animal interactions (HAI). Positive HAI have potential benefits on animal welfare, and though their overall effects are well-documented, their underlying mechanisms remain poorly understood. Temporal features have been linked to emotional states during human interactions, but this link remains unexplored in the context of HAI. This research aimed to characterise temporal features of different HAI and their potential link with the pigs' engagement and affective state. Specifically, this study focused on temporal behavioural synchrony, assessing the temporal organisation of the pig and human behaviours. We compared two types of interactions: free-form (FF) and imposed contact (IC). In the FF interactions, the human's responses were contingent upon the pig's actions, offering gentle tactile contact (such as strokes, rubs, and scratches) in response to the pig's cues, to which the pigs had been habituated. Conversely, the IC interactions involved non-contingent human behaviour, following a standardised protocol consisting of a repeated sequence of approaching, imposed contact, and withdrawing. Using cross-recurrence quantification analysis (CRQA), we extracted three metrics of synchrony to describe this temporal organisation: recurrence rate (behavioural matching), entropy (predictability), and Qlos (leader-follower relationship). Contrary to our expectations, the results showed higher entropy in FF interactions (P=0.024) and a tendency towards higher recurrence rate in IC interactions (P=0.073), while no significant effect could be found regarding Qlos. These results likely reflect the structured nature of the IC interactions versus the unstructured nature of the FF interactions. However, two behavioural profiles, Component 1 'Conflict of motivation: Engage with human versus stress behaviour' and Component 2 'Human versus environment', identified by principal component analysis, were found to be associated with the synchrony metrics, where higher recurrence rate was associated with higher engagement and less indicators of stress (P=0.017), while higher recurrence rate (P=0.002) and lower entropy (P=0.005) were associated with higher interest in the human. Further analysis is required to measure level of contingency and its associations with the pigs' general behavioural responses in both interaction contexts.

10.2. Zusammenfassung

In dieser explorativen Studie untersuchten wir zeitliche Merkmale positiver Mensch-Tier-Interaktionen (HAI). Positive HAI haben potenzielle Vorteile für das Wohlergehen von Tieren, und obwohl ihre allgemeinen Auswirkungen gut dokumentiert sind, sind die zugrundeliegenden Mechanismen nach wie vor schlecht verstanden. Zeitliche Merkmale wurden mit emotionalen Zuständen während menschlicher Interaktionen in Verbindung gebracht, aber dieser Zusammenhang bleibt im Kontext von HAI unerforscht. Ziel dieser Studie war es, die zeitlichen Merkmale verschiedener HAI und ihren möglichen Zusammenhang mit dem Engagement und dem emotionalen Zustand der Schweine zu untersuchen. Die Studie konzentrierte sich insbesondere auf die zeitliche Verhaltenssynchronität und untersuchte die zeitliche Organisation der Verhaltensweisen von Schweinen und Menschen. Wir verglichen zwei Arten von Interaktionen: Freiform (FF) und erzwungener Kontakt (IC). Bei den FF-Interaktionen waren die Reaktionen des Menschen von den Handlungen des Schweins abhängig und boten sanften taktilen Kontakt (wie Streicheln, Reiben und Kratzen) als Reaktion auf die Signale des Schweins, an die die Schweine gewöhnt waren. Bei den Interaktionen mit dem IC hingegen wurde ein nicht kontingentes menschliches Verhalten gezeigt, das einem standardisierten Protokoll folgte, das aus einer wiederholten Abfolge von Annäherung, Kontaktaufnahme und Rückzug bestand. Mithilfe der Cross-Recurrence-Quantification-Analysis (CRQA) extrahierten wir drei Metriken der Synchronie, um diese zeitliche Organisation zu beschreiben: Recurrence-Rate (Verhaltensübereinstimmung), Entropie (Vorhersagbarkeit) und Qlos (Führer-Folge-Beziehung). Entgegen unseren Erwartungen zeigten die Ergebnisse eine höhere Entropie bei FF-Interaktionen (P=0,024) und eine Tendenz zu einer höheren Wiederholungsrate bei IC-Interaktionen (P=0,073), während für Qlos kein signifikanter Effekt gefunden werden konnte. Diese Ergebnisse spiegeln wahrscheinlich die strukturierte Natur der IC-Interaktionen gegenüber der unstrukturierten Natur der FF-Interaktionen wider. Zwei Verhaltensprofile jedoch, Komponente 1 "Motivationskonflikt: Beschäftigung mit Menschen versus Stressverhalten' und Komponente 2 'Mensch versus Umwelt', die durch die Hauptkomponentenanalyse identifiziert wurden, wurden mit den Synchroniemetriken in Verbindung gebracht, wobei eine höhere Wiederholungsrate mit höherer Beteiligung und weniger Stressindikatoren vom Schwein (P=0,017) verbunden war, während eine höhere Wiederholungsrate (P=0,002) und eine geringere Entropie (P=0,005) mit einem höheren Interesse am Menschen verbunden waren. Weitere Analysen sind erforderlich, um das Ausmaß der Kontingenz und deren Zusammenhang mit den allgemeinen Verhaltensreaktionen der Schweine in beiden Interaktionskontexten zu messen.

10.3. Tables

10.3.1. Table 1. Control measures and Outcome measures

Control measures	**Outcome measures**
Entropy (Vanoncini et al., 2022)	
Synchrony (FF): proportion of synchrony, RR, Qlos (Griffioen et al., 2019; Vanoncini et al., 2022)	Synchrony (IC): proportion of synchrony, RR, RRpeak, Qlos (Griffioen et al., 2019; Vanoncini et al., 2022)

10.3.2. Table 3. Model Outputs Objective 1 RR: Model 1.1-1.2

Full-null comparison:			
	X^2	df	p
Model 1.1: log_RR ~ test*day + batch + (1|pig)			
Comparison to Nullmodel: log_RR ~ (1|pig)	4.032	4	0.402
Model 1.2.: log_RR ~ batch + day + test + (1|pig)			
Comparison to Model 1.1.	0.050	1	0.822

Model estimates:					
	Estimates	SE	df	t	p
(Intercept)	1.418	0.558	38	2.541	0.015
test	0.628	0.669	45	0.939	0.353
day	-0.01	0.669	45	-0.015	0.988
batch	0.289	0.542	24	0.533	0.599
test:day	0.229	1.079	24	0.212	0.834

ANOVA:						
	Sum Sq	Mean Sq	Num df	Den df	F	p
test	7.437	7.437	1	25	3.513	0.0726
day	0.147	0.147	1	25	0.070	0.794
batch	0.603	0.603	1	24	0.285	0.599
test:day	0.095	0.095	1	24	0.045	0.834

Significance level: *p<0.05

10.3.3. Table 4. Model Outputs Objective 1 ENTR: Model 2.1-2.2

Full-null comparison:			
	X^2	df	p
Model 2.1: ENTR ~ test*day + batch + (1|pig)			
Comparison to Nullmodel: ENTR ~ (1|pig)	9.285	4	0.054
Model 2.2.: ENTR ~ batch + day + test + (1|pig)			
Comparison to Model 2.1.	1.069	1	0.301

Model estimates:					
	Estimates	SE	df	t	p
(Intercept)	2.479	0.196	39	12.659	0
test	-0.524	0.236	45	-2.219	**0.032***
day	-0.340	0.236	45	-1.441	0.156
batch	0.230	0.188	24	1.226	0.232
test:day	0.368	0.374	24	0.984	0.335

ANOVA:						
	Sum Sq	Mean Sq	Num df	Den df	F	p
test	1.522	1.522	1	25	5.801	**0.024***
day	0.322	0.322	1	25	1.229	0.278
batch	0.394	0.394	1	24	1.503	0.232
test:day	0.254	0.254	1	24	0.968	0.335

Significance level: *p<0.05

10.3.4. Table 5. Model Outputs Objective 1 Qlos: Model 3.1-3.2

Full-null comparison:			
	X^2	df	p
Model 3.1: Qlos ~ test*day + batch + (1|pig)			
Comparison to Nullmodel: Qlos ~ (1|pig)	3.517	4	0.475
Model 3.2.: Qlos ~ batch + day + test + (1|pig)			

Comparison to Model 3.1.			0.605	1	0.437
Model estimates:					
	Estimates	SE	df	t	p
(Intercept)	0.916	0.100	49	9.143	0
test	-0.056	0.125	49	-0.446	0.657
day	0.010	0.125	49	0.081	0.936
batch	-0.003	0.089	49	-0.030	0.976
test:day	0.149	0.176	49	0.846	0.402
ANOVA:					
	Sum Sq	Mean Sq	Num df	Den df	F	p
test	0.005	0.005	1	49	0.046	0.830
day	0.097	0.097	1	49	0.924	0.341
batch	0.00093	0.000093	1	49	0.0009	0.976
test:day	0.075	0.075	1	49	0.716	0.402

Significance level: *p<0.05

10.3.5. Table 6. Objective 2 PCA loadings

Loadings:		
	PC1	PC2
approaching_dur	0.611	0.3
body.contact_dur	-0.703	0.016
contact.by.pig_dur	-0.893	0.204
curled.tail_dur	0.306	0.382
elimination_freq	0.585	-0.343
exploring_dur	-0.026	-0.795
following_dur	-0.53	0.658
hanging.tail_dur	-0.161	-0.452
immobile_dur	0.87	-0.003
look.for.escape_dur	0.215	0.195
physical.int_dur	-0.732	0.564
wagging_dur	-0.16	-0.347
withdrawing_dur	0.696	0.402
low.vocal_freq	0.607	0.359
high.vocal_freq	0.595	0.284

10.3.6. Table 7. Model Outputs Objective 2 ´'Component 1 - Conflict of motivation: Engage with human versus stress behaviour (Engage)' ´: Model 4.1-4.2

Full-null comparison:						
				X^2	df	p
Model 4.1: Dim1_Engage ~ test*day + batch + log_RR + ENTR + Qlos + (1|pig)						
Comparison to Nullmodel: Dim1_Engage ~ (1|pig)				38.239	7	**2.73E-06*** **
Model 4.2.: Dim1_Engage ~ batch + day + test + (1|pig)						
Comparison to Model 4.1.				35.627	4	**3.45E-07*** **
Model estimates:						
	Estimates	SE	df	t	p	
(Intercept)	1.702	1.987	44	0.857	0.963	
test	0.713	0.805	41	0.886	0.381	
day	0.191	0.609	39	0.313	0.756	
batch	-0.483	0.514	23	-0.940	0.357	
log_RR	-1.187	0.476	44	-2.492	**0.017***	
ENTR	0.065	1.025	44	0.063	0.950	
Qlos	0.536	0.689	39	0.778	0.441	
test:day	-0.666	1.028	24	-0.648	0.523	
ANOVA:						
	Sum Sq	Mean Sq	Num df	Den df	F	p
test	0.533	0.533	1	41	0.407	0.527
day	0.255	0.255	1	21	0.195	0.663
batch	1.157	1.157	1	23	0.884	0.357
log_RR	8.134	8.134	1	44	6.213	**0.017***
ENTR	0.005	0.005	1	44	0.004	0.950
Qlos	0.793	0.793	1	39	0.606	0.441
test:day	0.550	0.550	1	24	0.420	0.523

Significance level: *p<0.05, **p<0.01, ***p<0.001

10.3.7. Table 8. Model Outputs Objective 2 ´ Component 2 – Human versus environment (Interest)´: Model 5.1-5.2

Full-null comparison:						
				X^2	df	p
Model 5.1: Dim2_Interest ~ test*day + batch + log_RR + ENTR + Qlos + (1|pig)						
Comparison to Nullmodel: Dim2_Interest ~ (1|pig)				38.063	7	**2.95E-06*** **
Model 5.2.: Dim2_Interest ~ batch + day + test + (1|pig)						
Comparison to Model 5.1.				12.569	4	**0.014***
Model estimates:						
	Estimates	SE	df	t	p	
(Intercept)	3.640	1.653	43	2.203	0.033	
test	-0.125	0.660	42	-0.189	0.851	
day	-0.359	0.497	41	-0.722	0.474	
batch	-0.222	0.401	24	-0.553	0.585	
log_RR	1.274	0.396	43	3.219	**0.002****	
ENTR	-2.511	0.855	44	-2.936	**0.005****	
Qlos	-0.480	0.588	42	-0.816	0.419	
test:day	1.131	0.804	25	1.407	0.172	
ANOVA:						
	Sum Sq	Mean Sq	Num df	Den df	F	p
test	0.808	0.808	1	42	0.759	0.389
day	0.538	0.538	1	23	0.505	0.484
batch	0.326	0.326	1	24	0.306	0.585
log_RR	11.029	11.029	1	43	10.360	**0.002****
ENTR	9.180	9.180	1	44	8.623	**0.005****
Qlos	0.708	0.708	1	42	0.665	0.419
test:day	2.107	2.107	1	25	1.979	0.172

Significance level: *p<0.05, **p<0.01, ***p<0.001

10.4. List of Figures

10.5. List of Tables

10.6. Supplementary Figures

Figure S1: Steps of data analysis

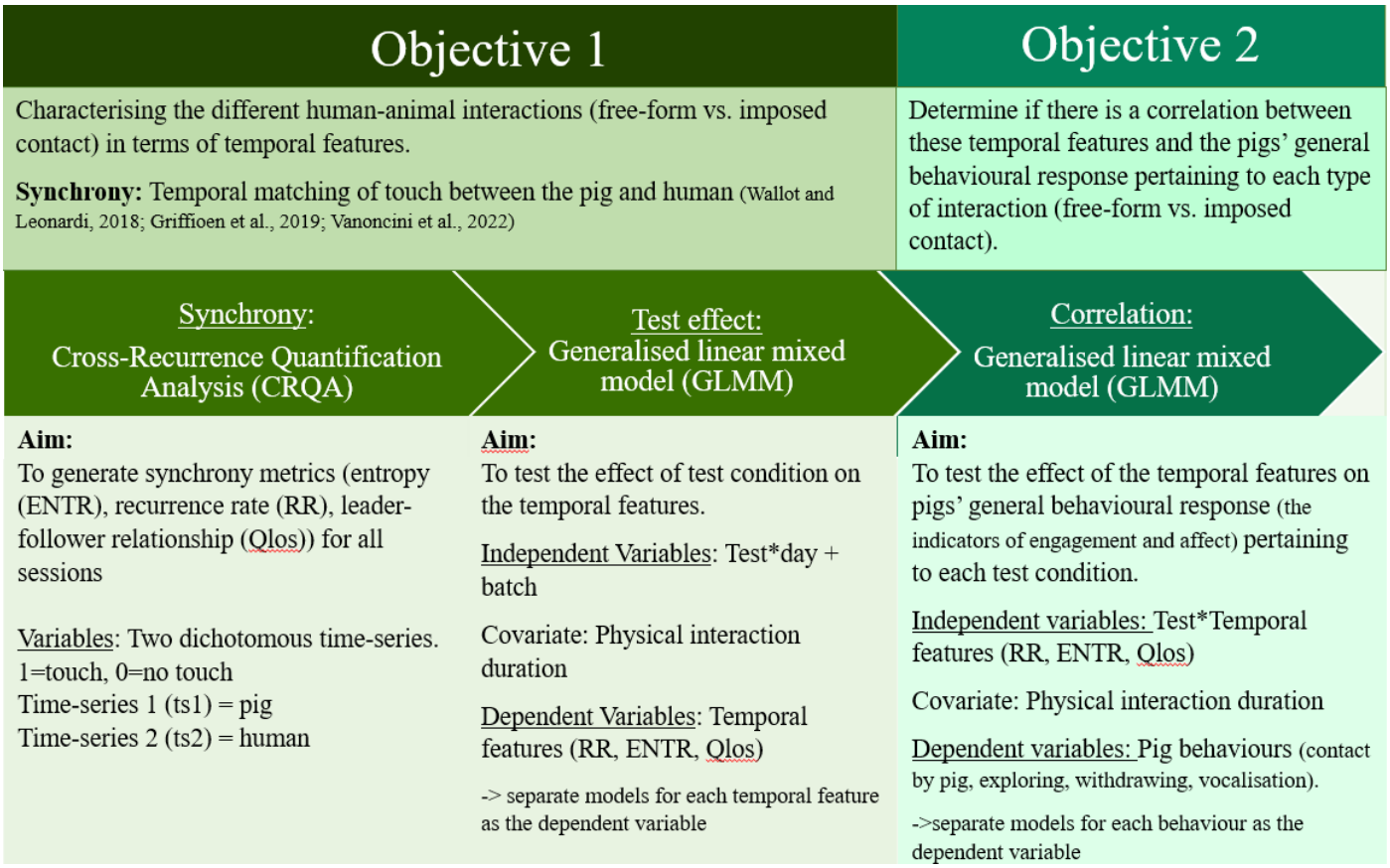

Figure S2: PCA Variables 1:2