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Dyadic Adjustment:
Interpersonal Synchrony in Physiological and Behavioral Processes

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Abstract

This dissertation investigates how the temporal structure of two oscillating signals adjust to each other in a dynamic manner, as a function of two people's level of togetherness. The ability to adapt one's intentions and behaviors in response to a partner's displays; namely, dyadic adjustment, is a key factor in romantic relationships. The quality of a relationship is contingent upon the ability of partners to promote an understanding of each other's subjective states and behaviors, facilitating cohesive unity as opposed to a fragmented duality. Mirror neurons, which encode actions, emotions, and sensations experienced by oneself and others, are believed to be essential components for the interindividual awareness that characterizes human social behavior. The question being asked here is whether comparable mechanisms might also arise through primordial non-cortical mechanisms, given the holistic functioning of our brain-body system. For this purpose, the physiological parameters of 8 romantic couples and 8 unknown couples were determined during a laboratory face-to-face mediated interaction. Additionally, it was investigated the degree of behavioral adjustment trough a newly designed finger tapping task geared toward the quantification of sensorimotor synchronization. Measures of individuals' perception of their relationship with an intimate or unknown partner were obtained using self-report questionnaires. We hypothesized that the level of synchronization between individuals, as determined by correlation analysis, would be greater in the experimental group compared to the control group. The results showed that the heart rate series of romantic partners were more significantly synchronized than those of unfamiliar couples. However, the behavioral data did not reveal any significant difference between the romantic couples and their unfamiliar counterparts. Moreover, our study revealed a novel finding indicating that as the duration of the relationship increases, the level of synchrony in heart rate between

partners also increases. Overall, our findings highlight the importance of understanding the temporal dynamics of interpersonal physiology and the mechanisms underlying dyadic adjustment. The study also suggests that non-cortical mechanisms may contribute to affiliation and social cohesion, in addition to mirror neuron systems.

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Introduction

In physical sciences, the alignment of two independent events' frequencies over time is defined as synchronization. Likewise, humans tend to coordinate and adjust themselves with others in daily life interactions, promoting healthy and effective social interaction. Social neuroscience describes interpersonal synchrony "as the spontaneous, rhythmic, and temporal coordination of actions, emotions, thoughts, and physiological processes between two or more participants" (Ackerman & Bargh, 2010; Bernieri & Rosenthal, 1991; Palumbo et al., 2017). For instance, humans can actively control behavioural synchrony during singing, dancing, and implementing team tactics in sport competitions. Synchrony might also occur unintentionally, playing a fundamental role in forming social bonds; namely, when inter-individual coordination arises on a neurobiological and physiological level. Can being synchronized, at times, be a pro-social and affiliative mechanism?

The primary purpose of this dissertation is to investigate and quantify the relationship between dyadic adjustment and interpersonal synchrony. In the next paragraphs of this paper, synchrony will be described as an indicator of affiliative states in multiple relational units (dyads). The paper will concentrate on the state of the art with respect to the behavioral and the neurophysiological mechanisms underpinning affiliative processes in love relationships and those driving to attraction in a blind date setting. To this aim, behavioural and physiological factors will be then analysed individually using a paradigm geared toward the dynamical assessment of reciprocal coordination between humans. Given that, by definition, this complex phenomenon evolves over a wide time frame, rather than emerging at a specific point in time, a finger-tapping task was designed allowing its operationalization on a time-frequency basis.

1. Synchronic Behavior

1.1 Comparative approach

Several studies investigated the evolutionary advantages of synchrony adopting a comparative perspective, attempting to construct phylogeny of rhythmic group's behaviour. The phenomenon of synchronization might be found in a variety of species apparently too simple to be compared to Human beings. Although these species do not have actual social cognition, they show complex states of interindividual adjustments during a shared experience.

In the late 1960s, John and Elisabeth Buck published a paper regarding a unique phenomenon. The two researchers observed in South-east Asia an almost perfect synchrony in fireflies' intermittent bioluminescence. Several species of fireflies were accurately identified after selecting some of them for additional laboratory research. The bioluminescence of these fireflies was then captured on camera and measured with a photometer. By means of these measurements, it was possible to assess the extreme regularity of the males' pulsations (approximately two flashes per second), with some minor asynchronies resulting from the copresence of individuals from different species. For members of the same species (i.e., *Pteroptyx Malaccae*), the maximum discrepancy was estimated to be 20 ms. Initially, fireflies followed their own endogenous rhythm, then they seemed to spontaneously align such rhythm with the one of other individuals in their proximity. It seems that physical proximity is fundamental for the phenomenon to happen: when physically or visually separated from one another, synchrony goes out and the fireflies return to their endogenous rhythm independently. The research reveals that synchronized flashing in fireflies is solely performed by males and is associated with mating behavior, which has the potential to attract females to a specific location.

Further evidence raises questions about synchrony's adaptive role and those factors that might have contributed to its persistence.

Shared behavioral pattern is typically commenced and experienced by group members, but it is possible for individuals outside the group to also detect it. An additional species that exhibits collective rhythmicity is the Ryukyu Kajika, commonly known as the Japanese River Frog. Legett and colleagues have studied this phenomenon in 2020, concluding that synchrony is used to counteract predation, making the single frog more difficult to detect. In the lek mating system, alternation serves a reproductive function. In some species, male animals gather with the explicit goal of participating in competitive displays and intricate courtship rituals to attract potential mates. Asynchronous behavior during this competition can assist an individual in standing out from the group. This alternation is also found in cicadas, which exhibit similar behaviour in sexual competition. This evidence tends to demonstrate that, based on the contextual aspects and environmental selection pressures, constant synchrony is not always advantageous; however, synchrony is generally considered to be more adequate for the collective's benefit and cohesion.

Additional evidence is found in songbirds (Aronov D. et al., 2011) highlighting the importance of joint rhythmicity in the development of intraspecific behavioral traits. During their early developmental stages, fledglings learn species-specific singing patterns, which they can then perfectly reproduce to attract females as adults. Their audio-motor neurons (in the HVC nucleus) have evolved to allow an almost perfect timing in their firing, between their parent's (father) singing and its phono-articulatory representation. These sensory-motor neurons are selectively and millisecond-accurately activated depending on the type of singing and the perceived 'syllables'. If this type of neural “mirroring” is missing, the songbirds won’t be able to adaptively use their singing in sexual competition. Yasuo Nagasaka and colleagues (2013) evaluated rhythmic actions in a species which is phylogenetically close to humans and lives in complex social organization. This comparative study allows for a more reliable investigation of the evolutionary processes that have resulted in analogous behaviour in the human species. Researchers used a rhythmic-button-pressing paradigm to study whether Japanese macaques’ dyads would establish spontaneous synchronization of arm motion while they were facing one another. “The monkeys showed synchronization, and their behaviour was participant-partner dependent […] and visual information from the partners facilitated synchronization” (Nagasaka Y. et al., 2013). The proximate explanation about the brain areas and neurophysiological processes responsible for this social coordination remain largely unknown. In macaque studies, the ventral premotor cortex, and the rostral region of the inferior parietal lobule, was activated for motor control during action execution and observation (Nagasaka Y. et al., 2013; Rizzolatti & Craighero 2004). The visuo-motor neurons in this frontoparietal pathway, which researchers define “mirror system” (Gallese et al., 1996), exhibit functional properties comparable to the audio-motor neurons observed in songbirds. The mirror system along with other cerebellar structures stand as the most plausible mechanistic explanation responsible for the dynamic adjustment of actions’ temporal structure between two and more individuals.

These animal model studies illustrate how natural selection has favoured rhythmic coordination between the behavior of close individuals, leading to extend research in this field to the human species, adopting an integrated vision of the brain-body system.

1.2 Developmental Synchrony: Parent-infant reciprocity

It has been extensively reported the significant association between the quality of childrens' first meaningful relationship and its effects on developmental outcomes (e.g., emotion regulation, Landy & Menna, 2001), and social competence, (Black & Logan, 1995). The presence and interaction with an intimate partner can enhance and sustain an individual's sense of security by fulfilling his desires for comfort and protection from threats, both throughout childhood and into adulthood (Bowlby, 1973). According to Bowlby (1973) and his important attachment theory, the initial intimate relationship forms the basis of attachment patterns forming the foundations of adult emotion regulation across one's lifespan. During ontogenetic development, humans as a social species are strongly influenced by the interpersonal relationships they can establish. Our mental and physiological processes depend largely on the quantity and quality of these relationships: therefore, they can't be truly understood without considering the relationship itself (Gallese, 2017).

As Viaux-Savelon et al., stated in 2016 "given that the relationship between an infant and his caregiver is bidirectional in nature, the dyad should be thought of as a dynamically interacting system" (Viaux-Savelon et al., 2016). Numerous studies evaluate parent-infant dimension from the newborns' perspective, examining the signs they send to the mother and how these can lead to synchronic patterns, especially during aroused inter-individual interaction such as face-to-face engagement (Feldman, 2012). Some evidence suggests a primitive mother-fetus coupling already in the intrauterine environment. The fetus is directly interfaced with the mother's state, which at time determine significant shifts on the dynamics of his neurobiological and physiological systems away from equilibrium: high maternal stress and increased anxiety levels are correlated with an increase in fetal's mean heart rate (Monk et al., 2000); following hypooxygenation of mother's arterial blood, fetal heart rate variability and body motion are significantly reduced (Bekedam et al., 1991); fetal motor activity beginning at 20 weeks gestation gets synchronized with mother electrodermal and heart rate activity (DiPietro et al., 2006); the mean fetal heart rate reduces during sleep in line with the mean maternal heart rate (Patrick et al., 1982).

Although the mechanisms underlying such rich variability in physiologic changes remain unknown, it can be assumed that the fetus is indirectly exposed to similar fluctuations during mother's daily life experiences, especially in both positive and negative socio-affective interactions. The core concept driving this study relates to a complex interactive system where the outcomes in child's health and pathological deviation could be partially linked back to the prenatal period, and the child's indirect experiences during its gestation.

Leclère (2014) states that, throughout the postnatal period, in the domain of mother-child reciprocity, the dynamic adaptation of behaviors' temporal structure involves verbal and non-verbal communication, emotional displays, and facial expression. The mother's sensory cues (e.g., touch, smell, gaze, heart rhythms) and her behavioral adjustment to the newborn state are crucial in defining its social structure, interaction, and prosocial conduct. During early stages, children must encounter the harmonious interaction between their displayed desires and the parent's emotional and physical presence; if this correspondence does not occur, the child will experience negative emotional state and premature physiological stress responses. Developmental studies have also shown that infant-parent interactions move back and forth from synchronous to a-synchronous behaviours. Such a pattern might be developmentally more adequate compared to endless synchrony and is especially crucial for development of self-regulation and individual growth (Feldman, 2007).

Considering this evidence, synchrony must be conceptualized in accordance with different contexts, thus, as previously stated, its effect doesn't always conform to the rule "the more the better". Assessing the time and form of the mother-infant reciprocity, Peggy C. MacLean et al., in the 2014 described the critical role of face-to-face interactions. They investigated emotion regulation and maternal interaction styles by observing 84 full-term neonate behaviors during the Still-Face paradigm. The Face-to-Face Still-Face (FFSF) paradigm, originally introduced by Tronick and colleagues in 1978, is a widely recognized and empirically validated method to evaluate an infant's ability to regulate their socio-emotional behavior when exposed to a social stressor. This task entails the sequential presentation of three episodes: i) the baseline play episode, ii) the Still-Face episode, iii) the reunion play episode, in which the mothers were encouraged to play normally with their babies. During the second episode, mothers were requested to maintain a neutral facial expression and refrain from responding to their child's requests, avoiding any physical interaction or eye contact with their infant. Mother-infant interactions were recorded and analysed across episodes for mutual eye gaze, self-regulation, and child affect measures. Mutual gaze as a substitute for measuring mother-infant synchronicity, was quantified second-by-second as the mother and child established genuine eye contact between each other. Their findings supported the assumption that "an infant's experience of being synchronous with their mother and of being responded to contingently is associated with observable changes in an infant's emotion regulation with positive changes in the infant's affective experience apparent in real-time." Feldman et al. (2011) revealed that, during face-to-face engagements between mothers and their three-month-old infants, in addition to explicit reciprocity, it gets generated a pre-reflexive biological synchrony in heart rate acceleration and deceleration. The ability to impact the physiological processes of individuals in our proximity may be an evolutionary system that evolved during phylogeny and inherently predisposes us to relationship and openness to the other during our ontogeny.

1.3 Fundamentals of human synchronous behavior

Interpersonal synchrony is widespread across various human activities and, as previously stated, has recently been suggested as an evolutionary-based mechanism for facilitating social bonding (Launay, Tarr, & Dunbar, 2016). The evidence on interpersonal synchrony focuses mainly on temporal adjustment of behaviour, assessing a variety of body movements: chair rocking in shared rhythm (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007), spontaneous synchronization of leg movements in athletes (Varlet & Richardson, 2015), handclapping in concert halls, conversations (Fujiwara & Daibo, 2016; Tschacher et al., 2014).

Most of these occurrences are based on referential behaviors known as sensorimotor synchronisation (SMS) (Repp, 2005), in which an action’s rhythm is temporally coordinated with a predicted external rhythmic signal. In recent years, there has been a growing interest in neuroscience for the evaluation of motor control, timing, and sensorimotor synchronization (both visual and auditory). Sensorimotor synchrony it is commonly considered a core component of a more extensive concept – interpersonal coordination (Bernieri & Rosenthal, 1991). This term refers to the behavioural link between two or more individuals and can be conceptualized in two different ways: behavioural mimicry and interpersonal synchrony. Behavioural mimicry is the automatic tendency to reproduce a model’s behaviour, which acts as a social regulator by promoting affiliation (Chartrand & Lakin, 2013). Rapid Facial Mimicry (RFM) has at its core a mirror multimodal mechanism (Coudé & Ferrari 2018), which prompts empathy and engagement between interacting subjects, supporting the emergence of communication and emotional resonance. Interpersonal synchrony differs from mimicry as, in the latter, behaviours are identical, but they occur after some delay; whereas, in interpersonal synchrony, behavior that complements another's actions, such as the alternation of speaking turns in a conversation, can also be considered synchronized, if they occur at the same time (Ackerman & Bargh, 2010; Chartrand & Lakin, 2013). In most cases, synchronization can be defined as mimicry, including the spatial and temporal prediction of others' movements or behavior. Thus, it is likely to have similar effects on perceived affiliation and bonding. Dance and music performances have been extensively studied as examples of movements prediction and rhythmic adjustment between actions and perception, although additional research would be essential to comprehend the underpinning mechanism and the causal relationship between bond and behavioral synchrony.

In the human species it is extensively established that perception of another person's actions activates motor brain regions involved in producing a corresponding movement ourselves (e.g., Gallese, Keysers and Rizzolatti, 2004; Rizzolatti & Craighero 2004). Researchers studying human social interactions revealed that two individuals during verbal interaction may unintentionally mirror each other's non-verbal behavior, such as a facial expression or gesture (Condon and Sander, 1974). According to M. J. Hove (2009), activation of a common neural substrate facilitates interpersonal synchrony through a predictive simulation with high temporal precision of other's movements, leading to the merging of one's own and other's sensorimotor experience. Other circuits that could be engaged in similar processes could be found in cortico-cerebellar loops, because the cerebellum has been shown to be the core component not only for movement timing (Zatorre, & Evans, 1998), but also, for internal representations of sensorimotor dynamics and temporal prediction (Tesche & Karhu, 2000).

Studies have shown that also in the theatre, collective actions can lead to a state of inclusive, spontaneous, and highly synchronized motion among individuals. To investigate this condition Dahan et al. (2016) used a “mirror game”, a warm-up exercise from dance classes and theatre, in which two participants are required to stand, while keeping eye contact and producing synchronized mirror-like motions. Researchers propose the mirror game is in the interest to quantitatively evaluate the similarity of the dyad’ s performance, seeking for markers of togetherness and affiliation in the dyadic gesture. “The players face each other, holding handles that can move along parallel tracks half a metre long, and the motion of the handles is accurately recorded” (Dahan et al., 2016). This experimental setting enables players to produce rhythmic hand motions at different amplitudes and frequencies. Nevertheless, results show that instants of synchronous togetherness often rise and fade, collapse, and restart. Synchrony, as its underpinning time series metrics, is a non-linear phenomenon, and thus: “people do not remain locked in synchrony; instead, they repeatedly enter and exit synchrony. In many important interactions, such as therapy, marriage, and parent-infant communication, it is the ability to exit and then re-enter synchrony that is thought to build strong relationship” (Dahan et al., 2016).

Several laboratory studies (Chen et al., 2002; Repp et al., 2005; Repp and Penel, 2004;). investigated sensorimotor synchronization and spatiotemporal adjustments of movements by mean of body percussion (finger tapping), in response to a series of visual cues (flashing metronome). Others study has focused also on auditory stimuli to accurately investigate interpersonal finger tapping coordination. Heggli et al. (2018)

conducted a study in which they paired random participants with the purpose of understanding interindividual synchrony and the mechanisms that people use to maintain the provided rhythm individually, compared with another person, or the computer. After being connected through headphones, each pair's members were isolated in separate cubicles without visual contact. Before each trial, participants were advised who they would hear from. Two distinct sounds were selected such that participants could identify the sounds as originating from themselves or from others' tapping. A metronome with a tempo of 96, 120, or 150 beats per minute served as the referent input. They were told to tap on their keyboards for 8 beats, after which the referential stimuli would stop and the subject would receive feedback from one of three sources: the computer metronome, their partner's tapping, or their own tapping. In the two-person condition, where individuals only heard beats produced by the other participant, both sides continuously adapted to the other's auditory output. This was noticed on each tap occurrence and persisted across all 15 pairs during the trial. A connected unity was created as a result, where two followers reciprocally adapted to one another on a millisecond timeline.

These predictive and reactive abilities emerged during indirect interaction in a finger tapping task but given the phenomenon's complexity and the numerous potentially impacting aspects, as Randal (2011) suggested, it is important to distinguish between types of sensorimotor synchronies (unidirectional or bidirectional coupling, in-phase or anti-phase rhythmicity) and the way they are implemented in an experimental paradigm.

In the current paper, "synchrony" will indicate an interrelated co-variation and will be examined through bodily motion in a bidirectional finger-tapping task.

2. Physiological Synchrony

Humans have a strong predisposition to create social connections with unrelated others (e.g., Dunbar & Shultz 2010), and this tendency is most likely supported by an array of physiological, neurobiological, and cognitive mechanisms. Numerous studies have been conducted to determine the association between physiological synchrony, "the temporal coordination of physiological processes between two or more individuals" (Mayo & Gordon 2020), and shared social outcomes (Palumbo et al., 2017; Mayo et al., 2021). Specifically, peripheral physiological measures constitute indices of changes in autonomic arousal that occur not only when we experience any type of gratifying or threatening stimuli in the environment, but during engagement with others as well. Therefore, the extent to which interpersonal autonomic responses are synchronized over time is a fundamental component of shared experiences, and it captures aspects of reciprocal influence and co-regulation between people during shared interactions. The theoretical model of interpersonal neurophysiology describes human beings and their social competences as an emerging product of mutual dependence between body, mind, and relationships with others. Given the continuous nature of its signal, heart-related measurements are frequently implemented in interpersonal synchrony studies.

The heart and the brain have usually been studied separately, although these are anatomically and physiologically interconnected. Components of heart rate variability have attracted considerable attention in psychology, and have become important indices in behavioural, social, and psychophysiological research (Papousek et al., 2010). Heart Rate is an electrophysiological index dynamically modulated by both parasympathetic (PNS) and sympathetic (SNS) branches of the autonomic nervous system (ANS), which measures the number of heart beats per minute as instant changes.

In general, SNS responses contribute to states of heightened arousal needed for urgent a ction, whereas PNS activity occurs throughout social attention, rest, and digestion (Sbarra et al., 2014). Heart Rate Variability (HRV) is the fluctuation in the time intervals between adjacent heartbeats, and its derived measurements are generally grouped into time-domain and frequency-domain, both having clinical and cognitive-emotional significance (Berntson et al., 1997). According to a holistic and integrated vision, in the Polyvagal theory, Stephen Porges (1998) describes the mechanisms through which physiological states reflect feelings of safety and threat in both the individual and social dimensions. According to this comparative approach, complex social behavior and emotional regulation come from the evolutionary structural changes that occurred in the Autonomic Nervous System. Stephen Porges' research suggests that the latest system in the vertebrates' body, which he calls the Social Engagement System (SES), mediated by the vagus nerve, acts as a "brake" on the SNS, regulating the adrenal glands to attenuate adrenaline release and influencing the beats' rhythm of cells with an oscillatory potential in the sinoatrial node of the heart, supporting states of calmness and social communication (facial expression, vocalization, listening).

A recent work of Madsen and Parra (2022) found intersubject correlation (ISC) between participants' heart rate, electro-encephalography, and pupil size, while individually observing and processing instructional videos. However, as often seen adopting a solipsistic approach, avoiding the co-presence of two people in the experimental setting could lead to evaluate intersubjective relationships from an overly reductionist perspective, masking the dynamic processes during an ongoing social interaction. Despite an excessive methodological reductionism, this research offers an interesting point of view about the factors that are required to observe the hypothesized intra-subject correlation: "effective cognitive processing of a common stimulus, a strong attentional state toward it, and a robust coupling between brain activity and the physiological signal in question”. Congruently with the above statement, physiological synchrony has been found also during a group experience of a common emotional stimulus. In 2015, Golland et colleagues studied whether physiological and emotional states can converge among "merely co-present" participants without explicit interactions. They measured electrocardiogram (ECG) on 26 triples and collected emotional responses from participants who viewed an emotional movie in the same group, and control participants who did watch the movie in different groups. The ISC was determined for participants in the experimental condition and compared to the control groups’ ISC. “We found that the autonomic signals of co-present participants were synchronized and that the degree of this synchronization was correlated with the convergence of their emotional responses, reported after the viewing.” (Golland et al., 2015). These results demonstrate that when people's attention is drawn toward the same emotional input, they encounter moment-to-moment emotional exchange, which results in common emotional reactions.

An autonomic mediated resonance arises even in the absence of direct communication, and the following study appears to further corroborate these findings. Recently, Ardizzi and colleagues found co-variated physiological measures of groups of twelve unknown individuals, organized into quartets, attending live theatre performances as spectators. “Results showed an expected increment in synchrony among people belonging to the same quartet during both performances attendance and rest periods. Furthermore, participants’ cardiac synchrony was found to be correlated with audience’s convergence in the explicit emotional evaluation of the aesthetic performances they attended to” (Ardizzi et al. 2020). The phenomenon of cardiac synchrony could be part of a larger mechanism of reciprocal adjustment and shared emotional states.

Thus, this mechanism can also be extended to other aspects related to autonomic activity that have a body-brain connection, such as Galvanic Skin Resistance (GSR). This is demonstrated in a study by Behrens et al (2020), which further shows the need to implement a shared process that jointly involves both members of the couple. Behrens and colleagues investigated whether tasks necessitating cooperation would lead to greater synchronized physiological responses in dyads. The group conducted a study in which participants were paired and presented a version of the prisoner's dilemma. The task was carried out in a face-to-face condition, in which participants could see each other and communicate non-verbally, and a face-blocked condition, during which a panel was placed between pairs to avoid any visual contact. The study found the face-to-face condition led to higher cooperation, as well as synchrony in skin conductance between pairs.

Stephen Porges described several ways of activating the SES but noted that the easiest way to activate this system is for a person to be engaged in non-threatening eye contact. The above study appears to be further evidence of the intersubjective mechanisms discussed: for this reason, we suppose that heart rate synchrony may represent a process of joint vagal activation, when both partners are involved in the same experience. In line with the aforementioned assertion, an eye contact condition was included to our paradigm, which promoted a high attentional engagement by using the other's co-presence as a common stimulus.

2.1 Romantic attachment, attraction, and physiological dynamics

"Humans' well-being is shaped by the ability to connect with each other" (Samara Kret et al., 2021). Social neuroscientific research has shown that owing to a shared biological nature, a sense of similarity emerges between the Self and Other, mediating the implicit certainties we simultaneously hold about others.

“This we-centric space allows us to personally characterize and provide experiential understanding to the actions performed by others, and the emotions and sensations they experience” (Vittorio Gallese., 2008). This new model of social intelligence refers to a broader theoretical framework known as embodied simulation, as suggested by Gallese (2003, 2005, 2011; Ammaniti & Gallese 2014). According to this conceptual perspective, similarity can vary along a continuum, where the opposite extreme is otherness, which is also necessary in a healthy relationship to understand other’s desires, thoughts, emotions, and intentions, while keeping them separate from the self. Thus, we can adjust our behaviour, thoughts, needs and perhaps the underlying processes shaping our brain-body mechanisms, promoting cohesion and empathy at an implicit level.

As Medved H. K. (2016) suggested: “Well-adjusted couples will increasingly work as a team and a cohesive unit rather than as two separate entities”. In this regard, the current section of the dissertation aims to present the concept of affiliation, which can easily be read in terms of emotional attunement, empathy, adjustment, and overall social cohesion. The expression “affiliation” refers to the spontaneous establishment of reciprocity (partners' ability to adjust to one another) and intimate social bonds in romantic couples. Romantic dyads constitute one of the contexts in which the number of studies investigating synchrony dynamics - psychophysiological synchrony specifically- has been increasing in the last decade (e.g., Karvonen et al., 2016; Saxbe et al., 2010). The need for affiliative relationships in our species goes beyond reproduction and/or the acquisition of resources: we seek intimate interactions to gain social and emotional fulfilment, as well as emotional attunement in the form of implicit reciprocal understanding. To achieve a satisfactory degree of affiliation, romantic partners should share similar views regarding quality of communication, decision making, and affective expression. Couples who have good marital adjustment show high levels of a specific type of behavioural co-regulation. Much evidence suggests that acting synchronously with others promotes affiliation (e.g., Macdonald & Wilson, 2005), but the causal role of interpersonal physiological synchrony on conjugal affiliation is yet poorly understood in the relevant literature. Previous research has shown how physiological synchronization increases when people have trust relationships (Mitkidis et al., 2015). Hence, the dynamical adjustment of physiological processes in a dyad, can determine affiliation in a real-life relation.

Multiple factors may influence the amount of covariation in partners' physiological time series, particularly in the case of cardiac synchrony. The emotional valence of the interaction seems to be the primary factor that determines the degree of relational synchrony, yet the environment also plays a significant role (Palumbo et al., 2017; Timmons et al., 2015). Both Levenson (1983) and Coutinho (2021) registered the presence of cardiac synchrony during dyadic interactions when compared to controls surrogate couples. In these two experiments participants performed a "structured interaction task in the lab where they discussed positive and negative aspects of their own relationship" (Coutinho et al., 2018). Synchrony may exist in various form, in any situation of altered shared emotional states, caused by empathic engagement or conflict. Likewise, the differences in dominance and power experienced by couples also affects interpersonal synchrony during problem-solving tasks (Dunbar & Mejia, 2013). Therefore, in the implemented experiment (see methods and materials), the role of dominance (leader) and submission (follower) was considered as a potentially influential variable in determining the direction of physiological synchrony.

In a paper published in 2014, Ferrer and colleagues, in the context of attachment theory, evaluated the association between close relationship and health within various affective dyadic interactions. They recruited 32 romantic couples to participate in a series of laboratory tasks aimed at identifying coregulation processes between adult romantic partners. Men's and women's Respiratory Sinus Arrhythmia (RSA) were compared to their partners' physiological responses at various epochs of the experiment.

The RSA, or variability in the heart's interbit intervals across the respiratory cycle, has received much interest because of its application in emotion regulation, health and psychopathology prevention. The RSA pattern is generated by cardiorespiratory processes, acting as a regulator for vagal contribution to the heart rhythm. Specifically, inspiration reduces vagal neuron activity, preventing its influence on the heart and enabling the sympathetic branch to effectively accelerate heart rate. Conversely, expiration triggers vagal activation, which with its inhibitory effect on the heart, slows down the heartbeat (Berntson, Cacioppo, & Quigley, 1993). The previously mentioned Polyvagal Theory, which conceptualizes RSA in social interactions, states that RSA tends to increase when people engage in social interactions and feel secure in their surrounding environment. Porges, however, describes also how reductions in RSA happen simultaneously as fight-or-flight reactions gain priority (Porges, 1998).

Given that vagal activation facilitates social interaction trough physiological regulation, in their study, Ferrer et al. expected that "high-quality relationships should promote self-regulatory capacity and that interactions with one's partner are less physiologically taxing for people in high-quality relationships" (Ferrer, 2014). To test this hypothesis, participants were initially seated and requested to refrain from making any physical contact during the baseline task; participants were then engaged in three conversation tasks (i.e., positive conversation, neutral talks, and negative discussion). During the negative discussion with their romantic partner, men exhibited a significant rise in RSA when compared to baseline levels, but women did not show the same change in cardiorespiratory pattern. Positive cross-partner effects for RSA were observed regardless of the gender, throughout the interaction tasks. When one of the two members of the couple had high levels of RSA in that specific moment, the partner's RSA consistently increased on the following epoch. Some couples in the overall sample displayed more physiological synchronization than others. Relationship quality, quantified by the Perceived Relationship Quality Components Inventory (PRQC), modulated the co-regulation of the RSA: higher-quality relationships was associated with significantly greater physiological synchronization.

In a similar research, Gates, and Blandon (2015) recruited 49 families to examine the physiological linkage of married couples while playing with their children, in an almost natural laboratory setting. After filling out questionnaires to assess the quality of their marriage, hausband-wife dyads participated in 10-minute play sessions with their children, as they normally do in their daily life dynamics. Through a time-varying analysis of cardiac data, for each married partners have been computed a second-by-second RSA during the interaction activity. The results show that although synchrony can arise in different modalities, its occurrence is high for many couples. Dyads with elevated RSA synchrony are more likely to mirror the physiological arousal of their partner (in-phase synchrony), although, those with reduced synchrony will have a greater tendency to exhibit compensatory or opposing levels of arousal (anti-phase synchrony). "Higher matched RSA across time (i.e., in-phase) was associated with greater levels of reported marital conflict for both husbands and wives. In contrast, compensatory linkage patterns (anti-phase) were associated with less marital conflict, suggesting this type of physiological linkage reflects adaptive interaction patterns. The ability of one individual to reduce arousal at a time when the other increases arousal may serve to maintain a level of homeostasis within the dyad, even while the individuals themselves are reactive" (Gates, 2015). The current finding and their interpretation add significant insights to the literature on physiological linkage in intimate relations. Like mentioned above, higher synchrony is not always a healthy approach. That is, the ability to regulate the degree of synchrony in a specific social context is considered to be more adaptive than a high amount of synchrony per se. It could be argued that the most successful cooperation stems from a balance between synchrony (in-phase and anti-phase), its absence, and reciprocal adjustment to reach synchrony again.

In accordance with our theoretical framework and hypothesis, the following research, raises interesting question about the causal direction between physiological synchrony and interpersonal attraction. Thanks to the combination of multiple measures, Samara Kret et al., 2021 were able to acquire a new entry point to understand dyadic attraction and affiliation in pairs of strangers, providing a more holistic understanding of bodily-nonverbal signals that drive social interactions. Coherently with our perspective, in this study attraction was examined as a dynamic construct, arising from behavioural and/or physiological synchrony in an experimental setting that recreates real-life dating interactions**.** Their primary hypothesis was that attraction could be attributed to the level of synchronicity between individuals, and their aim was to define which behavioural or physiological changes predicted attraction, and test how accurate people were at predicting whether a partner wanted to date them. Intentional signals such as mimicry or gaze direction, did not predict attraction at the individual level. "Correlations have been found between the number of partners' smiles, hand gestures, and face touching. The greater expressiveness exhibited by one member of a couple, the more likely it is for the other member to mirror their expressions. Despite this, behavioural expressions did not significantly predict the level of mutual attraction reported at the end of the interaction". In addition, their results showed that attraction can be predicted by involuntary mechanism such as synchrony in heart rate and skin conductance between individuals. "This suggests that physiological synchrony could potentially explain more than visible mimicry can capture […]. In consequence, we propose that when people align on the autonomic level, these physiological changes can trigger feelings of attraction via body-to-brain signaling.". Hove and Risen (2009) conducted a study to investigate behavioural adjustment in strangers. In their paradigm participants carried out a tapping task led by a visual cue, with the presence of an experimenter who tapped in time with the subject or out-of-synch. Post-test questionnaires revealed participants found the experimenter more likable in the synchronous tapping condition, compared to out-of-synch trials. If shared physiological processes and synchronous behavior can improve our impression of others, then an existing relationship should also influence interpersonal synchrony.

The present study introduces a new experimental procedure where both in-phase and anti-phase synchrony could emerge at a behavioural and physiological level. More specifically, well-adjusted couples could show a more adaptive behavioural and physiological synchrony than that of couples who have poor adjustment or pairs of strangers. In the latter, a higher level of implicit adjustment, at the behavioral or physiological level, could confirm the relationship between attraction and synchrony in a blind date setting.

Experiment

3. Methods and Material

Participants

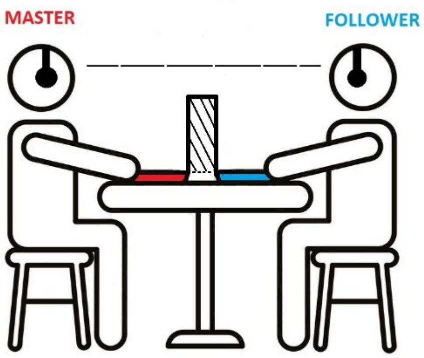
Initially, 18 couples were enrolled in this study. For the pilot study, we selected 8 pairs of romantic couples and 8 randomly paired strangers as control. Both couples and controls were under 50 years old (25.04 ± 2.715 years), and they had no experiences with musical instruments or trained rhythmic abilities. Both members of the pair played the role of master and follower as described in the procedure below. Our criteria for recruiting couples were relationship stability (at least 2-year relationships) and cohabiting. On average, the eight romantic couples have maintained a stable relationship for a period of 3.25 ± 0.866 years. The 16 control participants did not know each other nor had any interactions previous to the experimental task.

Pre-test Questionnaire

We decided to evaluate romantic couples' interpersonal adjustment using the Dyadic Adjustment Scale (DAS, Spainer, 1976). Introducing the DAS, Spainer (1976) refers to a previous study (Spanier and Cole, 1974) in which dyadic or marital adjustment is conceptualized in two main aspects: qualitatively and as a process. The DAS can help to consider broader time frames in a romantic relationship, specifically the overall degree of affiliation rather than relationship satisfaction at a specific point in time. Furthermore, the DAS allows evaluation of non-marital relationships, which makes it usable in several romantic couples regardless of their marital status. This scale includes 32 items, divided in four subscales: 1) Dyadic Consensus, 2) Dyadic Satisfaction, 3) Dyadic Cohesion, 4) Affectional expression. In the original study Cronbach's alfa was calculated to be 0.96 (Spanier, 1976), and recent reviews have confirmed good internal consistency (Graham et al, 2006). The scale isn't affected by age, educational status, relationship's duration, number of children or test-retest interval length (Carey et al, 1993) and has shown overall high reliability (Spanier, 1982). One limitation of the DAS is that the Affectional Expression subscale has been found to have a low Cronbach's alpha and seems to be affected by sample characteristics (Graham et al, 2006). In the control group, upon completion of the task, we conducted an additional assessment of mutual attraction between unknown participants using a Likert scale questionnaire. Specifically, two questions were presented to the participants: Firstly, to rate their partner's level of attractiveness, and secondly, to indicate their interest in meeting their partner again outside of the experimental context.

Experimental Procedure

Each of the pairs, both couples and strangers, was assigned a tapping task in which their aim was to synchronize with the beat they heard in headphones. A panel obstructed vision of the partner's hands, and the pairs were instructed to maintain eye contact with each other.



The tapping was executed and recorded on a Samsung tablet screen split in two hemi-fields. Each participant wore headphones to listen to their respective rhythms. One member of the pair, which will henceforth be referred to as the Master, began tapping in time with a metronome 15 seconds after beat onset.

The other member of the pair, the Follower, heard audio feedback of the master's tap for 15 seconds, after which they attempted to synchronize accordingly. The roles of Master and Follower were equally distributed (6 males, 6 females) and assigned in random order for a total of 12 trials. Both participants were presented with all tracks in the Master role (one per trial). Participants were unaware they would synchronize with their partner: Master and Follower headphones were connected to separate devices, and the former's auditory stimulus was external (and properly randomized), while the latter's was the master's tapping audio feedback. For the same reason, participants were told the study investigated social facilitation, and that swapping seats to invert Master/Follower roles was actually an attempt to control for distracting variables (i.e. some sort of mock distractor to be placed in the experimental setting). We prepared 6 different stimuli to submit to the Master, consisting of metronome clicks with tempos 60, 120 and 160 bpm. Each track presented all 3 tempos in a different order, for a total of six possible combinations. This was done for two reasons; 1) changing metronome speed abruptly controls for habituation and learning effects during trials; 2) tempo changes during trials allow to evaluate synchrony dynamically, by measuring the time it takes for dyads to realign and adjust to each other as well as overall tapping alignment. The tempo changes occurred every 3500ms, for a total trial duration of 10500ms.

We devised a software to randomize the order in which audio tracks were presented and distribute the Master and Follower roles across trials. The software indicated who would lead the tapping ("M" for male or "F" for female) and which of the 6 tracks they would listen to during the trial. After a brief preparation, during which the members of the couple sat according to the program's instructions, the pulse transducer to estimate ECG was then settled on the participant's non-dominant hand, and the trials began. On the tablet, in the Master's hemi-field, the instruction "GET READY " appeared (t0). Shortly after (t1), the software played the assigned metronome track in their headphones. For the first 15 seconds, the master's interface was coloured faint red and didn't record any tapping. In this phase, the participant was instructed to listen only without trying to synchronize yet. The follower, whose hemi-field stayed white without any instruction, was not listening to anything at this time (t1-t2). From second 15 (t2) to second 30 (t3) the Master's half of the screen turned vibrant red, and the software started to register every tap being made. During this time interval, the rhythm remained the same and, at t2, the follower interface turned faint blue, and he/she began to listen to the auditory stimulus (the Master's tapping). At second 30 (t3) the Follower's half of the screen turned vibrant blue, and the software started to record his/her tapping too (as he/she was supposed to try to synchronize to the output heard in headphones).

Then, after 5 seconds of joined tapping, the rhythm changed for another 35 seconds as we previously described, and then again for the last 35 seconds of the trial. At the end of this last interval (t4) the trial ended, and the software stopped recording taps until the following session. The data every trial returned were the time stamps of every tap of Master and Follower referring to t0 as starting point. The software also highlighted t1, t2, t3 and t4. Trials were separated by a pause in which participants were permitted to take the headphones off and have some rest.

Experimental Setup

With the aim to compare the heart rate variability and other cardiac components, between the members of the dyad while they were both tapping, the ECG of each participant was recorded throughout the experiment using LabChart 7 Pro software, starting at t0 and subsequently segmenting the raw signals with the corresponding moments of the behavioural task. The electrocardiogram was sampled at 1 kHz with an

ADInstruments PowerLab System, using for each participant a Finger Pulse Transducers (TN1012/ST) held in place using a hook-and-loop fastener around the middle finger. From the rhythmic heart activity different components were extracted (heart rate variability (HRV); heart rate (HR); Respiratory Sinus Arrhythmia RSA, as dependent variable to assess individual and dyadic cardiac responses at each epoch of the procedure. Data were converted and amplified with an eight-channel Bioelectrical signal amplifier (ML408). The ECG recording ended after that all the trials were accomplished.

Data Pre-processing

Given that the behavioral data obtained from the software described above, resulted in an inter-tap-interval (ITI) time series, no further pre-processing was deemed necessary. Thus, in the data analysis, the primary focus was directed towards the physiological data. The initial step of the analysis involved the pre-processing of the electrocardiogram (ECG) signals, which was of paramount importance in obtaining accurate and meaningful results. The ECG signals were meticulously selected and subsequently visualized to enable the accurate identification of specific features, namely the QRS complex, T and P wave. The identification of these features with precision is essential to acquire dependable measures of heart rate and other ECG parameters as they provide indications of both the depolarization and repolarization of the atria and ventricles of the heart.

As a result of the presence of artifacts in their electrocardiogram signal, two couples were excluded from the study, leaving 32 ECG signals of interest for further analysis due to their relatively high quality. To remove noise and artifacts from the signals, a high-pass filter with a cut-off frequency of 0.7 Hz was applied to eliminate low-frequency noise while retaining the lower frequency components of the ECG signal that are relevant for the analysis. A low-pass filter with a cut-off frequency of 35 Hz was then applied to remove high-frequency noise and muscle artifact while retaining the higher frequency components of the signal. The QRS complex was automatically identified and labelled by the LabChart software, with manual adjustments made to the QRS complex if necessary to ensure accurate labelling. Furthermore, HRV and Peak Analysis tools provided by the software were utilized to extract the heart rate, RR interval, and other relevant ECG parameters.

Finally, the pre-processed RR and ITI time series were exported for further analysis. To determine the time base for each tachogram and tapping series, we summed the inter-beat intervals and found the difference between the start and end times of the signal. However, the signals collected from each member of the couple were unevenly sampled, meaning that the time between successive measurements was not constant, and the total length of the signals could have varied.

To perform any comparison or additional statistical analysis between the two tachograms or two tapping series, we needed to resample and interpolate the signals on a common time base. The original signals were resampled at a rate of 4 Hz (or every 250 milliseconds) to ensure the time base for both signals were the same. The resampled signals contain discrete time steps that allow us to compare the two signals in a meaningful way (figure 1). However, the resampling process can lead to a loss of signal quality and potential artifacts in the data. To avoid this, we used cubic spline interpolation, a common method that estimates the value of a function at an intermediate point using a cubic polynomial. The cubic spline interpolation provides smooth and continuous functions that preserve the shape of the original signal and reduce the potential for artifacts in the data.

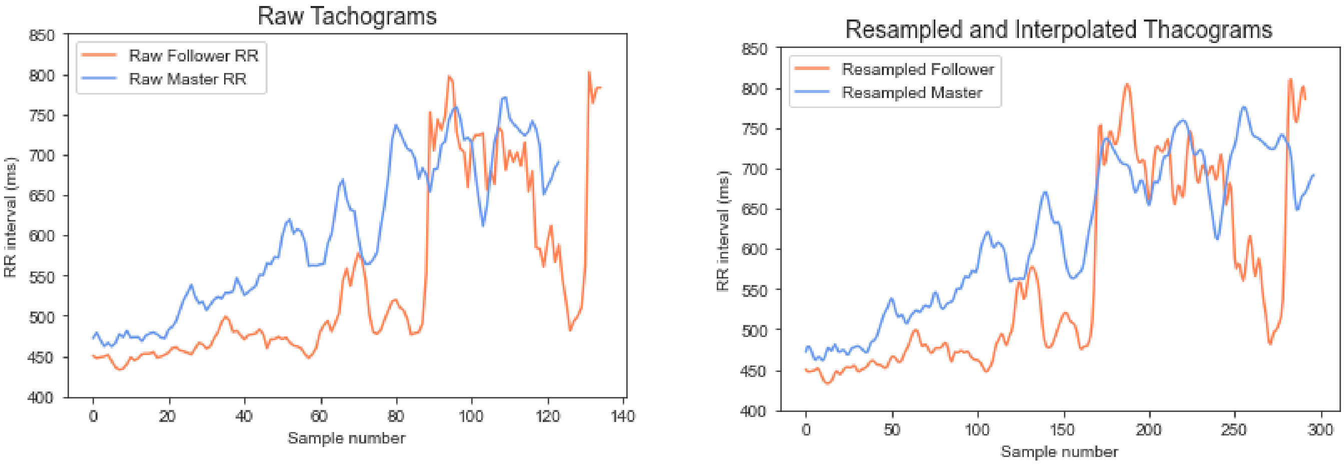


Figure 1.| *The plots illustrate a comparison between the original time series and the resampled and interpolated versions at a sampling rate of 4 Hz with a time interval of 250 ms. The original time series were resampled to achieve a uniform time base for both signals. The resampled time series exhibit an extended time range compared to the original time series. The comparison of the row signals shows that the resampled and interpolated signals are more aligned, indicating that the interpolation and resampling process successfully maintained the signal characteristics while achieving a uniform time base.*

The resulting resampled and interpolated signals were used for further statistical analysis to investigate the physiological and behavioral mirroring between romantic couples versus unknown couples.

4. Statistical Analysis

Once the data had been pre-processed, several statistical analyses were performed. Firstly, correlation analyses were implemented to investigate the temporal relationships between signals within each couple on a trial-by-trial basis. This was achieved by computing Pearson's correlation coefficient, which measures the linear association between two variables. Overall, correlation analysis can be a powerful tool for investigating the dynamical relationships between different variables, including both behavioral and physiological signals measured over time. The Pearson correlation coefficient varies between -1 and +1, where values nearing +1 indicate a significant positive correlation, values nearing -1 indicate a significant negative correlation, and values approaching 0 indicate no correlation. The degree of behavioral synchrony within couples over the 12 sequential trials can be determined by computing the correlation between the two finger-tapping signals in each trial. A positive correlation coefficient implies a strong relationship between the behaviors of the partners, which suggests a high level of behavioral synchrony. Conversely, a negative correlation coefficient indicates that the dyadic behaviors are either unrelated or exhibit an inverse relationship, which suggests a low level of behavioral synchrony. Similarly, the degree of physiological synchrony between the couples was determined by computing the Pearson's correlation coefficient for the two physiological signals within each couple. This allowed for an interpretation of the strength of the relationship between the physiological signals. As in the behavioral synchrony analysis, a positive correlation coefficient indicated a strong relationship over time between the participant's heart beating, suggesting a high level of physiological synchrony. On the other hand, a negative correlation coefficient indicated either an absence of a relationship or an inverse relationship between the physiological signals, suggesting a low level of physiological synchrony. To establish a non-synchrony baseline against which to compare the results of physiological and behavioral synchrony in the experimental and control groups, a third surrogate control group was created. To accomplish this, a symmetric correlation matrix was generated separately for the cardiac and behavioral data. Each matrix compared the time series of each individual, in each trial, with the time series of every other individual, in any trial and from any pair. To generate a new surrogate control dyad from the time series recorded on participants who co-presented during the experiment, 12 trials were randomly selected from each matrix. A follower and a master, who did not participate in the experiment together, were randomly paired to create a surrogate couple. This process was repeated 8 times, resulting in an additional surrogate control group that was perfectly balanced with the previously considered experimental and control groups. To ensure that each pair was unique and that the 12 trials within each pair consisted of different participants, certain constraints were applied to the random selection. Specifically, the time series for each trial were selected such that they had not been previously used within the new surrogate pair. For each couple, within the three different groups, the mean and standard deviation of the Pearson's correlation coefficients were calculated over the 12 trials. These summary statistics allow for a basic characterization of the physiological and behavioral time series data and facilitate their identification and comparison across the three groups of affiliation (i.e., romantic, unknown, and surrogate couples). The ANOVA table has been generated to determine the extent to which affiliation contributes to the variance in cardiac synchrony. The sum of squares (SS) for the affiliation factor was calculated by summing the squared deviations between each observation's mean and the overall mean, where the mean was computed separately for each group in the affiliation factor. In contrast, the residual sum of squares (SSR) was obtained summing the squared deviations of each observation from its group mean, which quantifies the unexplained variability in physiological synchrony after taking into account the impact of the affiliation factor. From these values, eta-squared (η^2), a measure of effect size, has been computed, to quantify the proportion of variance in physiological synchrony that can be explained by affiliation factor. Finally, Tukey's honest significance difference (HSD) test has been performed to determine whether there are significant differences between the means of cardiac synchrony for different affiliative groups. A comparable ANOVA was applied to investigate the association between behavioral synchrony and affiliative groups.

The accuracy and reliability of the results were ensured by building the models using established statistical techniques and following a rigorous analytical framework. Specifically, the analysis involved the comparison between means and standard deviations of the three groups that were independent of each other, estimating the coefficients of the linear model, evaluating their statistical significance, and assessing the goodness of fit of the model. An exploratory linear regression model was then created to explore the relationship between cardiac and behavioral synchrony in the overall sample. In the subsequent paragraph, we will provide a detailed account of the analysis performed for each affiliative group. By conducting a thorough investigation of each group separately, we aim to gain a deeper understanding of the relationship between synchrony and dyadic adjustment, and to identify any potential differences or similarities across the different groups. The analysis will include a comprehensive description of the statistical methods employed, both for the physiological and behavioral data. After the presentation of the statistical methods utilized, the current dissertation will present the results obtained and the conclusions derived from the findings.

Romantic Couples

Initially, a linear regression model was computed to explore the relationship between cardiac and behavioral synchrony in the experimental group. Subsequently, the focus of the analysis was on physiological synchrony in romantic couples. Two linear regression models were conducted to investigate the potential association between physiological synchrony and various relationship parameters. The first model included the average scores reported by both romantic partners on the Dyadic Adjustment Scale as the independent variable, while in the second model, the duration of the relationship was used as the independent variable. These analyses were performed on the same subset of the overall sample, that was used in the previous analysis, namely the couples with romantic affiliation. The subsequent analysis focused on the behavioral data of romantic couples, which was measured using the previously mentioned finger-tapping task. To quantify the relationship between tapping synchrony and the mean DAS scores, a linear regression model was utilized. Additionally, a linear regression analysis was conducted to examine the association between the duration of the relation and tapping synchrony. The primary objective of this analysis was to investigate the degree to which tapping synchrony increases or decreases based on the duration of the relationship and the time spent together.

Unknown Couples

This analysis aimed to investigate the extent of cardiac and tapping synchrony in unfamiliar couples. To explore the possible association between physiological and behavioral synchrony in these unaffiliated couples, a linear regression model was utilized. Subsequently, a linear regression model was employed to examine the potential relationship between physiological synchrony and the mean self-reported attraction scores of both partners in each respective couple. The subsequent analysis aimed to investigate the behavioral data obtained from the finger tapping task performed by unfamiliar partners. To assess the association between tapping synchrony and reported attraction scores, a linear regression model was employed, similar to the approach used for the physiological signals.

5. Experimental Results

Physiological Synchrony. Figure 2 shows the results of the one-way ANOVA for independent sample on cardiac synchrony ($F_{(2,21)} = 5.93$, $p = 0.009$, $\eta_p^2 = 0.36$) and cardiac synchrony variability between groups ($F_{(2,21)} = 0.36$, $p = 0.699$, $\eta_p^2 = 0.03$).

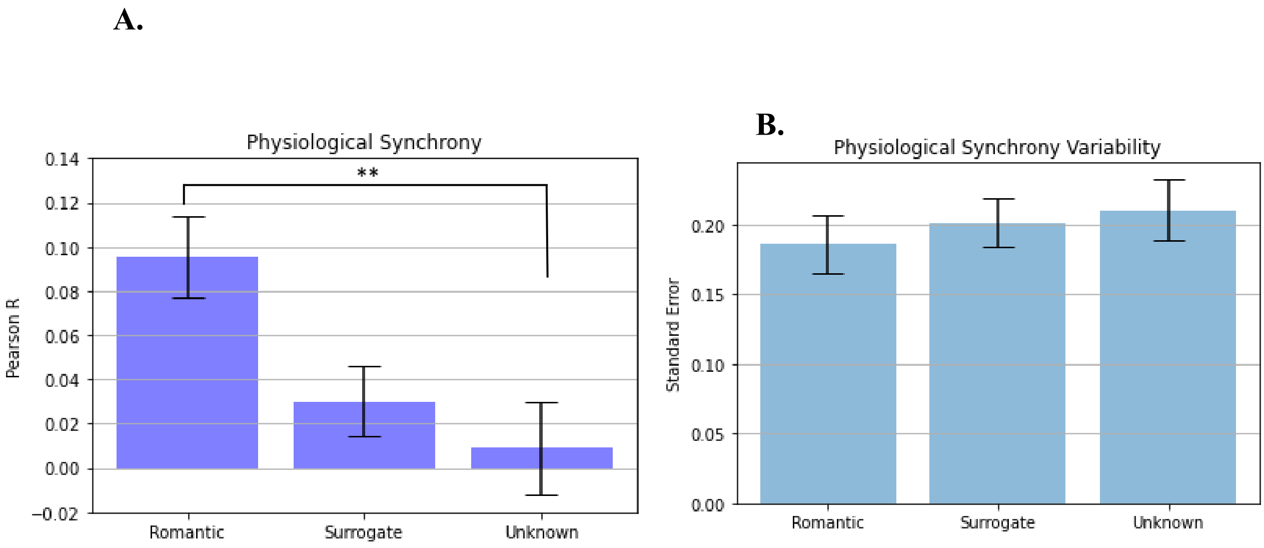


Figure 2.|* *A) *shows the results of two one-way ANOVA analysis for independent samples, on the differences in Heart Rate Synchrony among three groups based on affiliation levels: romantic, surrogate and unknown. The mean score in the romantic group was significantly higher than the score in the unknown group (p = 0.009), but there was no significant difference between the romantic and surrogate groups (p = 0.053). The unknown group had a non-significantly lower score than the surrogate group (p = 0.701).* ***B)*** *shows the differences in Synchrony Variability among three groups. No significant differences were found in this analysis.*

Subsequently, Tukey post-hoc tests were conducted to determine which specific group differences were significant. The romantic group had a greater heart rate synchrony mean score (M = 0.095, SE = 0.018) than both the unknown group (M = 0.009, SE = 0.021) and the surrogate group (M = 0.03, SE = 0.016). The mean score for the romantic group was significantly higher than the mean score for the unknown group, with a mean difference of (-0.086), 95% CI (-0.152, -0.02), p = 0.009. Based on the statistical analysis, although there was no statistically significant difference between the romantic and surrogate groups (mean difference = -0.065, 95% CI (-0.131, 0.001, p = 0.053), it should be noted that the p-value is close to the threshold of statistical significance (α = 0.05). Therefore, further investigation may be warranted to determine if there is a meaningful difference between these two groups. Finally, the unknown group had a non-significantly lower scores than the surrogate group, with a mean difference of (-0.021), 95% CI (-0.0871, 0.7004), p =0.7).

Behavioral Synchrony. The outcomes of the independent sample one-way ANOVA on tapping synchrony and tapping synchrony variability between groups are displayed in Figure 3, indicating a statistically significant difference ($F_{(2,21)} = 187.192$, $p < 0.001$, ηp2 = 0.947) and ($F_{(2,21)} = 179.205$, $p < 0.001$, ηp2 = 0.944), respectively.

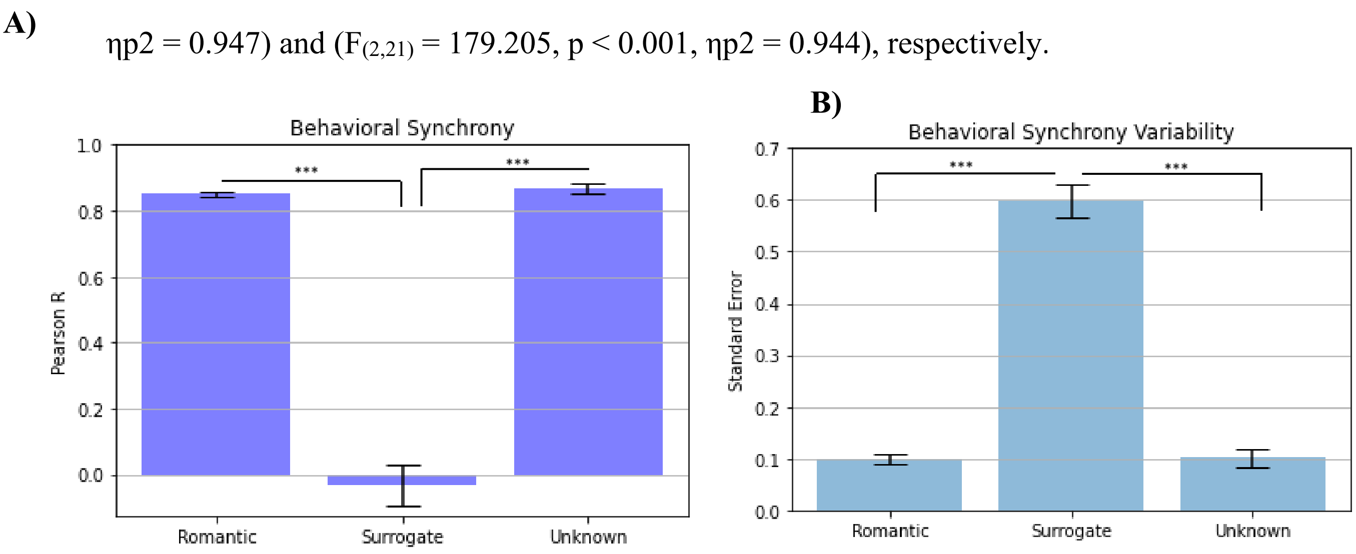


Figure 3*|* *Show the results of the independent sample one-way ANOVA and Tukey's post-hoc tests on tapping synchrony and tapping synchrony variability between three groups: romantic, unknown, and surrogate. Both tapping synchrony and tapping variability showed significant group differences (p < 0.001).* ***A)*** *shows romantic and unknown groups having higher tapping synchrony mean scores than the surrogate group. The romantic and unknown groups did not differ significantly from each other, but both were significantly higher than the surrogate group (p < 0.001).* ***B)*** *shows that tapping variability was significantly lower in both the romantic and unknown groups compared to the surrogate group (p < 0.001), with no significant difference between the romantic and unknown groups (p = 0.995).*

Tukey's post-hoc tests were used to identify the specific group differences in tapping synchrony that were statistically significant. The mean tapping synchrony score for the romantic group (M=0.849, SE=0.008) was similar to the unknown group (M=0.866, SE=0.017), but both of them were higher than the surrogate group (M=-0.034, SE=0.062). Specifically, the romantic group had a non-significant, lower mean score than the unknow group, with a mean difference of (0.017), 95% CI (-0.117, 0.151), p= 0.944. However, the mean score for the romantic group was significantly higher than that of the surrogate group, with a mean difference of (-0.884), 95% CI (-1.018, -0.75), p<0.001. Lastly, there was also a statistically significant difference between the surrogate and unknow groups, with a mean difference of 0.901), 95% CI (0.767, 1.035), p<0.001. The result of the Tukey post-hoc tests on the tapping variability, indicates that the dependent measure was significantly lower in both the romantic and unknown groups compared to the surrogate group (p < 0.001), with no significant difference between the romantic and unknown groups (p = 0.9949).

Linear Regression between physiological synchrony and behavioral Synchrony.

We conducted a linear regression to examine the relationship between heart rate synchrony and tapping synchrony considering both the experimental and control groups. The regression model showed a non-significant negative association between physiological and tapping synchrony (β =-0.01, SE = 0.14, t = -0.08, p = 0.935).

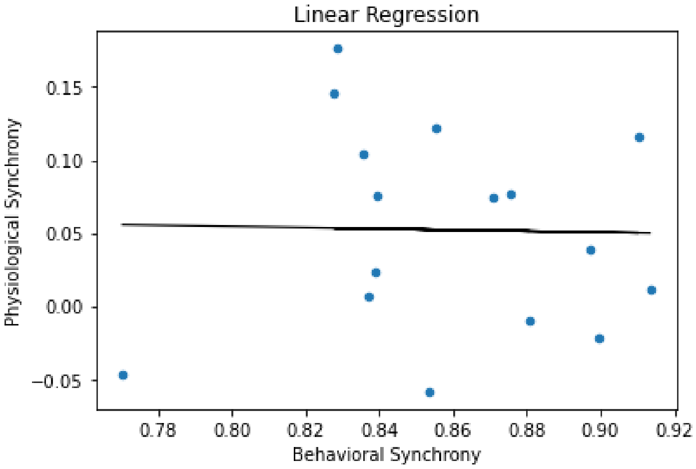


Figure 4.*| Shows the results of the linear regression model between tapping synchrony and cardiac synchrony considering both the control and experimental groups.*

To further examine the relationship between tapping synchrony and cardiac synchrony, we conducted additional linear regression analyses separately for the two groups. In the Romantic group, the regression model showed a non-significant negative association between tapping synchrony and cardiac synchrony (β = -0.26, SE = 0.16, t = -1.63, p = 0.155). A non-significant association was found between tapping synchrony and cardiac synchrony in the Unknown group (β = 0.41, SE = 0.28, t = 1.46, p = 0.196).

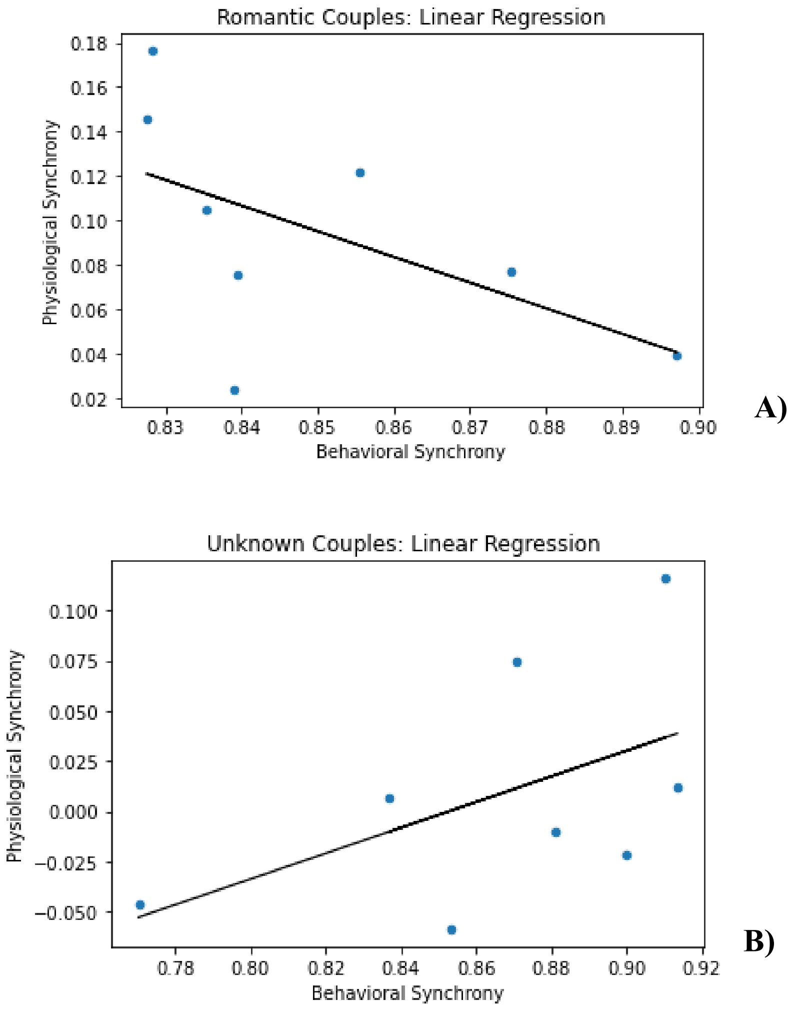
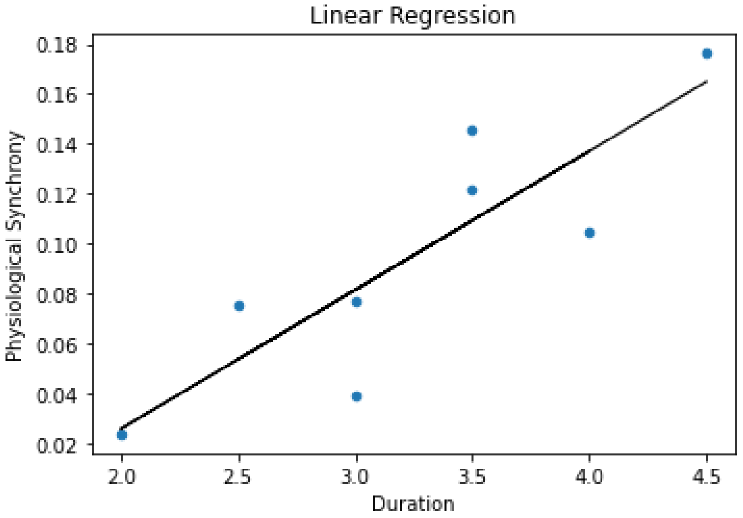
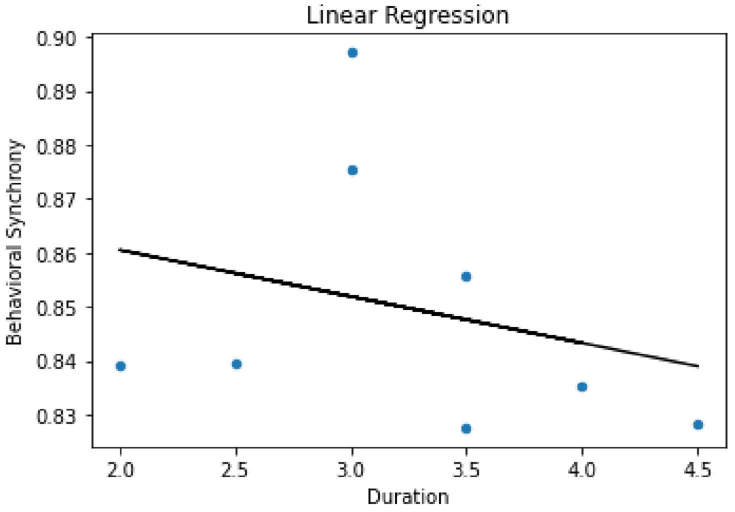


Figure 5.| *Linear regression analyses examining the relationship between tapping synchrony and cardiac synchrony in Romantic (**A**) and Unknown (**B**) dyads. The x-axis represents the tapping synchrony between the dyad, and the y-axis represents the cardiac synchrony.*

Romantic couples. In the supplementary analysis, we conducted four linear regression models to investigate the relationship between the duration of a romantic relationship, the self-reported evaluation of the quality of the relationship and both the physiological and behavioral synchrony. The first analysis revealed: a statistically significant positive relationship between the duration of the romantic relationship and the degree of synchrony in heart rate between partners ($\beta = 0.056$, SE = 0.014, $t = 4.11$, $p < 0.01$). On the other hand, the second analysis established a non-significant negative relationship between the duration of the romantic relationship and the degree of synchrony in the behavioral finger tapping task ($\beta = -0.009$, SE = 0.0122, $t = -0.71$, $p = 0.51$). This indicates that as the duration of the relationship increases, the synchrony in heart rate between partners also increases; vice versa, there may be a tendency for behavioral synchrony to decrease as the duration of the romantic relationship increases, but the result did not reach statistical significance. However, it's important to note that the sample size for this analysis was relatively small, which may limit the reliability and generalizability of the results. Additionally, it's crucial to keep in mind that this analysis does not establish causality, and there could be other variables that may explain the observed relationship.



A)



B)

Figure 6.**|** ***A)*** *Shows the relationship between the duration of a romantic relationship and the degree of synchrony in heart rate between partners;* ***B)*** *The scatter-plot shows the relationship between the duration of a romantic relationship and the degree of synchrony in the finger tapping tasks between partners.*

The second analysis focused on evaluating the reported quality of the relationship. The results revealed a statistically non-significant negative relationship between physiological synchrony and the DAS score (β = -5.834e-05, SE = 1.832e-0, t = -0.03, p =0.976). On the other hand, there was a non-significant positive relationship between behavioral synchrony and the DAS score (β = 0.001, SE = 0.001, t = 1.22, p = 0.266). However, similar to the first analysis, the sample size for this analysis was relatively small, which may limit the reliability and generalizability of these results.

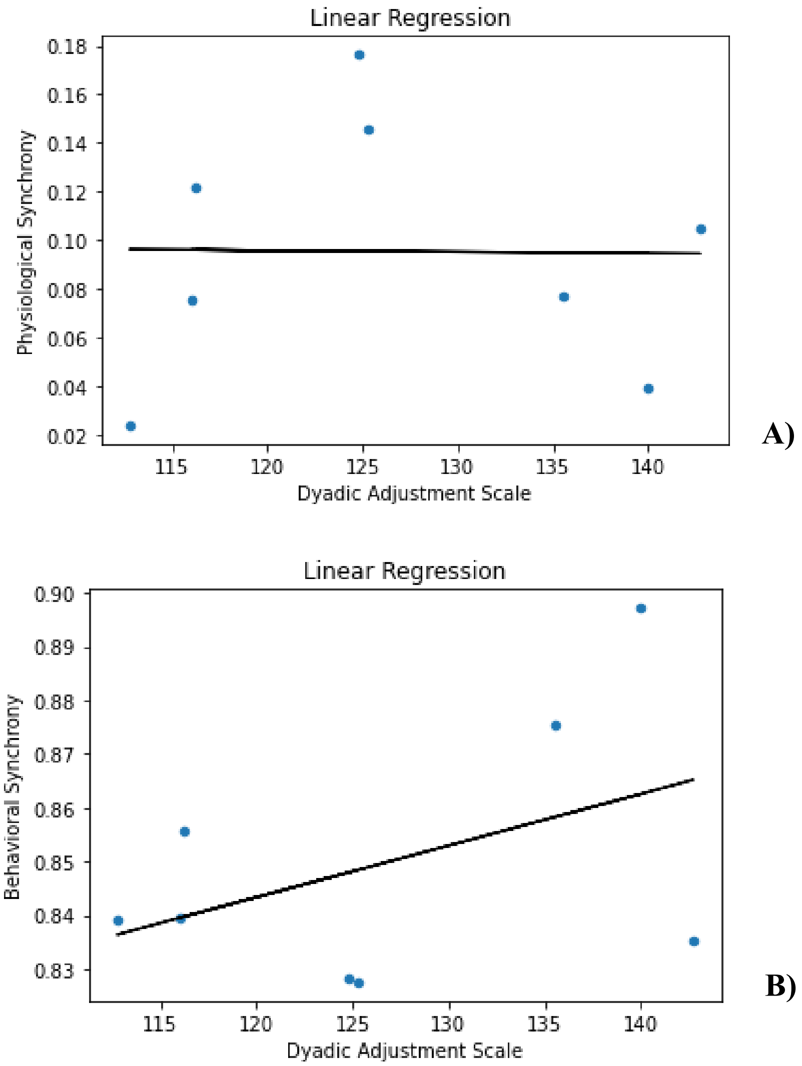
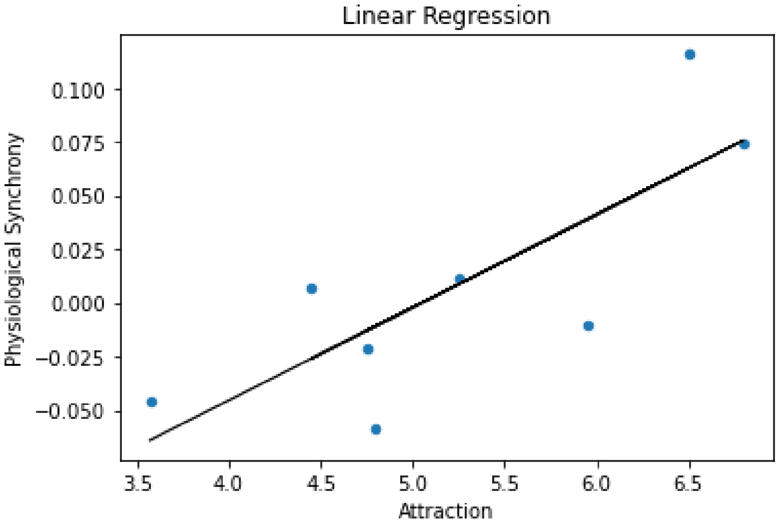


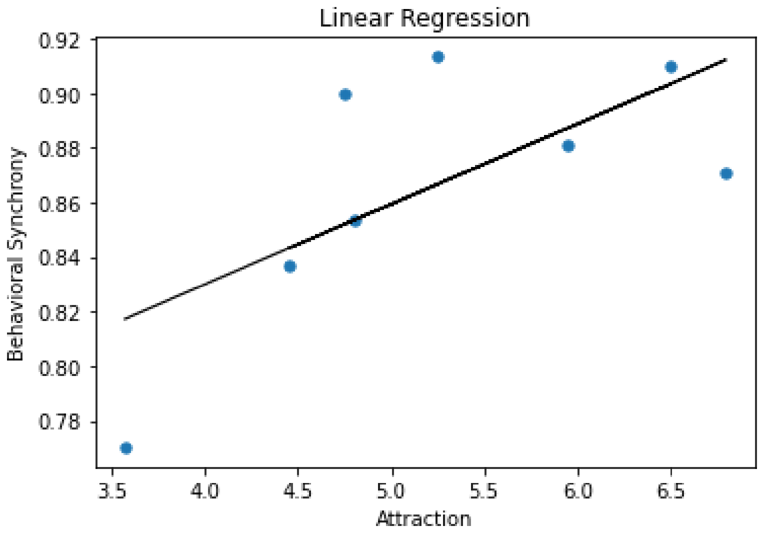
***Figure** 7.| **A)** Shows the relationship between heart rate synchrony and the self-reported evaluation of the quality of the relationship (DAS score). **B)** Shows the relationship between behavioral synchrony (measured by the finger tapping task) and DAS score.*

Unknown couples. The analysis conducted on the control group aimed to evaluate mutual and perceived attraction between two individuals during a blind-date interaction. Physiological and behavioral synchrony were measured to assess the relationship between synchrony and mean reported attraction score. The results showed a significant positive relationship between physiological synchrony and mean reported attraction score (β = 0.043, SE = 0.0134, t = 3.23, p = 0.018) in the control group. In addition, a non-significant positive relationship was found between behavioral synchrony and mean reported attraction score (β =0.029, SE = 0.013, t = 2.26, p = 0.065) in the same group. Taken together, the β coefficient, SE, and t-value it is possible that a relationship between behavioral synchrony and mean reported attraction score exists, but further research with larger sample sizes is needed to confirm this hypothesis.

These findings suggest that both physiological and behavioral synchrony are important predictors of attraction in a blind-date scenario. However, similar to the first analysis, due to the relatively small sample size, the reliability and generalizability of these results may be limited.



A)



B)

Figure 8.| ***A)*** *shows the relationship between heart rate synchrony and the self-reported evaluation attraction toward the unknown counterparts;* ***B)*** *shows the relationship between behavioral synchrony (measured by the finger tapping task) and attraction score.*

6. Discussion

The present study aimed to investigate sensorimotor synchronization and physiological interrelated co-variation between two interacting individuals. To achieve this goal, we designed a face-to-face finger-tapping task. The task required participants to tap their fingers to a referential auditory beat while facing each other (see Methods and Materials). The results discussed below represent the main findings of this pilot study. These analyses were selected as the primary focus of the experiment, as they were considered to be fundamental in understanding the potential limitations and implications of the apparatus. By focusing on this analysis, we aimed to gain a deeper understanding of the strength and direction of the relationship between the variables, and to inform future directions for this line of research. The study compared the behavioral performance and physiological parameters of two groups: romantic couples and unknown couples. The romantic couples were enrolled in the experimental group as representatives of a cohesive unit where two partners are closely linked to each other in terms of emotional attunement, empathy, and dyadic adjustment.

In contrast, unknown individuals were randomly paired in the control group, representing an unrelated dyad, where the only kind of affiliative linkage that could emerge would be the one established by first sight mutual attraction. The affiliation that exists between the members who make up the multiple dyads differentiates the two groups in this study.

The study's findings revealed that physiological synchrony was significantly higher in romantic couples compared to the control group. However, no significant differences were observed in behavioral synchrony between the two groups. Based on the result of a linear regression analysis, it was found a non-significant relationship between heart rate synchrony and tapping synchrony in the overall sample and neither in the experimental and control groups separately considered. The exploratory analysis conducted in this study suggests a dissociation between physiological and behavioral signals in the task assessment. Although group differences in performance were not significant, the analysis found a significant association between physiological synchrony and affiliative levels. This suggests that physiological synchrony provides a clearer understanding of ongoing social interactions, in regard to what explicit performance measures can reveal. The elevated levels of cardiac synchrony observed among the romantic couples suggest greater physiological co-regulation between them, indicating high coherence in their autonomic arousal changes during shared neutral interactions. However, the same phenomenon was not observed among couples who had met for the first time in the laboratory setting and lacked a comparable level of connection and consequential mutual influence.

To investigate the difference in physiological synchrony observed among the groups that did jointly engage in the task, we established a baseline of non-synchrony by randomly pairing cardiac time series from individuals who did not participate in the finger tapping task together. This surrogate served to further prove the absence of physiological synchrony among couples with no affiliative connection. Our statistical analysis revealed that the unknown group exhibited a non-significantly lower level of synchrony compared to the surrogate group. Additionally, the experimental group exhibited higher levels of physiological synchrony than the surrogate group, with a trend towards statistical significance.

These findings suggest that sharing the same experience with someone with whom we lack an emotional or bodily connection, elicits an adjustment of physiological parameters to the other's internal state, comparable to what may occur with a stranger with whom we were not co-present during the task. Overall, this result is in line with previous research that has shown that individuals in romantic relationships tend to exhibit greater physiological synchrony than those who are not involved in the same shared experience (i.e., surrogate couples) (Coutinho, et al., 2021). Our research, which replicates this finding, also indicates that when examining pairs of unrelated individuals engaged in a real, shared experience, they exhibit reduced physiological connectivity compared to individuals in a romantic partnership. This phenomenon may be explained by the coherent physiological responses activated through the autonomic nervous system, as people in proximity experience similar emotions during a current social interaction. Responses such as increased heart rate, respiration rate, and skin conductance may be more similar as a function of the level of togetherness between the individuals. We found that well-adjusted and affiliated partners become more synchronized in their heartbeat during a shared experience where the copresence, eye-contact, and engagement with the other were the main emotional stimulation we implemented. Furthermore, our study represents the first investigation which demonstrates a significant relationship between the duration of a romantic relationship and the level of synchrony in heart rate between partners. Our finding highlights that, as the time spent together in a romantic relationship increases, the degree of mutual cardiac co-variation also increases between partners. The extent of this phenomenon may vary depending on the history of successes and failures in attempting to adjust to each other during the romantic relationship. Even though these findings are correlational and therefore require further experimental verification in order to assess the direction of causality between physiological synchrony and affiliation, our study adds to the growing body of literature on physiological synchrony and provide initial insight into the potential effect of “physiological mirroring” between individuals in dyadic adjustment.

Notably, the absence of significant differences in behavioral synchrony between the two groups suggests that the ability to adjust one’s behavior in response to changes in a partner’s behavior may not be strongly associated with the presence of affiliation between the interacting parts or the time spent in the love relationship. Despite the null main findings, preliminary analyses revealed that additional factors, such as attraction scores of the unknown couples, approached significance in influencing the levels of behavioral synchrony observed in the control group. However, no significant relationship was observed in the experimental group, between behavioral synchrony and perceived relationship quality (as measured by a self-reported questionnaire, i.e., DAS).

Implementing in this pilot study a new version of a finger tapping experiment, we have found that this task could potentially identify individuals who are more attracted to each other and more likely to want to see each other again. This finding is consistent with the research conducted by M. J. Hove (2009), where a similar finger tapping task was used to measure sensorimotor synchronization between participants and the experimenter. The level of synchronization was found to be a predictor of participants’ likability towards the experimenter: “Participants who tapped closer and more consistently with the experimenter rated her more likeable on the subsequent questionnaire” (Hove, 2009). Additionally, we found an effect of physiological synchrony on reported attraction; a significant positive relationship has been observed between cardiac synchronization and reported attraction in the control group. Similarly, a recent study has examined physiological signals in unknown couples during a blind date experimental setting. Interestingly they found that “the level of skin conductance synchrony promoted attraction during both verbal and nonverbal interaction, and the level of heart rate synchrony promoted attraction during verbal interaction.” (Kret, 2019). Our task has demonstrated for the first time, that cardiac synchrony can emerge even without verbal interaction, as we implemented an eye contact condition according to Porges’ (2003) assumption about the SES activation on an individual level. These findings suggest that when two people are involved in a non-threatening eye contact, a joint vagal activation alter the SNS homeostasis regulating the temporal structure of physiological parameters in both individuals. Similar physiological responses can occur because of an imminent attempt at connection, or adjustment between individuals.

The findings of this pilot study should be interpreted with caution due to the presence of several limitations that must be acknowledged. Firstly, the sample size was small, which may have resulted in limited statistical power of the analyses. Furthermore, the study only examined one aspect of behavioral synchrony, and future research could expand the investigation to encompass other forms of synchronic behaviors, such as hands clapping, vocal or facial expressions, or movements able to display each other internal states, known as vitality forms (Stern., e.t., al 2013). This would enable to study whether a significant difference emerges through a more direct activation of the mirror system, which we think could potentially drive attraction and affiliation. A new experimental paradigm could be designed so to remove, for example, the shading panel. Thus, by directly observing each other's actions, the processes of rhythmic prediction and sensorimotor synchrony could be more accurate and determine a difference between groups based on the level of affiliation. At the same time, we would check if the eye contact condition no longer implemented, is a necessary component to activate the SES. Individual differences in rhythmic movement ability or rhythm perception could have also impacted the relationship between affiliation and behavioral synchrony observed in our study. Therefore, it could be valuable to include a baseline check of participants' rhythmic abilities prior to the experiment and to control for their performance in the statistical analysis.

Furthermore, the temporal structure of the referential stimulus used in our finger tapping task may have influenced the relationship between dyadic adjustment and behavioral synchrony. Specifically, the metronome to which the master tapped could have displayed more rapid changes in its frequencies, potentially resulting in a more complex task for the dyad. Additionally, odd arousing distractors with emotional connotations could have been introduced to the master's headphones to examine their potential impact on the dyad's behavioral and physiological responses.

By taking these steps and exploring the impact of these variables, future research could more accurately assess the degree to which affiliation impacts dyadic adjustment in the context of a referential stimulus-mediated interaction.

Conclusions

The objective of the present study was to investigate the mutual adjustment in the temporal structure of physiological signals and rhythmic behaviours as a function of the level of togetherness between two individuals.

Novel findings in this study suggest that non-cortical mechanisms may contribute and perhaps, promote affiliation over time, and attraction during a blind date. The study's findings revealed that physiological synchrony was significantly higher in romantic couples compared to randomly paired individual. When individuals encounter comparable environmental modifications, their physiological reactions may become associated with those of others in proximity. This reciprocal association can occur spontaneously due to affiliation or mutual attraction, facilitating efficient co-regulation and implicit state adjustment. Therefore, co-regulation is a crucial aspect of social interaction, facilitating emotion regulation, effective stress management between individuals in various social contexts. Such automatic and preflexive processes of co-regulation may represent a primordial foundation for more complex and explicit processes of dyadic adjustment, such as communication, negotiation, and problem-solving in intimate relationships. Overall, this study provides important insights into the temporal dynamics of interpersonal physiology and the mirroring mechanisms underlying dyadic adjustment, adding a novel finding about cardiac synhcrony and how it can develop over time. The findings seem to confirm that "physiological synchrony may provide a medium for rendering social signals into embodied emotions" (Kret et al., 2019). This potentiality highlights the need for future research to investigate the causal role of non-cortical mechanisms in social behaviour and cohesion.

Despite the non-significant difference observed in behavioral synchrony between the two groups, our finger tapping task may have experimental applications to investigate attraction and affiliation in various relational contexts. Further research is needed to elucidate the factor determining this null finding. Investigating vitality forms could be particularly promising as they have been shown to convey explicit emotional contents through the cinematic of the gesture and their temporal dynamics, making them a potential candidate to observe the hypothesized relation between behavioral adjustment and affiliation. Considering the findings presented in this paper, future research should broaden the scope of investigation to encompass a more diverse range of populations and relationship settings. Given the importance of physiological coordination in early developmental stages, it would be of great interest to explore autonomic changes between the fetus and mother during social interactions with varying emotional connotations. Furthermore, if the coupling between maternal and fetal physiological parameters in the intrauterine environment is deemed significant, it would be compelling to compare dyads such as strangers, siblings, and heterozygotic twins who share similar sequences of physiological variations and prenatal experiences. Such inquiries would contribute to a more comprehensive understanding of physiological synchrony and its implications on the development of social abilities.

The present study has provided significant insights into the interindividual cardiac dynamics underlying dyadic adjustment in romantic relationships. Our findings suggest that to gain a better understanding of the social dimension, it is necessary to shift from a solipsistic approach to a more natural yet controlled approach that emphasizes the holistic dynamics of our brain-body system, rather than solely focusing on individual brain-centred responses. This approach may facilitate a more comprehensive understanding of the intricate dynamics that characterize romantic relationships, thereby promoting efficacious interventions in family systems psychology, with the goal of augmenting both the quality and duration of such relationships.

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