

Mini-Review

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Exploring cardiac physiological synchrony and its implications for stress and anxiety

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Abstract

When two individuals share a common experience, their heartbeats can become synchronized in a phenomenon known as cardiac physiological synchrony (CPS). This interpersonal coupling of heart rate and heart rate variability is considered a component of social behavior and may facilitate close emotional, physical, and prosocial interactions. However, the exact mechanisms underlying CPS are unknown, including its potential differential roles in various types of empathy. Notably, CPS is distinct from the direct electrical coupling that occurs between cardiomyocytes. We therefore review the current literature on CPS and the hypothesized mechanisms driving heartbeat synchronization. The consequences of either reduced or increased CPS during social interaction are not well studied. Existing evidence suggests that CPS may tune social interaction, potentially promoting prosociality or alleviating stress and anxiety depending on context. We hypothesize that variations in CPS may correspond to different types of empathy and could be linked to specific types of anxiety. Finally, we discuss the implications of CPS for mental health, therapeutic interventions, and strategies aimed at reducing chronic stress and anxiety. A deeper understanding of CPS mechanisms and consequences could help to noninvasively improve mental and physical well-being and mitigate structural degeneration in brain regions essential for memory and cognition.



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Keywords: Physiological coupling, physiological synchrony, affective empathy, cognitive empathy, empathy, stress, anxiety

INTRODUCTION

Cardiac physiological synchrony (CPS) refers to the phenomenon in which individuals exhibit coordinated or coupled cardiac activity patterns, such as heart rate or heart rate variability, in social or shared contexts. This synchrony reflects underlying mechanisms that can be broadly categorized into three domains:

- (1) Cognitive/attentional mechanisms: CPS emerges from shared attention, emotional engagement, or alignment of mental states during social interactions or collective experiences;
- (2) Mechanical/vibrational entrainment: Passive physiological coupling occurs via physical signals such as vibrations, respiration, or other bodily rhythms that influence cardiac timing;
- (3) Environmental modulation: External factors potentially influence autonomic nervous system dynamics and thereby modulate CPS.

Section 1 explores these categories in detail, highlighting their distinct mechanisms, conditions of operation, and implications for social behavior and health [Table 1].

‘Social behaviors’ refer to the ways individuals interact with each other, including communication, cooperation, competition, and conflict. These behaviors are shaped by both biological and psychological factors and are essential for building relationships, forming communities, and maintaining societal structures. Empathy is a key component of social behavior and can be divided into cognitive and affective dimensions^[1]. Cognitive empathy involves understanding another person’s thoughts and emotions without necessarily experiencing them. Affective empathy involves experiencing emotions that mirror those of others, creating a deeper emotional connection. Both forms of empathy are influenced by learning from past situations and shared social contexts. During social interactions, individuals can also connect physiologically through the coupling of biological processes, including heart rate, heart rate variability, skin conductance, body temperature, and respiratory sinus arrhythmia (for a review, see^[2]). Research indicates a strong link between high levels of affective empathy and increased general anxiety^[3], while individuals with less accurate cognitive empathy tend to exhibit higher social anxiety^[4]. This review highlights the mechanisms thought to induce CPS and the various contexts in which it occurs. Understanding how CPS is generated and its specific roles in social interactions may help leverage CPS as a noninvasive therapeutic tool to improve mental health.

Following the discussion of CPS mechanisms, **Section 2** examines potential implications and applications, particularly regarding stress and anxiety. Given the established links among social connection, physiological coupling, and emotional well-being, CPS presents promising avenues for therapeutic intervention. This section explores the role of CPS in modulating stress and anxiety, its relevance in social and clinical contexts, and emerging interventions that leverage physiological synchrony to enhance psychological outcomes.

As demonstrated in the Graphical Abstract, multiple mechanisms contribute to CPS entrainment, including attentional states and environmental influences. Interpersonal synchrony can manifest through CPS, neural coherence (such as oscillatory activity and mirror neuron interactions), emotional mimicry, and endocrine responses like cortisol co-regulation. Such synchrony may, in turn, influence social behaviors, including empathy, stress, and anxiety, while creating feedback loops that affect both physiological and psychological

Table 1. Circumstances and limitations under which different mechanisms hypothesized to contribute to CPS may occur [Cognitive-attentional: (a); Passive-physical entrainment: (b); Environmental modulation: (c)]

Mechanism	Conditions under which it operates	Known limitations	References
(a) Attentional entrainment via audiovisual stimuli	Requires attentional engagement with shared stimuli (e.g., narrative, music)	Requires sustained attention; not driven by co-presence or respiration	[14,15]
(a) Passive entrainment via shared experiences (non-interactive)	Occurs when individuals independently process similar stimuli with aligned attention	Weaker coupling if attention is low; mechanisms are unclear without interaction	[15]
(a) Sensorimotor/movement-based coupling	HR synchronization arises during synchronized voluntary or observed movement tasks (e.g., finger tapping)	Requires precise timing/sensory feedback; persistence without cues remains unclear	[12]
(b) Oscillatory-system entrainment (external periodic forcing, e.g., Vibration-based entrainment)	Weak mechanical vibrations (e.g., during sleep or external application) can entrain heart rhythms. The heart acts like a relaxation oscillator; entrainment has been reported within $\pm 3\%$ of intrinsic HR	Narrow effective frequency range reported so far; may not apply to irregular rhythms	[7,22,28,29,41]
(c) Environmental modulation	Solar or geomagnetic fluctuations may modulate HR and HRV, potentially affecting CPS dynamics	Mechanisms remain speculative; reported effects are inconsistent	[31,32]

CPS: Cardiac physiological synchrony; HR: heart rate; HRV: heart rate variability.

states at intra- and interpersonal levels.

YOUR HEAD OR YOUR HEART? SUGGESTED MECHANISMS AND CONTEXTS OF CARDIAC PHYSIOLOGICAL SYNCHRONY

CPS refers to the unconscious alignment of heart rate (HR) and heart rate variability (HRV) among individuals during shared experiences. The underlying drivers of this synchrony remain unclear, and it is not yet known whether it reflects a direct cardiac function or arises indirectly through cognitive or respiratory processes. Evidence suggests that higher CPS is linked to improved teamwork^[5,6] and stronger group cohesion^[7]. Physical contact may enhance cardio-respiratory coupling, reducing pain^[8], and it has been proposed that ‘Super Synchronizers’ (individuals with a heightened sensitivity to synchronizing physiological responses) are rated as more attractive to potential partners in speed-dating tasks^[9]. CPS may also reflect affective empathy, arising from subconscious mirroring of internal states, facial expressions, and posture^[10,11]. Clarifying the mechanisms of CPS may help us understand its benefits and therapeutic value in mitigating stress, loneliness, and anxiety, both in social contexts and in solitude [Table 1]. This review examines the evidence for the mechanisms proposed to induce CPS.

Cognitive/attentional mechanisms

Audiovisual stimuli

Shared experiences can produce synchronized neural processing among individuals, potentially resulting in correlated brain and heart rate patterns^[12–14]. Several studies have shown that when individuals experience the same environmental stimuli - such as listening to a story^[15], enjoying music^[13], or tapping their fingers in rhythm^[12] - their brains process information similarly, and their heart rates begin to correlate. For example, CPS during storytelling has been correlated with improved recall of the narrative, suggesting a link to attentional engagement or the degree of immersion in the experience^[15].

Two studies employing finger-tapping or video-watching tasks showed that physiological coupling is modulated by attention and predicts memory performance, but is not driven by respiratory patterns^[15,16]. One study specifically indicated that attentional engagement in a shared experience is necessary for CPS, with only signals correlated with brain activity - such as gaze position, pupil size, HR, and saccade rate -

predicting physiological coupling, whereas respiration and head movements showed no correlation^[16]. Further supporting the role of attention, CPS in response to audiovisual stimuli, particularly visual cues, can occur even without direct interaction or simultaneous exposure to the stimulus^[11,15]. CPS has even been observed when participants watched the same emotional movie separately^[17,18]. Interestingly, similar human-horse CPS appears to occur only when the horse attends to the human rather than its peripheral environment^[19].

Movement

CPS may also serve nonsocial functions, related to sensorimotor synchronization within individuals for the rhythmic coordination of perception and action^[9]. However, it can enhance social experiences by interacting with mirror neurons in the brain, which modulate activity both when an individual performs an action and when they observe a similar action^[11,20]. Specifically, the cardiac cycle appears to couple with both voluntary motor actions and the observer's perception of these actions. In the executor, movements occur out of phase with heartbeats, while in the observer, heartbeats occur out of phase with the executor's movements^[21]. This suggests that CPS may actively contribute to social interaction by potentially coordinating facial expressions, postures, or group movements^[10,11].

Mechanical/vibrational entrainment

CPS can also occur in the absence of visual or cognitive engagement, suggesting that direct mechanical or vibrational signals may facilitate coupling between individuals. For example, CPS of HR and HRV has been observed between co-sleeping partners^[22], with couples also exhibiting synchronization of rapid eye movement (REM) and non-REM sleep stages^[23]. One possible mechanism is weak ballistocardiographic vibration transmitted through the bed surface. Similarly, fetal-maternal CPS has been attributed to entrainment by acoustic stimuli arising from maternal blood vessel pulsation, with stronger coupling occurring at higher maternal breathing rates that may fall within a frequency range optimal for the fetal cardiac system^[24].

These findings are consistent with considering CPS within the framework of an oscillatory system, in which the heart can be synchronized by rhythmic external inputs. At the cellular level, donor cardiomyocytes have been shown to align their contraction rate with host cardiomyocytes via gap junction formation^[25]. The heart has been likened to a relaxation oscillator, capable of entrainment by external forces such as vibration^[22], acoustic signals^[24], or low-power electrical stimulation^[26,27], provided that the periodicity closely matches its intrinsic rhythm. Experimental evidence indicates that small deviations in stimulation frequency (approximately $\pm 3\%$) are more effective in modulating heart rhythm than larger mismatches ($\pm 5\%$ - 10%)^[28,29]. Additionally, interoceptive accuracy appears to influence autonomic responsiveness, with individuals more adept at perceiving their own HR showing stronger modulation in response to external stimuli^[30].

Environment

Environmental impact

Environmental factors, including solar and geomagnetic activity, can also influence physiological mechanisms such as HRV. For instance, increased solar wind intensity has been linked to increased HR, potentially signaling a biological stress response. Although CPS is thought to be important for social interactions, environmental variability could add complexity to how coupling emerges^[31-33].

CPS appears to be more directly associated with affective empathy, likely through shared autonomic regulation during emotional resonance. Stronger HR and HRV coupling have been observed in contexts involving emotional sharing (e.g., touch, shared pain, narrative immersion)^[34]. By contrast, CPS may relate to cognitive empathy through processes such as joint attention, shared task engagement, or perspective-

taking, which indirectly modulate physiological states [Table 1]. Future studies exploring the relationship between CPS and different forms of empathy, and whether they are mediated by distinct mechanisms, may provide deeper insight into the role of CPS and its applications in daily life in relation to stress and anxiety.

IMPLICATIONS OF CARDIAC PHYSIOLOGICAL SYNCHRONY ON STRESS AND ANXIETY

CPS and its reciprocal relationship with stress and anxiety make it a promising noninvasive therapeutic avenue with broad applications [Table 2]

CPS and mental health

Social isolation is known to increase loneliness, stress, and anxiety. It is therefore reasonable to presume that improving socialization may be beneficial to emotional and physical well-being^[35]. Given the proposed role of CPS in social interaction^[6,7,9,11], increasing CPS may be considered a therapeutic method to promote well-being by reducing stress and anxiety. Stronger CPS has been observed between partners with higher attachment anxiety, potentially serving as a mechanism to mitigate anxiety in specific social contexts, as attachment anxiety is also known to negatively affect immune responses and cortisol release^[36,37]. Another study showed that manipulating perceptions of social identity can enhance physiological synchrony between relative strangers and even predict friendship interest. These findings suggest that prejudice-reduction interventions could aim to foster physiological synchrony^[38]. Interestingly, in such cases, CPS appears to mediate a transition from negative to positive social interactions- reducing potential conflict- rather than merely strengthening relationships or attraction.

Further research is needed on ‘leading synchrony’, which refers to the degree to which each partner drives synchrony, and on how susceptible different people are to synchronization. Leading synchrony is dependent upon task type, sex, and social anxiety status^[36,39]. In people without social anxiety disorder (SAD), higher levels of social anxiety are associated with increased CPS, which may guide appropriate social behavior. Conversely, SAD is linked to reduced CPS, which correlates with negative relational outcomes such as seeming emotionally distant or unresponsive^[39,40]. Reduced CPS in SAD is thought to result either from self-focused attention, which prevents shared engagement with external stimuli, or from the suppression of emotional expression and physiological responses as a form of self-concealment. Both mechanisms could interfere with the ability to generate CPS with others. Consequently, measuring CPS has been proposed as a potential diagnostic tool, and biofeedback interventions aimed at increasing CPS have been suggested for SAD. As SAD is more prevalent in females^[41] and positively correlates with social camouflaging in adults with autism^[42], therapeutic induction of CPS may be particularly beneficial in certain populations.

CPS in therapeutic settings

Physiological synchronization has also been investigated between therapists and patients, with increased skin conductance coupling observed during cognitive behavioral therapy (CBT)^[43]. Self-reported ratings have likewise been found to correlate with measured CPS during psychotherapy sessions^[21]. While it remains unclear whether increased CPS during therapy directly improves patient outcomes, the therapist-patient alliance is known to play a crucial role in the therapeutic process^[44]. Enhancing CPS may therefore improve self-reported experiences and strengthen the therapeutic relationship. Treating or preventing anxiety may help reduce the risk of dementia, or alleviate its earliest symptoms and delay progression^[45,46]. In dementia, neuropsychiatric symptoms have been linked to the closeness of the caregiver-care recipient relationship, and CPS has been proposed as a mechanism that could foster this closeness and therefore reduce symptoms^[47,48]. Furthermore, a meta-analysis of people with Alzheimer’s disease reported a decline in cognitive empathy, whereas emotional empathy remained unaffected^[49].

Table 2. Applications of physiological coupling in therapy and stress and anxiety contexts

Application	Description	Status/Notes	References
Couples and attachment anxiety	Higher CPS observed in partners with elevated attachment anxiety; may buffer anxiety-related effects on immune and stress responses	Hypothesized mechanism; requires further clinical validation	[36,37]
Social identity and prejudice reduction	Manipulating social identity can enhance physiological synchrony between strangers, potentially improving social bonds	Early-stage experimental evidence; clinical impact untested	[43]
SAD	Lower CPS linked to SAD; CPS biofeedback proposed as a potential diagnostic or therapeutic tool	Theoretical framework; clinical trials pending	[39]
Therapist-patient synchrony during psychotherapy/ caregiver-recipient synchrony	Increased skin conductance and heart rate coupling observed during sessions; correlates with self-reported alliance	Correlational findings; causality and clinical impact not yet established	[43,44]
Closed-loop vibration stimulation during sleep	Imperceptible vibration at near-heart rate frequency to modulate autonomic activity and improve sleep quality or post-sleep arousal	Preliminary pilot studies; further replication required	[28,29]
HRV biofeedback	Training to increase HRV via slow-paced breathing and real-time feedback; associated with reduced stress and anxiety	Expanding evidence base	[51]

CPS: Cardiac physiological synchrony; SAD: social anxiety disorder; HRV: heart rate variability.

CPS-related interventions

Because CPS during sleep is thought to occur through ballistocardiographic vibrations transmitted via the bed^[22], one study tested closed-loop vibration stimulation at near-heart rate frequency to determine its potential benefits for sleep. The vibrations were delivered at an imperceptible intensity and set at +3% relative to HR, with the aim of activating the sympathetic nervous system to promote arousal. The study suggested that such stimulation may facilitate cognitive recovery after sleep, as indicated by faster Psychomotor Vigilance Task reaction times and higher self-reported arousal scores. In contrast, another study applied closed-loop vibration stimulation at -3% relative to HR, which successfully entrained participants' HR to the external rhythm and increased parasympathetic activity. These effects were specific to the -3% condition and were not observed at -5% or -10%^[28,29]. Together, these studies suggest that CPS-based interventions during sleep can be tailored either to enhance sleep quality via parasympathetic activation or to promote post-sleep arousal via sympathetic activation.

HRV biofeedback is also gaining popularity, as it allows individuals to monitor and regulate their HRV using real-time feedback. Slow-paced breathing (SPB) - reducing breathing rate to six breaths per min - is one approach shown to increase HRV^[50]. HRV biofeedback training has been linked to substantial reductions in self-reported stress and anxiety^[50,51]. Unlike interpersonal CPS, HRV biofeedback provides individuals with a target (the feedback signal) to synchronize with, thereby increasing HRV to a predetermined setpoint. This requires not only controlled breathing but also attentional focus on the breathing process while monitoring feedback as HRV changes. Such training can be delivered via mobile applications, enabling CPS-like effects even in the absence of social partners. Additionally, biofeedback may enhance interoceptive accuracy, which has been shown to influence heart rate responses to visual or auditory stimuli presented in rhythm with the cardiac cycle^[30].

DISCUSSION

Interpersonal synchrony refers to the alignment of physiological, neural, and endocrine processes between individuals during social interaction. Although the molecular and cellular mechanisms remain unclear, numerous physiological changes are hypothesized to be sensitive to synchrony. Heart rate, respiration, and HRV can spontaneously synchronize, reflecting coupled autonomic activity that interacts with hypothalamic-pituitary-adrenal (HPA) axis reactivity and buffers stress responses^[52,53]. Synchronized

oscillatory activity in frontal, parietal, and temporal regions has been observed during joint attention, cooperation, and emotional sharing, with mirror neuron systems facilitating shared affective states that influence HPA activation^[54,55]. Endocrine co-regulation is also evident in romantic partners and parent-infant dyads, where cortisol rhythms and acute stress responses align across individuals, indicating direct interpersonal HPA axis coupling^[53,56]. Emotional contagion via microexpressions, vocal prosody, and posture further propagates shared autonomic nervous system (ANS) and HPA activation, linking emotional connection to coordinated physiological states^[57].

The observed associations between CPS and higher therapy-patient ratings in clinical sessions^[21,43], improved REM synchronization in co-sleepers^[22,23], and increased friendship interest^[43] underscore the potential of CPS as a mechanism to enhance mental and physical well-being. As CPS is a noninvasive phenomenon, interventions designed to promote synchrony could offer promising avenues for reducing loneliness, anxiety, and depression^[35]. CPS could be particularly beneficial for older populations experiencing social isolation, as anxiety is associated with a 29% increased risk of dementia^[35]. Anxiety and chronic stress cause structural degeneration and dysfunction of brain regions involved in spatial memory and cognition, particularly the hippocampus and prefrontal cortex (PFC). Such degeneration may contribute to the heightened risk of neuropsychiatric disorders, including depression and dementia^[45]. Preventing or treating anxiety could therefore reduce dementia risk, alleviate early symptoms, and delay disease progression^[46].

A key limitation in CPS research lies in establishing causality. Correlation-based measures of physiological synchrony, such as the *Single Session Index* (SSI), quantify concurrent covariation in biosignals and have been consistently linked to shared emotional engagement in dyads and groups^[58,59]. However, these metrics are symmetric and do not provide directionality. By contrast, information-theoretic approaches such as *Transfer Entropy* (TE) and its symbolic variants (*Symbolic Transfer Entropy*, STE; *Normalized STE*, NSTE) estimate the extent to which the past of one signal improves prediction of another signal's future beyond its own history, enabling inference of directed statistical dependencies^[60-63]. TE/NSTE asymmetry can identify leader-follower relationships and moments of directed interpersonal influence in biosignals such as electrodermal activity (EDA), complementing SSI by providing directionality and sensitivity to temporal dynamics rather than absolute values. Nonetheless, TE/NSTE capture statistical information flow rather than definitive mechanistic causation and remain vulnerable to confounds such as shared external drivers or indirect pathways. Rigorous inference therefore requires control analyses (e.g., conditional/multivariate TE), surrogate testing, and ideally, experimental perturbations^[63,64].

CONCLUSION

CPS arises during shared experiences and likely corresponds to affective empathy^[10,11]. Although its exact mechanisms remain debated, CPS may depend on cognitive attention in scenarios such as listening to music^[13], finger tapping^[12], or human-horse interactions^[19]. In contrast, CPS during sleep or fetal-mother interactions may rely on alternative factors, including brain state and weak noninvasive forces (e.g., mechanical vibrations)^[22]. Further research is needed to illuminate the pathways underlying CPS, its role in social and emotional functioning, and its therapeutic potential. Distinguishing between cognitive 'top-down' mechanisms and sensory (e.g., mechanical) mechanisms of action is essential for developing CPS-based interventions, as these may play different roles in cognitive versus affective empathy. Moreover, elucidating the relationship between CPS, empathy, and other physiological markers such as oxytocin and cortisol helps determine whether CPS exerts causal or merely correlative effects on social behavior. Both cognitive and affective empathy have been positively correlated with higher levels of cardiac activity^[21,65]. Thus, investigating the physiological and psychological mechanisms of CPS presents important

opportunities for developing noninvasive therapeutic strategies to improve mental health.

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Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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