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Sociodian Rhythm: Eye Contact and the Neurobiology of Social Synchronization

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ABSTRACT

Background: Circadian rhythms regulate physiological processes in alignment with environmental light cycles. However, humans—particularly as highly social organisms—demonstrate behavioral and physiological adaptations that follow socially derived cues. This paper introduces the concept of sociodian rhythm, a social counterpart to circadian regulation, and proposes that social entrainment, particularly via eye contact, may serve as a dominant synchronizing mechanism.

Objective: To examine the theoretical basis, biological substrates, and evolutionary implications of sociodian rhythm, with a focus on how eye contact and social cues regulate behavioral and physiological synchrony in humans.

Methods: This review integrates findings from neuroscience, behavioral studies, chronobiology, and ethology to evaluate the interplay between social cues, circadian mechanisms, and eye-mediated neuroregulation. Comparative animal studies, neuroendocrine pathways, and psychophysiological models are also explored.

Results: Social cues—including gaze, pupillary mimicry, and oxytocin release—modulate internal timing systems via pathways involving the suprachiasmatic nucleus (SCN), lateral habenula (LHb), and nucleus accumbens. Eye contact acts as a rapid entrainment mechanism, facilitating alignment in arousal, emotional state, and partnership readiness. Sociodian rhythms may override or restructure circadian rhythms under socially dense conditions.

Conclusion: Sociodian rhythm emerges as a fundamental mechanism for collective behavior and group cohesion. Its regulation through eye contact and oxytocin-mediated synchrony suggests a neurobiological foundation for social timing that complements, and in some cases surpasses, light-based circadian entrainment.

Keywords: Sociodian rhythm; circadian synchronization; social entrainment; eye contact; pupillary mimicry; oxytocin; suprachiasmatic nucleus; social rhythm theory; lateral habenula; social neurobiology.

Introduction

The capacity to form partnerships and cooperate in groups has placed humans at the apex of evolutionary hierarchies. This paper is proposing that one facilitator of this cooperative dominance is what the authors name as sociodian rhythm—a regulatory mechanism in which the temporal architecture of an individual's behavior is entrained more by social cues than by light.

Sociodian rhythm describes a dynamic process wherein the sleep-wake cycle and daily activity rhythms are synchronized with others in a social group. While light remains the most influential zeitgeber in traditional circadian biology, social signals—such as the timing of communal meals, work schedules, cultural rituals, or even partner behaviors—can modify or override photic entrainment[1,2].

Human partnerships require coordination across time. In some cases, this may take the form of synchronous activity, where individuals operate during the same temporal windows. In others, it may involve asynchronous organization, with individuals taking turns assuming roles such as nighttime vigilance or early-morning tasks. From an evolutionary perspective, this temporal division of labor increases group survival by distributing effort and reducing vulnerability. For example, individuals with evening chronotypes may naturally assume late-night duties, enhancing collective safety during hours when others sleep[3].

In early human history, the alignment between light and social interaction was more consistent, as gatherings predominantly occurred during daylight. With the advent of artificial light, transportation, and digital connectivity, however, social interaction is no longer tied to solar cues. Consequently, the zeitgeber role of social stimuli has intensified, allowing human groups to maintain cohesion across variable schedules and geographies.

The sociodian rhythm hypothesis posits that humans are naturally disposed to synchronize with one another, using interpersonal signals—including gaze, voice, and emotional expression—as temporal anchors. These rhythms are particularly salient in cooperative settings, such as families, workgroups, and intimate partnerships, where timing mismatches may impair collaboration[4,5].

Sociodian rhythm conceptualizes human temporal regulation as a mutually adaptive, socially embedded process that is fundamental to collective functioning.

A. WHY SOCIODIAN RHYTHM, NOT CIRCADIAN RHYTHM?

While the circadian rhythm has been the primary biological framework for understanding human temporal organization, increasing evidence supports the dominance of socially derived rhythms—sociodian rhythms—in shaping daily behavior. The term sociodian emphasizes the entrainment of biological systems by social factors, in contrast to the light-driven synchronization central to circadian theory.

Humans frequently adjust their sleep-wake patterns not in response to environmental light, but in accordance with social obligations, such as employment schedules, religious observances, or cultural routines. Historically, circadian and social rhythms often overlapped—daylight hours coincided with social activity. Yet in modern societies, these domains have become increasingly dissociated. Social events may follow non-circadian periodicities, including weekly (e.g., weekends), monthly (e.g., pay cycles), or seasonal rhythms (e.g., holidays), none of which align strictly with the 24-hour solar day.

In many contexts, social cues serve as stronger zeitgebers than light. For example, in Western cultures, the workweek typically begins on Monday and ends on Friday, with Sunday reserved for rest. These conventions dictate individual behavior, override photic cues, and promote social synchrony across populations. This coordination is not merely habitual—it induces physiological changes, as individuals adjust their internal clocks to match communal expectations[3].

Group-living species, particularly humans, are highly sensitive to social entrainment. Factors such as economic pressures, shared security needs, and cultural norms encourage the formation of collective routines. These routines, in turn, reshape individual biological rhythms. When individuals fail to align with these rhythms—either due to mismatched chronotypes or lifestyle constraints—they may experience social jet lag: a misalignment between the endogenous circadian rhythm and socially imposed schedules[6].

Social jet lag has been associated with a range of adverse outcomes, including metabolic dysregulation, obesity, mood disorders, and even cancer.[7] Individuals who successfully adapt to the sociodian rhythm of industrial society are often better integrated socially and professionally, while those who remain out of sync may suffer both biologically and socially.

Interestingly, not all misalignment is maladaptive. A subset of individuals who do not conform to dominant social schedules may serve important evolutionary functions. For instance, those with late chronotypes may naturally assume protective nocturnal roles, creating a biological shift system that enhances group survival[8]. This suggests that even non-conforming chronotypes may play adaptive roles within a broader sociodian structure.

Future research should examine long-term health outcomes in individuals whose occupational schedules align with their chronotypes, particularly in shift work contexts. Demonstrating lower rates of systemic illness or increased life expectancy in these individuals would provide additional evidence for the evolutionary and physiological validity of the sociodian rhythm hypothesis.

B. SOCIAL SYNCHRONIZATION AND PHOTIC SYNCHRONIZATION

Emerging evidence from both animal and human studies suggests that social cues can override photic input in the entrainment of biological rhythms. While light remains the dominant zeitgeber in traditional chronobiology, social synchronization may exert an even more powerful influence—particularly in species with complex group dynamics such as humans[1].

B.1. Evidence from Invertebrates and Mammals

In honeybees, circadian rhythms are highly plastic in response to social context. Fuchikawa et al. (2016)[2] demonstrated that social stimuli can override photic entrainment: when isolated, worker bees follow standard light-driven rhythms, but within colonies, their circadian timing shifts according to communal roles and interactions. Mistlberger et al. (2004)[1] also showed that direct social interaction is not always necessary—olfactory and vibrational cues are often sufficient to maintain synchronization.

As group size decreases, synchronization becomes more difficult. In colonies with fewer than 30 bees, the absence of diverse social signals results in desynchronization[9]. Similarly, in human groups, individuals tend to align with "average timekeepers"—those in the central portion of the bell curve for sleep-wake cycles. This convergence illustrates that social homeostasis depends on the internal adjustment of biological clocks toward normative communal schedules[6].

Comparable findings have emerged in mammalian species. Rodent studies show that social stimuli, including arousal and locomotor activity, can shift circadian timing through non-photic pathways[10]. These pathways act through increased exposure to light (by promoting wakefulness) or by directly influencing clock gene expression in brain regions such as the SCN.

B.2. Synchrony Through Shared Routines

In human societies, synchronization is often achieved not through external enforcement but through shared daily rituals. Mealtimes, work hours, and leisure periods such as "after-work" socialization serve as communal timekeepers. Even in the absence of direct instruction, individuals tend to "join life" at roughly the same time, contributing to a collectively regulated rhythm[3].

The COVID-19 pandemic served as a natural experiment in the disruption of social zeitgebers. Extended lockdowns and remote work protocols led to significant social isolation and reduced exposure to socially regulated routines. Some studies reported decreased social jet lag during this period, as individuals aligned their sleep-wake cycles more closely with endogenous rhythms[11]. In contrast, other studies observed increased psychiatric symptoms, indicating that improved circadian alignment for some was offset by psychological costs associated with the absence of social entrainment and collective structure[12].

B.3. Social Isolation as a Zeitgeber Deficit

The breakdown of shared schedules, rituals, and in-person interactions likely impaired social entrainment mechanisms, including those mediated by eye contact, body language, and co-regulated routines. Although seasonal affective disorder and depression are often attributed to light deprivation, these may also result from a disruption of social rhythms—particularly in high-latitude countries where communal life slows during winter[7].

Indeed, social networks are consistently shown to buffer against psychiatric morbidity, including depression and suicidality[13]. These findings reinforce the hypothesis that social cues may be not only sufficient but necessary for circadian coherence, especially in the absence of strong photic input.

C. HOW MAY THE SOCIODIAN RHYTHM BE REGULATED?

Biological rhythms are orchestrated by a central pacemaker in the suprachiasmatic nucleus (SCN), which coordinates with peripheral oscillators found in organs such as the liver, kidneys, heart, stomach, olfactory bulb, and lateral habenula. These oscillators regulate gene expression and physiological processes according to internal and external time cues. While traditionally entrained by light, recent findings suggest that social stimuli can serve as powerful synchronizers, particularly in humans[1,14].

C.1. Oscillatory Network Theory and Coupling Strength

According to oscillatory network theory, effective rhythmicity depends on the strength and compatibility of coupling among oscillators[15]. When pacemaker cells in different tissues synchronize, a dominant biological rhythm emerges. Strong coupling within and across organisms is essential for achieving synchrony; weak connections lead to desynchronization or cacophony. Factors influencing synchrony include oscillator similarity (e.g., species -matching), population size, and mutual responsiveness[16].

In this context, social entrainment can be conceptualized as the synchronization of oscillatory systems across individuals. Groups with close social bonds may function as superorganisms, with interpersonal cues regulating internal states such as alertness, hormonal secretion, and affect.

C.2. Clock Gene Expression and Non-Photic Entrainers

Core clock genes such as BMAL1, PER, CRY, and CLOCK are regulated in a circadian manner in SCN neurons and peripheral tissues. These genes may also be modulated by non-photic entrainers, including physical activity, nutrition, medication, and social interaction[17]. Importantly, the rewarding quality of a stimulus increases its entraining power, as shown in studies where food anticipation and exercise reset circadian clocks independent of light[1].

Social interaction may possess inherent reward value, particularly when mediated through oxytocin release or emotional bonding. Consequently, social stimuli can influence gene expression in the SCN, thereby shifting the circadian rhythm in socially meaningful directions.

C.3. Evidence from Drosophila and Rodent Models

Experimental studies in Drosophila melanogaster have shown that social interactions alter locomotor activity rhythms, even in constant environmental conditions[18]. Pair bonding in fruit flies modifies individual clock gene expression, pheromone output, and behavior. Social synchrony in these insects appears to arise from interpersonal feedback loops, in which the behavior of one individual influences the internal clocks of others[19].

Similarly, studies in rodents show that social housing alters circadian gene expression. When isolated, animals show fragmented activity rhythms, while cohabitation restores rhythmicity and stabilizes behavioral outputs. These effects are believed to be mediated through olfactory, tactile, and visual cues, indicating that synchrony can emerge even without light cues[20].

C.4. Human Evidence: From Polar Missions to Darkness Studies

Human experimental studies offer further support. In classic work by Aschoff et al., individuals maintained rhythmic sleep-wake cycles even in total darkness—presumably due to social interactions that acted as timekeepers[21]. More recently, Weissová et al. (2019) studied researchers deployed to Svalbard, where constant daylight prevails during summer[22]. Despite the absence of natural light-dark cycles, participants' melatonin rhythms and sleep schedules remained stable, attributed to adherence to a shared social routine.

These studies mirror findings in social insects, with one notable difference: synchrony in humans can occur even in small groups, unlike honeybee colonies, where larger populations are required for collective entrainment. This may reflect the greater complexity and flexibility of human social cognition, including mechanisms such as empathy, verbal communication, and gaze-based regulation.

C.5.The Role of Reward Systems and Motivation

The lateral habenula (LHb), nucleus accumbens, and ventral tegmental area (VTA) constitute key components of the reward system and appear to interact with circadian pathways. The LHb, for instance, modulates dopaminergic and serotonergic tone, influencing mood and motivation. Its projections may mediate the motivational salience of social cues, acting as a filter that determines whether a social interaction is entraining or disruptive[23].

In summary, the regulation of sociodian rhythm involves a multilayered process:

- Clock gene modulation in response to rewarding social interactions
- Coupling strength across internal and interpersonal oscillators
- Motivational and affective circuits, particularly those involving the LHb and nucleus accumbens
- Neuroendocrine mediators, especially oxytocin and dopamine
- Cognitive-emotional synchrony, facilitated by eye contact and mutual attention

D. THE ROLE OF EYE CONTACT IN REGULATION OF SOCIODIAN RHYTHM

While rituals, routines, and socio-cultural conventions serve as macro-level entrainers of group behavior, dyadic processes such as eye contact appear to be among the most potent micro-regulators of sociodian rhythm. Eye contact initiates and maintains interpersonal synchrony, shaping not only emotional resonance and attentional alignment but also physiological entrainment, such as pupillary mimicry, heart rate variability, and oxytocin release[24].

D.1. Eye Contact as the First Social Zeitgeber

In early infancy, mutual gaze between caregiver and child is one of the earliest forms of social entrainment. Research shows that infants just 2–5 days old exhibit longer gaze durations toward direct eye contact compared to averted gaze[25]. This visual attunement forms the basis for synchrony in arousal, affect, and behavioral regulation, laying the neurodevelopmental foundation for later partnership formation[26].

Synchrony in the parent-infant dyad, often mediated through visual interaction, has been shown to predict secure attachment, emotional regulation, and resilience. From this dyadic template emerges the human capacity to entrain with larger social networks, indicating that eye contact may function as the initial scaffold for broader sociodian alignment[27].

D.2. Neurophysiology of Gaze and Synchrony

The eyes are evolutionarily specialized for social signaling. The white sclera, unique to humans, enhances gaze visibility, allowing observers to readily detect direction and intent[28]. Eye contact elicits robust neural responses in regions such as the amygdala, superior temporal sulcus (STS), and prefrontal cortex—areas implicated in emotion, intention reading, and social cognition[29].

Perhaps most notably, pupillary mimicry—the automatic synchronization of pupil size between individuals—serves as an unconscious mechanism for alignment. Dilated pupils in one individual cause dilation in the other, enhancing mutual arousal and attention[30]. This phenomenon is observed in infants and across species, suggesting deep evolutionary roots.

Pupillary responses are linked to autonomic activity, particularly through sympathetic and parasympathetic pathways, and modulated by emotional states. For example, increased amygdala activation in response to pupil dilation signals heightened vigilance, emotional salience, or perceived threat[31].

D.3. Eye Contact, Emotional Contagion, and Partnership Regulation

Studies show that eye-to-eye contact increases perceived trustworthiness, likability, and social interest[32]. Longer gaze durations facilitate deeper emotional resonance, potentially triggering emotional contagion—the mirroring of internal states across individuals. For instance, observing a fearful gaze activates the viewer's amygdala, even when the facial expression is perceived subliminally[33].

Emotional contagion mediated through gaze is not merely affective but regulatory. It influences partnership dynamics, conflict resolution, and group cohesion. In experimental contexts, direct gaze of 7 seconds or more has been shown to promote short-term cooperation, while prolonged gaze correlates with long-term bonding behaviors[32].

D.4. Oxytocin as a Mediator of Gaze-Induced Synchronization

Oxytocin, a neuropeptide central to social bonding, plays a key role in mediating the effects of eye contact. It is released during intimate activities such as touch, breastfeeding, and sexual interaction, but also in response to mutual gaze[34]. Nasal administration of oxytocin has been shown to increase eye gaze duration, emotional recognition, and affiliative behavior, particularly in fathers and individuals with social deficits[35].

Interestingly, oxytocin may modulate gaze differently across sexes. For example, male participants administered oxytocin showed increased trust toward individuals with dilated pupils, while female participants exhibited the opposite pattern[36]. These findings suggest a sex-specific calibration of social vigilance, potentially aligned with evolutionary roles in group protection and caregiving.

Furthermore, oxytocin synchronizes not only behavior but also physiology. Pupillary responses, emotional states, and even oxytocin levels themselves become aligned across bonded individuals, such as mothers and infants[37].

D.5. Intrinsically Photosensitive Retinal Ganglion Cell Pathways, Homeostasis, and Brain Region Connectivity

Recent findings implicate intrinsically photosensitive retinal ganglion cells (ipRGCs) in social rhythm regulation. These cells—previously known for their role in circadian photoentrainment—project not only to the SCN but also to the medial amygdala, lateral hypothalamus, lateral habenula, and bed nucleus of the stria terminalis[38].

These projections may facilitate homeostatic regulation of mood, feeding, cardiovascular response, and social behavior. It is proposed that gaze input via ipRGCs, coupled with emotional and hormonal feedback (e.g., oxytocin), triggers neurophysiological entrainment across individuals, establishing shared states of vigilance, calm, or readiness for cooperation.

E. THE ROLE OF THE LATERAL HABENULA AND DOPAMINERGIC CIRCUITS IN SOCIODIAN RHYTHM

While much attention has been given to photic entrainment via the suprachiasmatic nucleus (SCN), recent neurobiological insights point to the lateral habenula (LHb) as a key mediator in social entrainment, particularly in relation to reward evaluation, motivation, and rhythmic coordination. The LHb's role in modulating dopaminergic and serotonergic tone makes it a compelling candidate in the regulation of sociodian rhythm[39].

E.1. The Lateral Habenula as an Anti-Reward Node

The LHb receives afferent signals from limbic and basal ganglia structures—such as the nucleus accumbens, hypothalamus, and thalamus—and projects efferent signals to monoaminergic centers including the ventral tegmental area (VTA), substantia nigra (SN), and raphe nuclei (Hu et al., 2020)[2]. Predominantly glutamatergic, LHb neurons exert inhibitory control over reward systems, often functioning as an "anti-reward" mechanism. This modulation is essential for behavioral inhibition, aversive learning, and adaptive withdrawal from unrewarding or socially incongruent situations[40].

In normative states, LHb activity prevents excessive dopamine firing, thereby stabilizing reward sensitivity and promoting caution. However, when social cues are interpreted as affiliative or trustworthy—such as sustained eye contact or prosocial facial expressions—the LHb may be suppressed, allowing downstream dopaminergic disinhibition in the VTA and enhanced engagement with social environments[42].

E.2. Circadian and Social Rhythmicity in the Ventro Tegmental Area -Lateral Habenula Circuit Cells in the VTA and LHb show circadian patterns of activity, modulating behaviors such as sleep, arousal, and social responsiveness[43]. Dopamine release in the striatum, which receives input from the VTA, exhibits rhythmicity that peaks during periods of locomotor activity and social engagement—e.g., nighttime in nocturnal species or daytime in humans.

This rhythmic dopaminergic activity suggests a link between social participation and endogenous reward cycles. When social zeitgebers—such as interpersonal gaze, conversation, or ritual behaviors—activate reward circuitry, they may indirectly entrain circadian rhythms to match social schedules. Thus, sociodian rhythms may both override and recalibrate circadian rhythms in service of group cohesion.

E.3.Inhibiting the Lateral Habenula: Synchrony Through Suppression

We hypothesize that sociodian rhythm relies not only on activating social approach circuits but also on selectively suppressing anti-reward mechanisms, particularly the LHb. Eye contact, for instance, may reduce LHb-mediated inhibition, facilitating oxytocinergic and dopaminergic synchrony across individuals.

This theory is supported by evidence that; ipRGCs project to the LHb, as well as to the SCN, providing a conduit for light- and gaze-based modulation of reward circuits[44]. Oxytocin receptors are expressed in the LHb and locus coeruleus (LC)—both of which are involved in arousal regulation, attention, and social vigilance[45]. Pupil dilation, a marker of central arousal and LC activation, correlates with gaze-induced emotional alignment and likely reflects shared social orientation[46]. In this integrated model, eye contact is not merely a behavioral cue but a neural synchronizer: it dampens LHb inhibition, amplifies VTA reward firing, and entrains multiple individuals into a shared affective state that aligns with social timing.

E.4. The Nucleus Accumbens: A Final Modulator

Among all reward-related structures, the nucleus accumbens (NAc) may serve as the final integrator of sociodian rhythm. It regulates both temporal prediction and emotional salience, bridging limbic motivation with motor execution. Given its output to the LHb and its input from the VTA, the NAc is strategically positioned to; suppress circadian rhythms that conflict with social demands, prioritize actions aligned with social reward and initiate motor readiness for cooperative behavior.

The nucleus accumbens may function as a social metronome, suppressing biologically driven rhythms when required and initiating new, socially adaptive rhythms.

F. CLINICAL IMPLICATIONS AND FUTURE RESEARCH

The concept of sociodian rhythm introduces new dimensions to clinical practice, particularly in psychiatry, sleep medicine, and psychosomatic disciplines. The integration of social zeitgebers—especially eye contact and affiliative cues—into the regulation of biological timing has significant ramifications for understanding and treating disorders characterized by desynchronization.

F.1. Mental Health Disorders

Disruptions in social rhythm have been linked to a broad range of psychiatric disorders, including major depression, bipolar disorder, and schizophrenia[47]. Social rhythm therapy (SRT), for instance, has shown efficacy in stabilizing mood episodes by encouraging regular social routines. Incorporating principles of sociodian rhythm into SRT could enhance its biological grounding and therapeutic precision. For patients experiencing social withdrawal, targeting gaze-based interventions and oxytocin pathways may help restore interpersonal synchrony and reduce symptom burden[48].

F.2. Chronotype and Occupational Health

Modern work schedules often misalign with individual chronotypes, creating a mismatch between endogenous rhythms and imposed social timing—a condition known as social jet lag[3]. Tailoring occupational environments to fit natural sociodian preferences could alleviate circadian misalignment, improve productivity, and reduce mental health risks. Future occupational guidelines might incorporate eye-contact protocols, team-based synchrony exercises, or social rhythm assessments to promote group cohesion.

F.3. Autism Spectrum Conditions

Eye contact, pupillary mimicry, and oxytocin signaling are often disrupted in autism spectrum disorder (ASD)[49]. Understanding sociodian rhythm may open novel pathways for therapeutic intervention. Interventions that enhance interpersonal synchrony—through gaze training, social entrainment protocols, or oxytocin administration—could mitigate core ASD symptoms. Moreover, eye-tracking studies might help clinicians assess sociodian functioning in neurodevelopmental conditions.

F.4. Sleep and Chronobiology

Sleep disturbances are commonly approached through light-based therapies. However, in contexts where photic cues are insufficient—such as polar regions, submarine environments, or space travel—social cues may serve as primary zeitgebers[50]. Designing sleep environments that promote synchronized eye contact, social bonding, and routine sharing may improve adaptation to atypical circadian conditions.

F.5. Future Research Directions

To further elucidate sociodian rhythm, neuroimaging studies should explore functional connectivity between SCN, LHb, and social cognition areas during eye contact. Longitudinal studies could examine whether strong sociodian entrainment predicts mental health resilience.

Clinical trials might assess the efficacy of gaze-based synchrony interventions in depression, ASD, and anxiety disorders. Cross-cultural research could investigate whether sociodian rhythms vary in collectivist versus individualist societies, and whether synchrony correlates with health outcomes.

Conclusion

Analogous to the way all living organisms align with the sun in relation to circadian rhythm, individuals collectively align with social life through changes in sociodian rhythm. Sociodian rhythm is therefore fundamental to the formation of collective behavior. Individuals participating in a shared sociodian rhythm function as components of a larger organism, exhibiting synchronized brain activity, heart rates, and other physiological processes.

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