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Short Communication

Low-Frequency Oscillations for Nonlocal Neuronal Coupling in Shared Intentionality Before and After Birth: Toward the Origin of Perception

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Abstract

The theoretical study observes literature to understand whether or not low-frequency oscillations can simultaneously alter the excitability of neurons from peripheral nervous subsystems in different individuals to provide Shared Intentionality in recipients (e.g., fetuses and newborns) and what are the attributes of ecological context for Shared Intentionality. To grasp the perception of objects during environmental learning at the onset of cognition, a fetus needs exogenous factors that could stimulate her nervous system to choose the relevant sensory stimulus. Low-frequency brain oscillations can cause the nonlocal coupling of neurons in peripheral and central nervous subsystems that provide subliminal perception. An external low-frequency oscillator and the proximity of individuals can stimulate the coordination of their heart rates and modulate neuronal excitability. External low-frequency oscillations can increase the cognitive performance of the subjects. The characteristics of this pulsed low-frequency field are oscillations with 400 and 700 nm wavelengths alternately with the pulsed frequency ranging from 1 to 1.6 Hz. This theoretical work contributes to knowledge about nonlocal neuronal coupling in different organisms that can appear due to low-frequency oscillations. The significance of the article is that it explains the neurophysiological processes occurring during Shared Intentionality - one of the central issues in understanding the cognitive development of young children, as the conventional view in cognitive sciences argues. The article's impact is a proposal of the universal mechanism of nonlocal neuronal coupling in shaping the embryonal nervous system in animals of all species, which opens new directions for research on the origin of perception of objects.

Keywords

Brain waves; ecological learning; heartbeats; Human Computer Interaction; neurotechnology; PEMF; non-local neuron coupling; perception**;** shared intentionality

1. Introduction

The theoretical article is a self-contained piece of original research on Shared Intentionality. The manuscript studies the impact of external low-frequency oscillations on the synchronization of local neuronal networks from peripheral and central nervous subsystems that provide for engaging individuals with the psychological states of others. According to the received view, Intentionality is the power of minds to aim at things and conditions [1]. This psychological construct means the directed quality of particular mental states [2]. Another psychological construct of Shared Intentionality was introduced in the 1980s to describe human abilities to share psychological states [3-5]. Searle defined the new construct as a social bond appearing during social encounters [4].

1.1 The State of the Art in Understanding Shared Intentionality

There is a broad consensus in cognitive sciences that Shared Intentionality is one of the leading providers of ecological learning in organisms at the onset of cognition [6-14]. Organisms at the reflexes substage of the sensorimotor stage of development lack communicative ability. Shared Intentionality enables them to process the organization, identification, and interpretation of sensory information for developing perception [12-14]. Then, this ecological training provides young organisms with statistical learning of social meanings in response to the history of relationships with the environment [12-15]. Due to Shared Intentionality, immature organisms (recipients) fill sensory stimuli with conventional meanings by collecting statistical information from cascading successful and unsuccessful attempts [12-15].

Numerous psychophysiological research declared to observe Shared Intentionality in pairs of individuals [16-19] by emulating the mother-newborn (or mother-fetus) communication model in these pairs [15, 20] and even by assessing the magnitude of this pre-perceptual communication [21, 22]. Recent research examined fidelity rates of the computer-aided method of diagnosing cognitive development delay in children that assessed the shared intentionality magnitude in neurodivergent and neurotypical children [23]. Neuroscience hyper-scanning research [24-28] registered an increased inter-brain activity when subjects completed shared cognitive tasks without communication in pairs, in contrast to when subjects performed a similar task alone. Recent theoretical articles proposed a hypothesis of neurobiological processes occurring during shared intentionality [12, 13]. They argued that this pre-perceptual communication succeeds via the nonlocal coupling of neurons [12, 13]. Many studies highlighted the contribution of low-frequency oscillations to shared intentionality appearance [15, 20-22]. A recent theoretical study proposed a mechanism of nonlocal neuronal coupling due to delta-nested gamma oscillations [29]. It introduced an idea of nonlocal neuronal coupling in individuals occurring in the temporal synchronization of different neuronal ensembles in low-frequency oscillations since the latter can synchronize brain gamma waves (due to the waves' interference) of already excited central and peripheral neuronal ensembles (due to the physiological entrainment of organisms being in the shared ecosystem) [29].

1.2 Research Problem

However, more knowledge is needed about attributes of the ecological context that provide neuronal coupling to understand the mechanism of stimulating Shared Intentionality at the cellular level. The current study aims to understand whether or not low-frequency oscillations can alter the excitability of neurons from peripheral neuronal subsystems in all participants simultaneously to provide Shared Intentionality. If so, these electromagnetic field parameters would establish the characteristics of the mother-fetus communication (MFC) model for developing bioengineering systems. The article's scope also encompasses the proposal of conceptual design for further research on understanding the universal mechanism of nonlocal neuronal coupling in shaping the nervous system of embryos in different species, which can shed light on the origin of perception.

1.3 Contributions

The significance of the hypothesis of nonlocal neuronal coupling due to low-frequency oscillations is that it explains the neurophysiological mechanism of Shared Intentionality, which is one of the central issues in understanding the cognitive development of young children, as the conventional view in cognitive sciences argues [6-14]. Because Shared Intentionality is a driver of ecological learning in organisms at the onset of cognition, it is likely that this inherited quality also (or, first of all) contributes to forming a nervous system in embryonal growth. While the hypothesis precisely describes the sophisticated mechanism of nonlocal neuronal coupling for human embryonal change, it can also develop knowledge about animal nervous system evolution. If so, this knowledge can reveal the origin of the perception of objects. Understanding the underlying mechanism of perception emergence can shed light on consciousness. The arguments in subsection 4.4 pose the concept design for further research that may contribute to understanding the evolution of embryonal nervous systems in animals of different species.

2. Materials and Methods

This theoretical study observes recent cognitive and computer science findings, which can shed light on relationships between low-frequency oscillations and simultaneous neuronal excitability in different organisms. The author searched SCOPUS and Web of Science databases of research studies on the topic and found 39 articles. The literature analysis in the section Results is outlined as five subsections defining findings supported by empirical evidence. The first subsection observes the literature on shaping perception in organisms at the reflex substage of the sensorimotor stage of cognitive development. The second subsection monitors empirical data from neuroscience research on neuronal excitability induced by internal low-frequency oscillations. The third subsection investigates the external low-frequency oscillations effect on the coordinated excitability of neurons. A literature analysis in the fourth subsection observes experimental data on the physiological synchrony of inter-beat intervals of the heart between group members that emerges due to the external rhythmical oscillator. The fifth subsection studies an association of low-frequency oscillations with increasing cognitive performance. The section Discussion elaborates on the findings of the previous subsections and deduces the main characteristics of the Mother-Fetus communication model. It also proposes a concept design for further research on the origin of perception.

3. Results: Low-Frequency Oscillations for Nonlocal Neuronal Coupling

3.1 Perception and Shared Intentionality at the Onset of Cognition

According to the received view in cognitive sciences, perception enables a holistic representation of an object by the organization, identification, and interpretation of sensory information. Perception is the prerequisite of cognition and awareness. However, little is known of how children at the reflex substage of the sensorimotor stage of cognitive development can independently grasp perception by solving the binding problem and succeeding in such a complex process as perception stability.

3.1.1 The Binding Problem

According to Treisman [30], the binding problem can be divided into three separate problems. (1) How are relevant elements that should be related as a whole selected and separated from elements that belong to other objects, ideas, or events? (2) How is the binding encoded so it can be transferred to other brain systems and used? (3) How are the correct relationships between related elements within the same object defined [30]? Many different ways of solving these problems are proposed. More research is needed to explore how our brains can flexibly bridge the gap between perception and action.

However, regardless of which of the proposed mechanisms is the most correct, the central issue is the simultaneous coordination of different sensory receptor modalities, i.e., choosing the relevant sensory stimuli of other modalities. Indeed, how does an organism (dynamic system) distinguish between a cacophony of stimuli (electromagnetic waves, chemical interactions, and pressure fluctuations) of different duration from the environment (also a dynamic system), which at any moment affect other parts of the nervous system in different ways, combining the corresponding sensory stimuli of one type or another? Even different durations of stimuli are a problem for the nervous system for multisensory integration. Which of them is correct for pairing if, at each moment, many triggers of different continuity intersect? Another problem is the additional processing times of simultaneous stimuli of other modalities. Various neural networks in the human nervous system contain thousands to hundreds of neurons. A total axon's length is hundreds and even thousands of meters. In this case, the pathways of different modality stimuli (from receptors to the neural brain zones that process perception) can contain significantly different lengths. Therefore, the time difference between processing two simultaneous stimuli of other modalities can become up to a second (although the speed of the nerve impulse can reach 120 m/s). Different neural networks in the human nervous system contain thousands to hundreds of neurons. A total axon's length is hundreds and even thousands of meters. In this case, the pathways of different modality stimuli (from receptors to the neuronal brain zones that process perception) can contain significantly different lengths (although the speed of the nerve impulse can reach 120 m/s). Therefore, the time difference between processing two simultaneous stimuli of other modalities can increase to a second (t: 1 s). The simultaneity of two (or more) events may be deemed coincident if they occur within an un-distinguishable time interval. In neurobiology, if the action potentials from many up-stream neurons arrive within the membrane time constant of the target (reader) neuron (t: 10-50 ms for a typical pyramidal neuron), their combined action is cooperative because each of them contributes to the discharge of the reader neuron [31]. That is, the nervous system can recognize two (or more) stimuli in multisensory integration as cooperative if they happen in a time difference within 50 ms. At the same time, the above analysis shows that different modality stimuli can achieve the neuronal zones of processing perception with a time lag of up to a second. Other processing times for stimuli make their integration for perception difficult. Stimuli cannot be recognized as simultaneous since the actions of the involved neurons are not cooperative. Even considering that some brain functions may be non-classical, i.e., occurring through nonlocal neuronal coupling, most likely the phenomena of consciousness and self-awareness [32], the time lag can be the same for stimuli of different objects (events) and other for stimuli of one thing (or event) but of different sensory modalities. Because the triggers of various events may coincide again, how can the blank mind independently attribute them to proper events?

Multisensory integration seems unlikely to occur without an instant and simultaneous clue to the relevant neurons about relevant sensory inputs for stimuli coupling. This clue should be relevant to the exact moment and specific sensory stimuli responsible for shaping a holistic representation of the object. Integrating stimuli of different processing continuity is too complicated for the immature organism at the reflex substage of the sensorimotor stage of cognitive development to complete it independently.

3.1.2 The Perception Stability

Newborns and infants cannot capture the same picture of the environment as adults. Their image is significantly reduced due to the immaturity (underdevelopment) of the eyes [33]. The hearing of newborns is somewhat worse than that of adults [34]. Newborns cannot sense environmental stimuli from social phenomena to the same extent as adults. Even if we assume that the newborn has somehow already mastered the perception, how can her mind pick up interpretations of phenomena similar to ours on its own, using other (different) sensory stimuli (distinguishable due to the underdevelopment of children's sensitivity) [22]? Thus, not only the processing time of stimuli differs (see the binding problem), but the results of processing similar sensory stimuli in immature and mature organisms should also be different.

Consequently, the corresponding holistic representations of objects can hardly occur in these organisms. However, as is known from numerous studies [14], holistic representations of objects corresponding to adults are somehow formed in young children. The quality of the perception stability of organisms is manifested in grasping similar (similar for mature and immature organisms) holistic representations of objects for all observers, regardless of the sensory capabilities of organisms.

Considering the above challenges in grasping perception, it is not easy to believe that perception can appear independently in organisms at the reflex substage of the sensorimotor stage of cognitive development. An ecological training of the immature organism is a reasonable mechanism.

However, a relevant stimulus cannot overcome the noise magnitude for beginning cognition if it passes through the senses [12-14]. The environment is uncategorized for the organism at this stage of development; the sensation is too limited by the noise to solve the cue problem. At this stage of development, organisms do not maintain meaningful communication via sensory cues [12-14]. While in the uncategorized environment, neither Intentionality nor perception can develop, experimental data show perception appearance in newborns [12-14] and even in fetuses. Empirical evidence shows the fetus's ability to perceive in intentional engagement with the environment. The movements of fetuses seem intentional [35], the intra-pair movements of the twins have an even higher degree of accuracy [36, 37]. Single fetuses show an ability for voice recognition [38-42]. Fetuses distinguish a change in the gender of a speaker reading a sentence [42]. The fetus can discriminate sounds (e.g., speech sounds-"babi" and "biba") [43]. They can learn frequently heard sounds (e.g., voices, music) and flavors they experience in the womb [43]. Neuroscience research studies revealed the underlying mediation of behavioral responses in response to language and voice stimuli [43]. At 33 weeks of gestation, activity increased in the fetal brain's left temporal lobe when exposed to an unfamiliar female voice compared with pure tones [43, 44]. At 34 weeks, the lower bank of the temporal lobe was significantly more active during exposure to a maternal voice than an unfamiliar female voice [43, 44]. The outcome of the mother-fetus collaboration reveals the beginning of cognitive development even in the first trimester of pregnancy.

This subsection highlights the challenges of organisms at the reflex substage of the sensorimotor stage of cognitive development for shaping perception. It seems that such an organism cannot successfully grasp perception independently. At the same time, empirical evidence shows the fetuses' intentional engagement with the environment, which, in more developed organisms, can mean a perception appearance.

<u>Finding 1.</u> The young organism needs exogenous factors to grasp the perception of objects in ecological learning at the onset of cognition.

3.2 Heartbeats for Neuronal Excitability

The brain produces a range of electromagnetic waves. According to the received view in neuroscience, more excellent amplitude waves in sleep conditions are registered in the diapasons at the approximate frequency of 0, 5, to 4 Hz, called slow and delta waves. There is a consensus of slow and delta wave radiation from different sources: slow waves are generated directly within cortical circuits, whereas delta rhythm is derived from intrinsic properties of thalamocortical cells and intracortical network interactions [45, 46]. Anyway, these waves' amplitude and slope reflect the synchronization level achieved in cortical neural ensembles, which depends on the local homeostatically regulated average synaptic strength [47]. Dang-Vu et al. [48] did not find a significant difference in brain activation when comparing slow and delta waves at the macroscopic systems level. From the perspectives of the current study, a spatial distinction of their sources (if there is one) does not change the outcome that appears in the brain waves' impact on different cells - the simultaneous effect on separated sensory neurons is what we are interested in studying. Notably, an excess of low-frequency spectral power and a deficit in ability at higher frequencies are associated with cognitive delay in children [49, 50].

The increasing experimental data show the rhythmic coordination of different peripheral and central subsystems occurring within the range of low EEG frequencies [51]. While numerous research studies have linked the lower oscillations with attention [52-55] and sensory processes [56], the empirical data show that screening of internal and external stimuli is continuous even in a deep sleep [57] and includes incentives that fall below the threshold of aware perception [46]. This means low-frequency oscillations may synchronize brain activity with autonomic functions [46]. These facts may also mean low-frequency oscillations are associated with unaware perception [46] and peripheral and central nervous subsystem coordination [51]. Due to peripheral and central jumpy subsystem coordination, unaware perception may overpass processes in deep brain structures responsible for attention, intention, self-reflection, and awareness. Remarkably, the absolute quantity of low-frequency brain activity increases throughout the first year [58] and continues until the fifth year [59]. Recording with the eyes open, Hagne [58] found an amplitude of brain activity of 10 to 20 µV in the first months of life, increasing to 20 to 40 µV at 6 to 12 months. Using the passive-eye-closure technique, Pampiglione [60] found an amplitude of 50 to 100 µV at age three months, increasing to 100 to 200 µV at age 9 months. According to Frohlich et al. [61], a neuroscience review shows that the delta wave amplitude in awake adults is under 15 µV and increases to 50 µV in the rapid-eye-movement sleep period [61]. Meanwhile, the amplitude of a person's electrocardiogram is generally within 5 mV [62], and average heart rates range from 60 to 100 bpm (1-1, 6 Hz, a similar range as the low-frequency brain waves). Heart waves are the body's most potent low-frequency electromagnetic oscillator, exceeding brain activity by three orders of magnitude.

Finding 2. Low-frequency oscillations can cause the temporal coordination of neurons in peripheral and central nervous subsystems that provide subliminal perception. A heart is the most potent low-frequency electromagnetic oscillator in the human body, whose power exceeds brain activity by three orders of magnitude.

3.3 External Oscillations for Neuronal Excitability

The neuroscience research study reported that external electromagnetic impulses of 1 Hz (60 pulses per minute by generating a magnetic field up to 2 Tesla with an impulse duration of 5 ms and a period of 1000 ms) modulated long-term corticospinal excitability of neurons in healthy brains [63]. The research observed a persistent increase of more than 60% in corticospinal excitability (as an index of Long-Term Potentiation-Like Cortical Plasticity), recording the motor-evoked potential from the contralateral first dorsal interosseous muscle [63]. This perturbation lasted for at least 30 min after the stimulation protocol, potentially maintaining a significant difference (at least 30%) for an even longer time [63]. Low-frequency pulsed electromagnetic fields modulated the cortical excitability of neurons in human brains even after a single-shot application [63]. Therefore, empirical data show that the excitability of different neurons could be modulated by external low-frequency oscillations [63].

Finding 3. External low-frequency oscillations can modulate neuronal excitability.

Two different mechanisms explain the increased neuronal excitability under low-frequency electromagnetic fields, relying on the direct impact of these oscillations on the intrinsic processes of neurons. According to Premi et al. [63], low-frequency electromagnetic oscillations act primarily at the synapse level, altering membrane ion channel function. It is proposed that Ca^{2+} and Na^{+} channel activity can be perturbed by magnetic fields, considering the diamagnetic anisotropic characteristics of membrane phospholipids [63]. Another hypothesis is that low-frequency oscillations mediate a transient and significant increase in A(2A) adenosine receptors' neuronal communication. Adenosine modifies cell functioning by operating G-protein-coupled receptors (GPCR; A(1), A(2A), A(2B), A(3)) that can enhance neuronal communication [64] since A(2A) has a vital role in the brain, regulating the release of other neurotransmitters such as dopamine and glutamate. Interactions between adenosine receptors and other G-protein-coupled receptors, ionotropic receptors, and receptors for neurotrophins also occur, contributing to a fine-tuning of neuronal function [64].

3.4 Heartbeat Synchronization

Research reported that one's electrocardiogram (ECG) signal was registered in another person's electroencephalogram (EEG) and elsewhere on the other person's body [65]. While this signal was most potent when people were in contact, it was still detectable when subjects were in proximity without connection [65]. According to McCraty et al. [65], even this weak field affects another person's heart activity when people touch or are close [65]. According to Gordon et al. [66], the single harmonic rhythm elicits physiological synchrony between group members (precisely, their hearts' inter-beat intervals, measured by electrocardiograms). They showed that physiological synchrony of inter-beat intervals of the heart - a cardiac measure of the ANS derived from electrocardiograms (ECGs) - emerged between group members due to the rhythmical oscillator [66].

Finding 4. An external low-frequency oscillator and the proximity of individuals can stimulate the coordination of their heart rates.

3.5 Low-Frequency Oscillations for Cognitive Performance

Research showed increasing cognitive performance in pairs of subjects (recipients and contributors) due to shared Intentionality induced by low-frequency oscillations in bioengineering systems [15, 20-22]. This research declared to emit low frequency-pulsed electromagnetic fields (LF-PEMF) of wavelengths of 400 and 700 nm alternately with the frequency of 1.3 Hz (80 impulses per minute, with impulse duration of 650 ms and a period of 1300 ms each) using smartphones [15, 20-22]. Research registered increased cognitive performance of recipients if contributors knew the correct answer when subjects completed shared cognitive tasks without communication in pairs [15, 20-22].

Finding 5. External low-frequency oscillations can increase the cognitive performance of the subject indwelling with another who knows the correct answer without communication within the dyad using sensory cues.

4. Discussion: Neuron Coupling in Organisms for Shared Intentionality

This section discusses the above-noted findings to understand whether the contributor's heart oscillations (or the resonance of low-frequency brain and heart oscillations) enable similar neuron excitability (nonlocal neuron coupling) in both the contributor and recipient that stimulates their Shared Intentionality. Can external low-frequency oscillations coordinate the heartbeats of these individuals to provide Shared Intentionality?

4.1 Inferences from the Five Findings

4.1.1 Inference from Finding 1

The young organism needs exogenous factors to grasp the perception of objects in ecological learning at the onset of cognition.

If grasping perception and assimilating knowledge succeed due to interaction with experienced organisms, pre-perceptual communication through nonlocal neuron coupling of nervous subsystems of different organisms would be a possible solution.

4.1.2 Inference from Finding 2

Low-frequency oscillations cause the temporal coordination of neurons in peripheral and central neuronal subsystems that provide subliminal perception. A heart is the most potent low-frequency electromagnetic oscillator in the human body, whose power exceeds brain oscillation activity by three orders of magnitude.

Because unaware perception may appear under low-frequency brain oscillations [46, 55] due to the coordination of peripheral and central neuronal subsystems [51], it is not too controversial to say that more powerful heart oscillation (which is also low-frequency while it exceeds brain activity by three orders of magnitude) can cause the subliminal perception. From the viewpoint of physics, it does not matter what source (the brain or heart) produces low-frequency oscillations - their electromagnetic fields can be described as waves transporting electromagnetic energy; meanwhile, the heart oscillations are three orders of magnitude more powerful. Therefore, heart oscillations (or the resonance of heart and low-frequency brain oscillations) can also cause the nonlocal coupling of neurons in peripheral and central nervous subsystems that provide subliminal perception.

4.1.3 Inference from Finding 3

External low-frequency oscillations can modulate neuronal excitability.

As noted above, from a physical point of view, oscillations with similar properties (internal or external) have the same effect on the nervous system. Therefore, the outer heart or the resonance of heart and low-frequency brain oscillations (or any external source of low-frequency oscillation with similar features) can modulate the coordinated excitability of neurons in an organism's peripheral and central nervous subsystems.

4.1.4 Inference from Finding 4

An external low-frequency oscillator and the proximity of individuals can stimulate the coordination of their heart rates.

Because perception enables a holistic representation of an object by the organization, identification, and interpretation of sensory information, one of the central problems in the perception appearance in the young organism (recipient) is the identification of a relevant stimulus. Subsection 3.1 shows the difficulties of organisms at the reflexes substage of the sensorimotor stage of development in the appropriate stimulus identification in the environment with the cacophony of stimuli: electromagnetic waves, chemical interactions, and pressure fluctuations. Multisensory integration seems unlikely to occur in the recipient without an instant and simultaneous clue to the relevant neurons (or networks) about appropriate sensory inputs for stimuli coupling [12-14].

Since heart oscillations (or the resonance of heart and low-frequency brain oscillations) can cause the nonlocal coupling of neurons in peripheral and central nervous subsystems, the physiological synchrony of inter-beat intervals of the heart in two or more individuals can provide the nonlocal coupling of neurons of these organisms (recipient and contributor): coordination of these organisms' peripheral and central nervous subsystems.

If nonlocal neuronal coupling succeeds in the same ecological context, these organisms begin to react similarly to similar sensory stimuli. While the recipient cannot independently identify the relevant trigger, the experienced organism (contributor) grasps a holistic representation of an object by involving specific sensorimotor networks. This reaction of the contributor's peripheral and central nervous subsystems becomes a template for the recipient. However, the recipient's correct response to the relevant stimulus is unaware. It overpasses processes in deep brain structures responsible for attention, intention, self-reflection, and awareness since the recipient does not yet possess perception ability. Indeed, empirical evidence shows that, in adults, the nonlocal neuronal coupling is associated with unaware perception, which appears due to low-frequency oscillations [46, 51]. This subliminal perception can mean a holistic representation of an object can succeed without employing deep brain structures. The organization, identification, and interpretation of sensory information can proceed without nervous subsystems responsible for attention, intention, self-reflection, and awareness.

In sum, Shared Intentionality can appear in a shared ecological context due to a similar mechanism as subliminal perception: nonlocal neuronal coupling under low-frequency oscillations. It means that in the case of the mother-fetus biological system, nonlocal neuronal coupling due to the mother's heart oscillations can provide Shared Intentionality in this biological system.

4.1.5 Inference from Finding 5

External low-frequency oscillations can increase the cognitive performance of the subject indwelling with another who knows the correct answer without communication within the dyad using sensory cues.

An essential stimulus for Shared Intentionality is a single cognitive task in the shared ecological context [15, 20-22]. Furthermore, Shared Intentionality can appear even in more aged organisms due to their physiological synchrony and external low-frequency oscillations [15, 20-22]. Given five findings, two possible ecological regimes can provide Shared Intentionality (see below).

4.2 Two Ecological Regimes of Shared Intentionality

4.2.1 Ecological Conditions Before Birth

As argued above, a fetus (recipient) cannot grasp perception independently. At the same time, evidence shows that fetuses can correctly react to stimuli, and this analysis suggests that it succeeds due to the coordinated peripheral neuronal subsystems of the recipient and contributor (mother). While this behavior manifests as an appearance of perception, it cannot be attributed to proper perception, as shown in Finding 1 above. The article suggests that this relevant recipient's behavior can succeed by her neuronal activities that overpass processes in deep brain structures responsible for attention, intention, self-reflection, and awareness. Accounting for the infers from subsection 4.1, this subliminal perception in a fetus can emerge due to the contributor's heart oscillations (or the resonance of heart and low-frequency brain oscillations), which provide neuron coupling for ecological learning. By choosing the relevant stimulus, the mother (specifically her neurons) can train the neurons of the immature organism to react correctly to this stimulus. Due to nonlocal neuronal coupling, the contributor's peripheral and central nervous subsystems become a template for the recipient. Because these oscillations stimulate Shared Intentionality in the mother-fetus dyad, the fetus can correctly choose sensory stimuli in developing perception that she can hear from outside the womb. This pre-perceptual communication contributes to the assimilation of knowledge without sensory cues. Three possible mechanisms of neuronal excitability due to low-frequency oscillations are shown in subsection 3.3.

The analysis shows the main features of the mother-fetus communication (MFC) model: (a) a lack of meaningful sensory interaction between subjects during the ecological training of the recipient by the contributor; (b) unintelligible and unfamiliar stimuli to the recipient in a shared ecological context; (c) a single low-frequency oscillator for these organisms. This model enables the recipient to choose the relevant stimulus from many irrelevant ones due to a contributor organism's intentionality [12, 13].

4.2.2 Ecological Conditions After Birth

Another interaction regime is the ecological conditions in organisms after birth. In more developed organisms (in the mother and child already separated after childbirth), Shared Intentionality can emerge if their interaction adheres to the MFC model's noted features. Recent studies proposed that the interpersonal dynamics of the mother and her child could stimulate their physiological synchrony [12-15, 21, 22]. These interpersonal dynamics can appear due to growing emotional arousal and interactional synchrony in organisms, indwelling social entrainment. Suppose these individuals are in intimate proximity (hugs, the child sits on the mother's lap, etc.). In that case, their heartbeats are synchronized [65] due to Finding 4, providing a single low-frequency oscillator for their peripheral and central neuronal subsystems due to Finding 2 and 3. Accounting for the infers from subsection 4.1. These overlapping processes can shape physiological synchrony that contributes to Shared Intentionality in the child (infant or toddler) and the mother.

However, many endogenous and exogenous factors limit shared intentionality appearance [15, 21, 22]. Therefore, growing interpersonal dynamics toward physiological synchrony for shaping Shared Intentionality is unpredictable. The analysis of subsection 4.1 allows us to suppose that external low-frequency oscillations (for example, music or rhythmical movements in dancing) can coordinate the heartbeats of the mother and her young child (infant or toddler) for modulating the excitability of neurons in their peripheral and central neuronal subsystems. In a lack of components needed for growing interpersonal dynamics independently, this intervention of low-frequency oscillations can facilitate shaping physiological synchrony in more aged organisms (even adults) for appearing Shared Intentionality. External low-frequency oscillations can coordinate individuals' heartbeats for modulating the coordinated excitability of neurons in their peripheral and central nervous subsystems that can provide Shared Intentionality under the condition of a single cognitive task in the shared ecological context.

4.3 The Attributes of Ecological Context for Shared Intentionality

Considering the empirical data on stimulating Shared Intentionality in dyads by smartphones' low-frequency oscillations presented in subsection 3.5, there are two possible viewpoints (also concomitant) for defining attributes of ecological context that enabled Shared Intentionality in the research [12-15, 21, 22] mentioned above.

The first viewpoint relies on the possible impact of pulsed color on neuronal excitability. The parameter of color temperature can describe a visible light source. The color temperature scale represents only the color of light emitted by a light source. Color temperature is usually measured in Kelvins. The wavelengths of 400 and 700 nm (violet and red colors, respectively) correspond to 27000 K and 1000 K color temperatures, respectively.

Interestingly, research tested the light spectrum's influence on humans, showing more sensible brain electrical activities to high color temperatures [67]. Finding 3 shows that external low-frequency oscillations can modulate neuron excitability. Given the above data with the data from subsection 3.5 and infers from subsection 4.1, it may also mean that low-frequency pulsed color oscillations of 80 pulses per minute (the frequency of 1.3 Hz) of 400 nm violet and 700 nm red colors alternately (or in other words LF-PEMF with the frequency of impulses of 1.3 Hz) can modulate similar neuron excitability in organisms for nonlocal neuron coupling.

From another perspective, the mobile phone is a source of electromagnetic fields that can also modulate neuronal excitability. The intensity of the electromagnetic field at a distance of 20 cm from the monitor (of a computer or smartphone) is not more than 1.5(-7) T (the range of 1.3-1.5 mG, (0.00013-0.00015 mT) [68]. For example, the heart produces magnetic fields at the chest surface, which have a peak intensity of about 10(-11) T (one microgauss) [69, 70]. According to McCraty et al. [65], even this weak heart field affects another person's heart activity when people touch or are close [65]. Consequently, the electromagnetic field of a smartphone, whose power is three orders of magnitude higher than the power of cardiac oscillations, should also affect human cardiac activity. As noted in subsection 4.1, coordinated heartbeats of different organisms can cause the neuronal excitability for nonlocal coupling of neurons in peripheral and central neuronal subsystems in these organisms that can provide Shared Intentionality. In sum, the smartphone's LF-PEMF of 400 and 700 nm wavelengths alternately, with the frequency of 1.3 Hz, can modulate similar neuron excitability in different organisms. This nonlocal neuronal coupling can cause Shared Intentionality.

4.4 A Concept Design for Studying the Origin of Perception

How the shape of embryos emerges during development is a fundamental question that has intrigued scientists for centuries. Charles Darwin noted that having similar embryos implied common ancestry. Nowadays, the significant growth of systematic knowledge on embryonal development in different species has been achieved by Evolutionary developmental biology (Evo-devo) - a field of biological research that compares the developmental processes of other organisms. Evo-devo has begun to uncover rules of bodybuilding in all animals during embryo development [71, 72]. It is already generally accepted that similar genes control dissimilar organs' development. These genes (so-called Gene toolkit) generate the patterns in time and space that shape the embryo and ultimately form the organism's body. A diverse set of genes in the gene toolkit provides a diversity of organisms. The regulation of gene expression is another quality of toolkit genes that contributes to a variety of species. Species do not differ much in their structural genes but in how the toolkit genes regulate gene expression.

However, mechanisms of the cell coupling for shaping embryos during development still challenge our knowledge. At the cellular level, what mechanisms are of four very general classes of tissue deformation, namely tissue folding and invagination, tissue flow and extension, tissue hollowing, and, finally, tissue branching [73]? Indeed, cell actions during an embryo formation, including shape changes, cell contact remodeling, cell migration, cell division, and cell extrusion, need control over cell mechanics [73]. This complex dynamical process is associated with protrusive, contractile, and adhesive forces and hydrostatic pressure, as well as material properties of cells that dictate how cells respond to active stresses [73]. Precise coordination of all cells seems to be a necessary condition. Moreover, such a complex dynamical process likely requires clear parameters of the final biological structure - the complete developmental program with a template for accomplishing it.

From the perspective of perception development, the current study pays more attention to the development of nervous systems in organisms. Besides the noted above issues of the nervous system development in embryos, another essential problem is building proper neural pathways of reflex arcs and teaching sensorimotor networks to specific reactions on particular sensory stimuli for developing primitive reflexes in the embryo before birth (about the complex problem of perception appearance in human fetuses, see subsection 3.1). Because after delivery, primitive reflexes are vital for newborns.

The genetic code is no more than a rule of causal specificity because cells use nucleic acids as templates for the primary structure of proteins [74], which cannot accomplish the sophisticated goal of shaping a nervous system alone. It seems that genes provide only a part of this developmental program - a genetic code that cannot coordinate the precise formation of neural tissue in ecological dynamics and neuronal activity in environmental training for the growing nervous system functions. It is unacceptable to say that DNA contains all information for phenotypic design [74].

The developmental mechanism of the nervous system in all vertebrates' embryos can be the same as we discussed above in 4.2 - the contributor's nervous system is likely a template for the recipient due to nonlocal neuronal coupling. Embryos of invertebrate animals develop much the same as vertebrates, obeying the same rules of the nervous system development. However, those invertebrate species born into a larva stage leave the mothers' organisms very different from the adults of the same species. Nevertheless, while they have a relatively opaque nervous system, e.g., with an estimated 12,000-15,000 neurons in insects [75, 76], the basic neuronal structures are already formed before the larval stage. Therefore, nonlocal neuronal coupling due to low-frequency oscillations can contribute to nervous system development even in invertebrate species born into a larva stage.

While the heart rates of all invertebrate species are oxygen and temperature-sensitive, especially in the band 5-15°C [77, 78], their cardiac range is in the low-frequency band [77, 78]. The Blackworm (Lumbriculus variegatus) shows a heart rate frequency of 0.07 Hz (average: 4.4 ± 0.8 beats per min); the Annelid worm (Nereis virens) - 0.11 Hz (6.82 ± 0.06 bpm); the Ponderous ark clam (Noetia ponderosa) - 0.24 Hz (14.5 ± 0.8 bpm); the Atlantic horseshoe crab (Limulus polyphemus) - 0.62 Hz (37.5 ± 3.5 bpm); the Atlantic blue crab (Callinectes sapidus) - 2.11 Hz (127 ± 9 bpm) [77].

After Darwin, we know that the stability and dissimilation of the phenotypic trait in species from different phylogenetic trees and environments may mean this inherited characteristic is common for all animals. Because cardiac oscillations are a more powerful source of electromagnetic fields in all organisms, these low-frequency oscillations can provide nonlocal coupling between the maternal and embryonal neurons in animals of all species. If so, the complete embryonal developmental program likely consists of the combination of genetic code with an additional evolutionary tool - ecological instructions derived from nonlocal neuronal coupling with the mother. These ecological instructions can contribute to grasping the perception of objects from the environment and the primary reflexes development. From this perspective, in vertebrate and invertebrate animals, maternal cardiac oscillations yield to embryos a template for the ecological effect of the nervous systems, building the latter with the diverse gene toolkit. However, in a similar environment, the complete developmental program of embryos likely provides a different extent of perception development and a diverse set of reflexes depending on the gene toolkit, even indwelling.

Therefore, the article's impact is a proposal of the universal mechanism of nonlocal neuronal coupling in shaping the embryonal nervous system in different species, which opens new directions for research on the origin of perception and reflexes development. Understanding the underlying mechanism of perception emergence can shed light on the origin of consciousness.

Further comparative analysis of empirical evidence through evaluation indicators can check whether this nonlocal neuronal mechanism stands true (is accurate, consistent, predictive, and universal):

First, research on cellular nonlocal coupling can prove or reject the hypothesis of the universal mechanism of nonlocal neuronal coupling in shaping the nervous system of embryos in different species.

Second, research on the development of reflexes can reveal the ecological component of primitive reflexes' emergence in embryos of different species.

Third, do inter-beat intervals of the mother's heart alone or the resonance of both organisms' heartbeats provide simultaneous neuron excitability in these organisms' peripheral and central neuronal subsystems for Shared Intentionality (goal-directed coherence in simple animals)?

Fourth, the MFC model establishment aims to formalize the analytic model for designing bioengineering systems, which would predictably assess Shared Intentionality. Because an analytical model is primarily quantitative (or computational), future studies should define the MFC model as a set of mathematical equations based on factorial analysis that would specify parametric relationships and their associated parameter values. The mother-child biological system evolves in endogenous factor dynamics (interpersonal psychological, e.g., moods, emotions, etc., and individual physiological, e.g., hormones) and exogenous factor dynamics (e.g., exciting environmental stimuli). The bioengineering system (based on the MFC model) retains the comparative state of present and past samples, thereby providing dynamic data analysis. Therefore, the MFC model should represent the time-varying state of the system. The dynamic model analysis would rely on the comparative analysis of the quantitative data using differential equations. The contemporary methods of the dynamic model analysis provide monitoring state using entropy functions. For defining time-varying forms of the biological system, they implement a feature set that contains entropy functions with distributed weights (e.g., for review [79, 80]).

4.5 Limitations

The recent theoretical article [29] proposed the neurophysiological mechanism of nonlocal neuronal coupling due to low-frequency nested gamma oscillations. The difference between the two approaches, the previous work [29] and the current study, is that the former proposed nonlocal neuronal coupling through gamma nested in low-frequency oscillation [29], i.e., due to properties of electromagnetic waves, while the present work supports ideas of neuronal excitability due to the intrinsic properties of neurons: altering membrane ion channel function [63] and increasing in A(2A) adenosine receptors' neuronal communication [64] in low-frequency oscillations. This previous study also raised the limitations of the hypothesis, which appear from the measurement techniques of neuronal activity that limit the research tools for observing temporal coordination during interpersonal dynamics in vivo. Neuroscience data only show indirect evidence of coordinated activity of neurons that we register to attend correlates [29]. Most likely, these techniques observe interference patterns resulting from the superposition of all oscillations of neuron orchestra [29]. Therefore, because of this measurement uncertainty, both approaches (from the recent article [29] and the current study) to the nonlocal neuronal coupling mechanism should be considered for further checking.

5. Conclusions

This theoretical study observed recent cognitive sciences and computer science literature to understand whether low-frequency oscillations can simultaneously alter the excitability of neurons from peripheral neuronal subsystems in different individuals to provide Shared Intentionality in recipients (e.g., immature organisms: the fetus and/or newborn). The literature review found that: 1) To grasp the perception of objects during ecological learning at the onset of cognition, a fetus needs exogenous factors that could stimulate her nervous system to choose the relevant sensory stimulus. 2) Low-frequency brain oscillations can cause the nonlocal coupling of neurons in peripheral and central nervous subsystems that provide subliminal perception. 3) External low-frequency oscillations can modulate the neuronal excitability. 4) An external low-frequency oscillator and/or the proximity of individuals can stimulate the coordination of their heart rates. 5) External low-frequency oscillations can increase the cognitive performance of the subject indwelling with another who knew the correct answer without communication within the dyad using sensory cues.

The article highlighted two possible regimes of Shared Intentionality: ecological conditions before and after birth. The LF-PEMF of 400 and 700 nm wavelengths alternately, with the frequency of 1.3 Hz, can modulate similar neuronal excitability in different organisms for Shared Intentionality. It means that bioengineering systems can stimulate Shared Intentionality in dyads by low-frequency oscillations. The literature shows that the characteristics of a person's electrocardiogram are generally within 5 mV, and average heart rates range from 1 to 1.6 Hz. The heartbeats stimulate both ecological regimes of Shared Intentionality. Therefore, this may mean that an external harmonic oscillator with characteristics of 5 mV and frequency from 1 to 1.6 Hz can stimulate Shared Intentionality under a single cognitive task in the shared ecological context.

The comparative result between the previous theoretical article and the current study is that the former proposed nonlocal neuronal coupling through gamma nested in low-frequency oscillation, i.e., due to the properties of electromagnetic waves. In contrast, the present work supports ideas of neuronal excitability due to the intrinsic properties of neurons: altering membrane ion channel function and/or increasing in A(2A) adenosine receptors' neuronal communication in low-frequency oscillations.

This theoretical work contributes to knowledge about nonlocal neuronal coupling that can appear due to low-frequency oscillations. The significance of the article is that it explains the neurophysiological processes occurring during Shared Intentionality - one of the central issues in understanding the cognitive development of young children, as the conventional view in cognitive sciences argues. The article's impact is a proposal of the universal mechanism of nonlocal neuronal coupling in shaping the embryonal nervous system in animals of all species, which opens new directions for research on the origin of perception of objects. Understanding the underlying mechanism of perception emergence can shed light on consciousness.

Further comparative analysis of empirical evidence through evaluation indicators can check whether this nonlocal neuronal mechanism stands true (is accurate, consistent, predictive, and universal). First, research on cellular nonlocal coupling can prove or reject the hypothesis of the universal mechanism of nonlocal neuronal coupling in shaping the nervous system of embryos in different species. Second, research on the development of reflexes can reveal the ecological component of primitive reflexes' emergence in seeds of other species. Third, do inter-beat intervals of the mother's heart alone or the resonance of both organisms' heartbeats provide simultaneous neuron excitability in these organisms' peripheral and central neuronal subsystems for Shared Intentionality (goal-directed coherence in simple animals)? Fourth, the MFC model establishment aims to formalize the analytic model for designing bioengineering systems, which would predictably assess Shared Intentionality. Because an analytical model is primarily quantitative (or computational), future studies should define the MFC model as a set of mathematical equations based on factorial analysis that would specify parametric relationships and their associated parameter values.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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